Handbook of Automotive Engineering and Electronics

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Chapter 1

Automatic Transmission

An 8-gear automatic transmission

An **automatic gearbox** is one type of motor vehicle transmission that can automatically change gear ratios as the vehicle moves, freeing the driver from having to shift gears manually. Most automatic transmissions have a defined set of gear ranges, often with a parking pawl feature that locks the output shaft of the transmission.

Similar but larger devices are also used for heavy-duty commercial and industrial vehicles and equipment. Some machines with limited speed ranges or fixed engine speeds, such as some forklifts and lawn mowers, only use a torque converter to provide a variable gearing of the engine to the wheels.

Besides automatics, there are also other types of automated transmissions such as continuous variable transmissions (CVTs) and semi-automatic transmissions, that free the driver from having to shift gears manually, by using the transmission's computer to change gear, if for example the driver were redlining the engine. Despite superficial similarity to other automated transmissions, automatic transmissions differ significantly in internal operation and driver's "feel" from semi-automatics and CVTs. An automatic uses a torque converter instead of clutch to manage the connection between the transmission gearing and the engine. In contrast, a CVT uses a belt or other torque transmission schema to allow an "infinite" number of gear ratios instead of a fixed number of gear ratios. A semi-automatic retains a clutch like a manual transmission, but controls the clutch through electrohydraulic means.

A conventional manual transmission is frequently the base equipment in a car, with the option being an automated transmission such as a conventional automatic, semi-automatic, or CVT. The ability to shift gears manually, often via paddle shifters, can also be found on certain automated transmissions (manumatics such as Tiptronic), semi-automatics (BMW SMG), and continuous variable transmissions (CVTs) (such as Lineartronic).

Comparison with manual transmission

Most cars sold in North America since the 1950s have been available with an automatic transmission. Conversely, automatic transmission is less popular in Europe, with 80% of drivers opting for manual transmission.. In most Asian markets and in Australia, automatic transmissions have become very popular since the 1990s.

Vehicles equipped with automatic transmissions are less complex to drive. Consequently, in some jurisdictions, drivers who have passed their driving test in a vehicle with an automatic transmission will not be licensed to drive a manual transmission vehicle. Examples of driving license restrictions are Croatia, Dominican Republic, Israel, United Kingdom, some states in Australia, France, Portugal, Latvia, Lebanon, Lithuania, Ireland, Belgium, Germany, Pakistan, the Netherlands, Sweden, Austria, Norway, Poland, Hungary, South Africa, Trinidad and Tobago, China, Hong Kong, Macau, Mauritius, South Korea, Romania, Singapore, Philippines, United Arab Emirates, India, Estonia, Finland, Switzerland, Slovenia, Republic of Ireland and New Zealand (Restricted licence only).

Automatic transmission modes

Conventionally, in order to select the transmission operating 'mode', the driver moves a selection lever located either on the steering column or on the floor (as with a manual). In order to select modes, or to manually select specific gear ratios, the driver must push a button in (called the shift lock button) or pull the handle (only on column mounted shifters) out. Some vehicles position selector buttons for each mode on the cockpit instead, freeing up space on the central console. Vehicles conforming to US Government standards must have the modes ordered P-R-N-D-L (left to right, top to bottom, or clockwise). Prior to this, quadrant-selected automatic transmissions often used a P-N-D-L-R layout, or similar. Such a pattern led to a number of deaths and injuries owing to unintentional gear selection, as well as the danger of having a selector (when worn) jump into Reverse from Low gear during engine braking maneuvers.

Automatic transmissions have various modes depending on the model and make of the transmission. Some of the common modes include

Park (P)

This selection mechanically locks the output shaft of transmission, restricting the vehicle from moving in any direction. A parking pawl prevents the transmission from rotating, and therefore the vehicle from moving, although the vehicle's non-driven roadwheels may still rotate freely. For this reason, it is recommended to use the hand brake (or parking brake) because this actually locks (in most cases) the rear wheels and prevents them from moving. This also increases the life of the transmission and the park pin mechanism, because parking on an incline with the transmission in park without the parking brake engaged will cause undue stress on the parking pin. An efficiently-adjusted hand brake should also prevent the car from moving if a worn selector accidentally drops into reverse gear during early morning fast-idle engine warm-ups. It should be noted that locking the transmission output shaft does not positively lock the driving wheels. If one driving wheel slips while the transmission is in "park," the other will roll freely as the slipping wheel rotates in the opposite direction. Only a (properly adjusted) parking brake can be relied upon to positively lock both of the parking-braked wheels. (This is not the case with certain 1950's Chrysler products that carried their parking brake on the transmission tailshaft, a defect compounded by the provision of a bumper jack). It is typical of front-wheel-drive vehicles for the parking brake to be on the rear (non-driving) wheels, so use of both the parking brake and the transmission park lock provides the greatest security against unintended movement on slopes. Unfortunately, the rear of most front-wheel-drive vehicles has only about half the weight on the rear wheel as is on the front wheels, greatly reducing the security provided by the parking brake as compared to either rear-wheel-drive vehicles with parking brake on the rear wheels (which generally have near half of the total vehicle weight on the rear wheels, except for empty pickup and open-bed trucks) or to front-wheel-drive vehicles with the parking brake on the front wheels, which generally have about two-thirds of the vehicle's weight (unloaded) on the front wheels.

A car should be allowed to come to a complete stop before setting the transmission into park to prevent damage. Usually, Park (P) is one of only two selections in which the car's engine can be started, the other being Neutral (N). In many modern cars and trucks, the driver must have the foot brake applied before the transmission can be taken out of park. The Park position is omitted on buses/coaches with automatic transmission (on which a parking pawl is not practical), which must be placed in neutral with the parking brakes set. Advice is given in some owner's manuals [example: 1997 Oldsmobile Cutlass Supreme owner's manual] that if the vehicle is parked on a steep slope using the park lock only, it may not be possible to release the park lock (move the selector lever out of "P"). Another vehicle may be required to push the stuck vehicle uphill slightly to remove the loading on the park lock pawl.

Most automobiles require **P** or **N** to be set on the selector lever before the internal combustion engine can be started. This is typically achieved via a normally open 'inhibitor' switch, which is wired in series with the starter motor engagement circuit, and is only closed when P or N is selected, thus completing the circuit (when the key is turned to the start position)

Reverse (R)

This engages reverse gear within the transmission, giving the ability for the vehicle to drive backwards. In order for the driver to select reverse in modern transmissions, they must come to a complete stop, push the shift lock button in (or pull the shift lever forward in the case of a column shifter) and select reverse. Not coming to a complete stop can cause severe damage to the transmission. Many modern automatic transmissions have a safety mechanism in place, which does to some extent prevent (but does not completely avoid) inadvertently putting the car in reverse when the vehicle is moving forwards. This mechanism usually consists of a solenoid-controlled physical barrier on either side of the Reverse position, which is electronically engaged by a switch on the brake pedal. Therefore, the brake pedal needs to be depressed in order to allow the selection of reverse. Some electronic transmissions prevent or delay engagement of reverse gear altogether while the car is moving.

Some shifters with a shift button allow the driver to freely move the shifter from R to N or D, or simply moving the shifter to N or D without actually depressing the button. However, the driver cannot put back the shifter to R without depressing the shift button to prevent accidental shifting, especially at high speeds, which could damage the transmission.

Neutral/No gear (N)

This disengages all gear trains within the transmission, effectively disconnecting the transmission from the driven roadwheels, so the vehicle is able to move freely under its own weight and gain momentum without the motive force from the engine (engine braking). This is the only other selection in which the vehicle's engine can be started.

Drive (D)

This position allows the transmission to engage the full range of available forward gear trains, and therefore allows the vehicle to move forward and accelerate through its range of gears. The number of gear 'ratios' a transmission has depends on the model, but they initially ranged from three (predominant before the 1990s), to four and five speeds (losing popularity to six-speed autos, though still favored by Chrysler and Honda/Acura). Six-speed automatic transmissions are now probably the most common offering Toyota Camry V6 models, the Chevrolet Malibu LTZ, Corvette, GM trucks, Pontiac G8, Ford Falcon BF 2005-2007 and Falcon FG 2008 - current in Australia with 6 speed ZF, and most newer model Ford/Lincoln/Mercury vehicles). However, seven-speed autos are becoming available (found in Mercedes 7G gearbox), as are eight-speed autos in the newer models of Lexus and BMW cars.

OverDrive (D, OD, or a boxed [D])

This mode is used in some transmissions to allow early computer-controlled transmissions to engage the Automatic Overdrive. In these transmissions, Drive (D) locks the Automatic Overdrive off, but is identical otherwise. OD (Overdrive) in these cars is engaged under steady speeds or low acceleration at approximately 35–45 mph (56–72 km/h). Under hard acceleration or below 35–45 mph (56–72 km/h), the transmission will automatically downshift. Vehicles with this option should be driven in this mode unless circumstances require a lower gear.

Third (3)

This mode limits the transmission to the first three gear ratios, or sometimes locks the transmission in third gear. This can be used to climb or going down hill. Some vehicles will automatically shift up out of third gear in this mode if a certain RPM range is reached in order to prevent engine damage. This gear is also recommended while towing a caravan.

Second (2 or S)

This mode limits the transmission to the first two gear ratios, or locks the transmission in second gear on Ford, Kia, and Honda models. This can be used to drive in adverse conditions such as snow and ice, as well as climbing or going down hills in the winter time. Some vehicles will automatically shift up out of second gear in this mode if a certain RPM range is reached in order to prevent engine damage.

Although traditionally considered second gear, there are other names used. Chrysler models with a three-speed automatic since the late 1980s have called this gear **3** while using the traditional names for *Drive* and *Low*.

First (1 or L [Low])

This mode locks the transmission in first gear only. It will not change to any other gear range. This, like second, can be used during the winter season, or for towing.

As well as the above modes there are also other modes, dependent on the manufacturer and model. Some examples include

D5

In Hondas and Acuras equipped with five-speed automatic transmissions, this mode is used commonly for highway use (as stated in the manual), and uses all five forward gears.

D4

This mode is also found in Honda and Acura four- or five-speed automatics, and only uses the first four gear ratios. According to the manual, it is used for "stop and go traffic", such as city driving.

D3 or 3

This mode is found in Honda, Acura, Volkswagen and Pontiac four-speed automatics and only uses the first three gear ratios. According to the manual, it is used for "stop & go traffic", such as city driving.

S or Sport

This is commonly described as 'Sport mode'. It operates in an identical manner as 'D' mode, except that the upshifts change much higher up the engine's rev range. This has the effect on maximising all the available engine output, and therefore enhances the performance of the vehicle, particularly during acceleration. This mode will also downchange much higher up the rev range compared to 'D' mode, maximising the effects of engine braking. This mode will have a detrimental effect on fuel economy. Hyundai has a Norm/Power switch next to the gearshift for this purpose on the Tiburon.

Some early GM's equipped with Tourqueflite transmsissons used (S) to indicate Second gear, being the same as the 2 position on a Chrysler, shifting between only first and second gears. This would have been recommended for use on steep grades, or slippery roads like dirt, or ice, and limited to speeds under 40 mph. (L) was used in some early GM's to indicate (L)ow gear, being the same as the 2 position on a Chrysler, locking the transmission into first gear. This would have been recommended for use on steep grades, or slippery roads like dirt, or ice, and limited to speeds under 15 mph.

+ −, and M

This is for the 'manual mode' selection of gears in certain automatics, such as Porsche's Tiptronic. The M feature can also be found in Chrysler and General Motors products such as the Dodge Magnum and Pontiac G6, as well as Toyota's Camry, Corolla, Fortuner, Previa and Innova. Mitsubishi and some Audi models (TT), meanwhile do not have the M, and instead have the + and -, which is separated from the rest of the shift modes; the same is true for some Peugeot products like Peugeot 206. Meanwhile, the driver can shift up and down at will by toggling the (console mounted) shift lever like a semi-automatic transmission. This mode may be engaged either through a selector/position or by actually changing the gears (e.g., tipping the gear-down paddles mounted near the driver's fingers on the steering wheel).

Winter (W)

In some Mercedes-Benz, BMW and General Motors Europe models, a 'Winter mode' can be engaged so that second gear is selected instead of first when pulling away from stationary, to reduce the likelihood of loss of traction due to wheelspin on snow or ice. On GM cars, this was D2 in the 1950s, and is Second Gear Start after 1990. On Ford, Kia, and Honda automatics, this feature can be accessed by moving the gear selector to 2 to start, then taking your foot off the accelerator while selecting D once the car is moving.

Brake (B)

A mode selectable on some Toyota models. In non-hybrid cars, this mode lets the engine do compression braking, also known as engine braking, typically when encountering a steep downhill. Instead of engaging the brakes, the engine in a non-hybrid car switches to a lower gear and slows down the spinning tires. The engine holds the car back, instead of the brakes slowing it down. For hybrid cars, this mode converts the electric motor into a generator for the battery. It is not the same as downshifting in a non-hybrid car, but it has the same effect in slowing the car without using the brakes. GM called this HR (hill retarder) and GR (grade retarder) in the 1950s.

Hydraulic automatic transmissions

The predominant form of automatic transmission is hydraulically operated; using a fluid coupling or torque converter, and a set of planetary gearsets to provide a range of gear ratios.

Parts and operation

A cut-away model of a torque converter

A hydraulic automatic transmission consists of the following parts:

- *Torque converter*: A type of fluid coupling, hydraulically connecting the engine to the transmission. It takes the place of a mechanical clutch, allowing the transmission to stay 'in gear' and the engine to remain running while the vehicle is stationary, without stalling. A torque converter differs from a fluid coupling, in that it provides a variable amount of torque multiplication at low engine speeds, increasing "breakaway" acceleration. This is accomplished with a third member in the "coupling assembly" known as the stator, and by altering the shapes of the vanes inside the coupling in such a way as to curve the fluid's path into the stator. The stator captures the kinetic energy of the transmission fluid, in effect using the leftover force of it to enhance torque multiplication.

- *Pump*, not to be confused with the impeller inside the torque converter, is typically a gear pump mounted between the torque converter and the planetary gearset. It draws transmission fluid from a sump and pressurizes it, which is needed for transmission components to operate. The input for the pump is connected to the torque converter housing, which in turn is bolted to the engine's flywheel, so the pump provides pressure whenever the engine is running and there is enough transmission fluid.
- *Planetary gearset*: A compound epicyclic planetary gearset, whose bands and clutches are actuated by hydraulic servos controlled by the valve body, providing two or more gear ratios.
- *Clutches and bands:* to effect gear changes, one of two types of clutches or bands are used to hold a particular member of the planetary gearset motionless, while allowing another member to rotate, thereby transmitting torque and producing gear reductions or overdrive ratios. These clutches are actuated by the valve body, their sequence controlled by the transmission's internal programming. Principally, a type of device known as a sprag or roller clutch is used for routine upshifts/downshifts. Operating much as a ratchet, it transmits torque only in one direction, free-wheeling or "overrunning" in the other. The advantage of this type of clutch is that it eliminates the sensitivity of timing a simultaneous clutch release/apply on two planetaries, simply "taking up" the drivetrain load when actuated, and releasing automatically when the next gear's sprag clutch assumes the torque transfer. The bands come into play for manually selected gears, such as low range or reverse, and operate on the planetary drum's circumference. Bands are not applied when drive/overdrive range is selected, the torque being transmitted by the sprag clutches instead. Bands are used for braking; the GM Turbo-Hydramatics incorporated this..
- *Valve body*: hydraulic control center that receives pressurized fluid from the *main pump* operated by the fluid coupling/torque converter. The pressure coming from this pump is regulated and used to run a network of spring-loaded valves, check balls and servo pistons. The valves use the pump pressure and the pressure from a centrifugal governor on the output side (as well as hydraulic signals from the range selector valves and the *throttle valve* or *modulator*) to control which ratio is selected on the gearset; as the vehicle and engine change speed, the difference between the pressures changes, causing different sets of valves to open and close. The hydraulic pressure controlled by these valves drives the various clutch and brake band actuators,

thereby controlling the operation of the planetary gearset to select the optimum gear ratio for the current operating conditions. However, in many modern automatic transmissions, the valves are controlled by electro-mechanical servos which are controlled by the electronic engine control unit (ECU) or a separate transmission control unit (TCU).

- *Hydraulic & lubricating oil*: called automatic transmission fluid (ATF), this component of the transmission provides lubrication, corrosion prevention, and a hydraulic medium to convey mechanical power (for the operation of the transmission). Primarily made from refined petroleum, and processed to provide properties that promote smooth power transmission and increase service life, the ATF is one of the few parts of the automatic transmission that needs routine service as the vehicle ages.

The multitude of parts, along with the complex design of the valve body, originally made hydraulic automatic transmissions much more complicated (and expensive) to build and repair than manual transmissions. In most cars (except US family, luxury, sport-utility vehicle, and minivan models) they have usually been extra-cost options for this reason. Mass manufacturing and decades of improvement have reduced this cost gap.

Energy efficiency

Hydraulic automatic transmissions are almost always less energy efficient than manual transmissions due mainly to viscous and pumping losses; both in the torque converter and the hydraulic actuators. A relatively small amount of energy is required to pressurize the hydraulic control system, which uses fluid pressure to determine the correct shifting patterns and operate the various automatic clutch mechanisms.

Manual transmissions use a mechanical clutch to transmit torque, rather than a torque converter, thus avoiding the primary source of loss in an automatic transmission. Manual transmissions also avoid the power requirement of the hydraulic control system, by relying on the human muscle power of the vehicle operator to disengage the clutch and actuate the gear levers, and the mental power of the operator to make appropriate gear ratio selections. Thus the manual transmission requires very little engine power to function, with the main power consumption due to drag from the gear train being immersed in the lubricating oil of the gearbox.

The energy efficiency of automatic transmission has increased with the introduction of the torque converter lock-up clutch, which practically eliminates fluid losses when engaged. Modern automatic transmission also minimize energy usage and complexity, by minimizing the amount of shifting logic that is done hydraulically. Typically, control of the transmission has been transferred to computerized control systems which do not use fluid pressure for shift logic or actuation of clutching mechanisms.

The on road acceleration of an automatic transmission can occasionally exceed that of an otherwise identical vehicle equipped with a manual transmission in turbocharged diesel applications. Turbo-boost is normally lost between gear changes in a manual whereas in an automatic the accelerator pedal can remain fully depressed. This however is still largely dependent upon the number and optimal spacing of gear ratios for each unit, and whether or not the elimination of spooldown/accelerator lift off represent a significant enough gain to counter the slightly higher power consumption of the automatic transmission itself.

History and improvements

Modern automatic transmissions can trace their origins to an early "horseless carriage" gearbox that was developed in 1904 by the Sturtevant brothers of Boston, Massachusetts. This unit had two forward speeds, the ratio change being brought about by flyweights that were driven by the engine. At higher engine speeds, high gear was engaged. As the vehicle slowed down and engine RPM decreased, the gearbox would shift back to low. Unfortunately, the metallurgy of the time wasn't up to the task, and owing to the abruptness of the gear change, the transmission would often fail without warning.

The next significant phase in the automatic transmission's development occurred in 1908 with the introduction of Henry Ford's remarkable Model T. The Model T, in addition to being cheap and reliable by the standards of the day, featured a simple, two speed plus reverse planetary transmission whose operation was manually controlled by the driver using pedals. The pedals actuated the transmission's friction elements (bands and clutches) to select the desired gear. In some respects, this type of transmission was less demanding of the driver's skills than the contemporary, unsynchronized manual transmission, but still required that the driver know when to make a shift, as well as how to get the car off to a smooth start.

In 1934, both REO and General Motors developed semi-automatic transmissions that were less difficult to operate than a fully manual unit. These designs, however, continued to use a clutch to engage the engine with the transmission. The General Motors unit, dubbed the "Automatic Safety Transmission," was notable in that it employed a power-shifting planetary gearbox that was hydraulically controlled and was sensitive to road speed, anticipating future development.

Parallel to the development in the 1930s of an automatically-shifting gearbox was Chrysler's work on adapting the fluid coupling to automotive use. Invented early in the 20th century, the fluid coupling was the answer to the question of how to avoid stalling the engine when the vehicle was stopped with the transmission in gear. Chrysler itself never used the fluid coupling with any of its automatic transmissions, but did use it in conjunction with a hybrid manual transmission called "Fluid Drive" (the similar Hy-Drive used a torque converter). These developments in automatic gearbox and fluid coupling technology eventually culminated in the introduction in

1939 of the General Motors Hydra-Matic, the world's first mass-produced automatic transmission.

Available as an option on 1940 Oldsmobiles and later Cadillacs, the Hydra-Matic combined a fluid coupling with three hydraulically-controlled planetary gearsets to produce four forward speeds plus reverse. The transmission was sensitive to engine throttle position and road speed, producing fully automatic up- and down-shifting that varied according to operating conditions.

The Hydra-Matic was subsequently adopted by Cadillac and Pontiac, and was sold to various other automakers, including Bentley, Hudson, Kaiser, Nash, and Rolls-Royce. It also found use during World War II in some military vehicles. From 1950-1954, Lincoln cars were also available with the Hydra-Matic. Mercedes-Benz subsequently devised a four-speed fluid coupling transmission that was similar in principle to the Hydra-Matic, but of a different design.

Interestingly, the original Hydra-Matic incorporated two features which are widely emulated in today's transmissions. The Hydra-Matic's ratio spread through the four gears produced excellent "step off" and acceleration in first, good spacing of intermediate gears, and the effect of an overdrive in fourth, by virtue of the low numerical rear axle ratio used in the vehicles of the time. In addition, in third and fourth gear, the fluid coupling only handled a portion of the engine's torque, resulting in a high degree of efficiency. In this respect, the transmission's behavior was similar to modern units incorporating a lock-up torque converter.

In 1956, GM introduced the "Jetaway" Hydra-Matic, which was different in design than the older model. Addressing the issue of shift quality, which was an ongoing problem with the original Hydra-Matic, the new transmission utilized two fluid couplings, the primary one that linked the transmission to the engine, and a secondary one that replaced the clutch assembly that controlled the forward gearset in the original. The result was much smoother shifting, especially from first to second gear, but with a loss in efficiency and an increase in complexity. Another "innovation" for this new style Hydra-Matic was the appearance of a "Park" position on the selector. The original Hydra-Matic, which continued in production until the mid-1960s, still used the "Reverse" position for parking pawl engagement.

The first torque converter automatic, Buick's Dynaflow, was introduced for the 1948 model year. It was followed by Packard's Ultramatic in mid-1949 and Chevrolet's Powerglide for the 1950 model year. Each of these transmissions had only two forward speeds, relying on the converter for additional torque multiplication. In the early 1950s, BorgWarner developed a series of three-speed torque converter automatics for American Motors, Ford Motor Company, Studebaker, and several other manufacturers in the US and other countries. Chrysler was late in developing its own true automatic, introducing the two-speed torque converter PowerFlite in 1953, and the three-speed TorqueFlite in 1956. The latter was the first to utilize the Simpson compound planetary gearset.

General Motors produced multiple-turbine torque converters from 1954 to 1961. These included the Twin-Turbine Dynaflow and the triple-turbine Turboglide transmissions. The shifting took place in the torque converter, rather than through pressure valves and changes in planetary gear connections. Each turbine was connected to the drive shaft through a different gear train. These phased from one ratio to another according to demand, rather than shifting. The Turboglide actually had two speed ratios in reverse, with one of the turbines rotating backwards.

By the late 1960s, most of the fluid-coupling four-speed and two-speed transmissions had disappeared in favor of three-speed units with torque converters. Also around this time, whale oil was removed from automatic transmission fluid. By the early 1980s, these were being supplemented and eventually replaced by overdrive-equipped transmissions providing four or more forward speeds. Many transmissions also adopted the lock-up torque converter (a mechanical clutch locking the torque converter pump and turbine together to eliminate slip at cruising speed) to improve fuel economy.

As computerised engine control units (ECUs) became more capable, much of the logic built into the transmission's valve body was offloaded to the ECU. (Some manufacturers use a separate computer dedicated to the transmission, but sharing information with the engine management computer.) In this case, solenoids turned on and off by the computer control shift patterns and gear ratios, rather than the spring-loaded valves in the valve body. This allows for more precise control of shift points, shift quality, lower shift times, and (on some newer cars) semi-automatic control, where the driver tells the computer when to shift. The result is an impressive combination of efficiency and smoothness. Some computers even identify the driver's style and adapt to best suit it.

ZF Friedrichshafen and BMW were responsible for introducing the first six-speed (the ZF 6HP26 in the 2002 BMW E65 7-Series). Mercedes-Benz's 7G-Tronic was the first seven-speed in 2003, with Toyota introducing an eight-speed in 2007 on the Lexus LS 460. Derived from the 7G-Tronic, Mercedes-Benz unveiled a semi-automatic transmission with the torque converter replaced with a wet multi clutch called the AMG SPEEDSHIFT MCT.

Automatic transmission models

Some of the best known automatic transmission families include:

- General Motors — Powerglide, "Turbo-Hydramatic" TH350, TH400 and 700R4, 4L60-E, 4L80-E, Holden Trimatic
- Ford: Cruise-O-Matic, C4, C6, AOD/AODE, E4OD, ATX, AXOD/AX4S/AX4N
- Chrysler: TorqueFlite 727 and 904, A500, A518, 45RFE, 545RFE
- BorgWarner (later Aisin AW)
- ZF Friedrichshafen automatic transmissions

- Allison Transmission
- Voith Turbo
- Aisin AW; Aisin AW is a Japanese automotive parts supplier, known for its automatic transmissions and navigation systems
- Honda
- Nissan/Jatco
- Volkswagen Group - 01M
- Drivetrain Systems International (DSI) - M93, M97 and M74 4-speeds, M78 and M79 6-speeds

Automatic transmission families are usually based on Ravigneaux, Lepelletier , or Simpson planetary gearsets. Each uses some arrangement of one or two central sun gears, and a ring gear, with differing arrangements of planet gears that surround the sun and mesh with the ring. An exception to this is the Hondamatic line from Honda, which uses sliding gears on parallel axes like a manual transmission without any planetary gearsets. Although the Honda is quite different from all other automatics, it is also quite different from an automated manual transmission (AMT).

Many of the above AMTs exist in modified states, which were created by racing enthusiasts and their mechanics by systematically re-engineering the transmission to achieve higher levels of performance. These are known as "performance transmissions". An example of a manufacturer of high performance transmissions of General Motors and Ford transmissions is PerformaBuilt.

Continuously variable transmissions

A fundamentally different type of automatic transmission is the *continuously variable transmission* or *CVT*, which can smoothly and steplessly alter its gear ratio by varying the diameter of a pair of belt or chain-linked pulleys, wheels or cones. Some continuously variable transmissions use a hydrostatic drive — consisting of a variable displacement pump and a hydraulic motor — to transmit power without gears. CVT designs are usually as fuel efficient as manual transmissions in city driving, but early designs lose efficiency as engine speed increases.

A slightly different approach to CVT is the concept of *toroidal CVT* or *infinitely variable transmission* (IVT). These concepts provide zero and reverse gear ratios.

Some current hybrid vehicles, notably those of Toyota, Lexus and Ford Motor Company, have an "electronically-controlled CVT" (E-CVT). In this system, the transmission has fixed gears, but the ratio of wheel-speed to engine-speed can be continuously varied by controlling the speed of the third input to a differential using an electric motor-generator.

Manually controlled automatic transmissions

Most automatic transmissions offer the driver a certain amount of manual control over the transmission's shifts (beyond the obvious selection of forward, reverse, or neutral). Those controls take several forms:

Throttle kickdown

Most automatic transmissions include some means of forcing a downshift into the lowest possible gear ratio if the throttle pedal is fully depressed. In many older designs, kickdown is accomplished by mechanically actuating a valve inside the transmission. Most modern designs use a solenoid-operated valve that is triggered by a switch on the throttle linkage or by the engine control unit (ECM) in response to an abrupt increase in engine power.

Mode selection

Allows the driver to choose between preset shifting programs. For example, 'Economy mode' saves fuel by upshifting at lower engine speeds, while 'Sport mode' (aka Power or Performance) delays shifting for maximum acceleration. The modes also change how the computer responds to throttle input.

Low gear ranges

Conventionally, automatic transmissions have selector positions that allow the driver to limit the maximum ratio that the transmission may engage. On older transmissions, this was accomplished by a mechanical lockout in the transmission valve body preventing an upshift until the lockout was disengaged; on computer-controlled transmissions, the same effect is accomplished by firmware. The transmission can still upshift and downshift automatically between the remaining ratios: for example, in the *3* range, a transmission could shift from first to second to third, but not into fourth or higher ratios. Some transmissions will still upshift automatically into the higher ratio if the engine reaches its maximum permissible speed in the selected range.

Manual controls

Some transmissions have a mode in which the driver has full control of ratio changes (either by moving the selector, or through the use of buttons or paddles), completely overriding the automated function of the hydraulic controller. Such control is particularly useful in cornering, to avoid unwanted upshifts or downshifts that could compromise the vehicle's balance or traction. "Manumatic" shifters, first popularized by Porsche in the 1990s under the trade name Tiptronic, have become a popular option on sports cars and other performance vehicles. With the near-universal prevalence of electronically controlled transmissions, they are comparatively simple and inexpensive, requiring only software changes, and the provision of the actual manual controls for the driver. The amount of true manual control provided is highly variable: some systems will override the driver's selections under certain conditions, generally in the interest of preventing engine damage. Since these gearboxes also have a throttle kickdown switch, it is impossible to fully exploit the engine power at low to medium engine speeds.

Second gear takeoff

Some automatics, particularly those fitted to larger capacity or high torque engines, either when '2' is manually selected, or by engaging a "winter mode", will start off in second gear instead of first, and then not shift into a higher gear until returned to D. Also note that as with most American automatic transmissions, selecting "2" using the selection lever will not tell the transmission to be in only 2nd gear, rather, it will simply limit the transmission to 2nd gear after prolonging the duration of 1st gear through higher speeds than normal operation. The 2000-2002 Lincoln LS V8 (the five-speed automatic *without* manumatic capabilities (as opposed to the optional sport package w/ manu-matic 5sp) started in 2nd gear during most starts both in winter and summer by selecting the "D5" transmission selection notch in the shiftgate (For fuel savings), whereas "D4" would always start in 1st gear. This is done to reduce torque multiplication when proceeding forward from a standstill in conditions where traction was limited — on snow- or ice-covered roads, for example.

Some automatic transmissions modified or designed specifically for drag racing may also incorporate a transmission brake, or "trans-brake," as part of a manual valve body. Activated by electrical solenoid control, a trans-brake simultaneously engages the first and reverse gears, locking the transmission and preventing the input shaft from turning. This allows the driver of the car to raise the engine RPM against the resistance of the torque converter, then launch the car by simply releasing the trans-brake switch.

Chapter 2

Suspension (Vehicle) & Automotive Suspension Design

Suspension (Vehicle)

The front suspension components of a Ford Model T.

The rear suspension on a truck: a leaf spring.

Part of car front suspension and steering mechanism: tie rod, steering arm, king pin axis (using ball joints).

Suspension is the term given to the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. Suspension systems serve a dual purpose — contributing to the car's roadholding/handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations,etc. These goals are generally at odds, so the tuning of suspensions involves finding the right compromise. It is important for the suspension to keep the road wheel in contact with the road surface as much as possible, because all the forces acting on the vehicle do so through the contact patches of the tires. The suspension also protects the vehicle itself and any cargo or luggage from damage and wear. The design of front and rear suspension of a car may be different.

History

Leaf springs have been around since the early Egyptians.

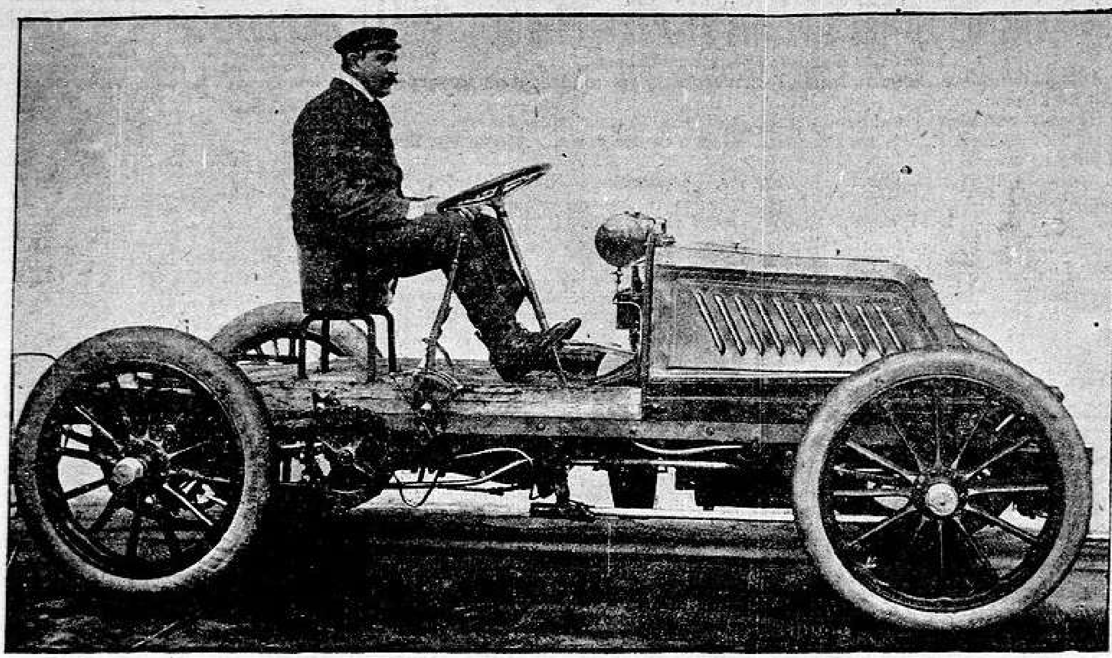
Ancient military engineers used leaf springs in the form of bows to power their siege engines, with little success at first. The use of leaf springs in catapults was later refined and made to work years later. Springs were not only made of metal, a sturdy tree branch could be used as a spring, such as with a bow.

Horse drawn vehicles

By the early 19th century, most British horse carriages were equipped with springs; wooden springs in the case of light one-horse vehicles to avoid taxation, and steel springs in larger vehicles. These were made of low-carbon steel and usually took the form of multiple layer leaf springs.

The British steel springs were not well suited for use on America's rough roads of the time, and could even cause coaches to collapse if cornered too fast. In the 1820s, the Abbot Downing Company of Concord, New Hampshire developed a system whereby the bodies of stagecoaches were supported on leather straps called "thoroughbraces", which gave a swinging motion instead of the jolting up and down of a spring suspension (the stagecoach itself was sometimes called a "thoroughbrace").

Automobiles



FOURNIER ON THE "MORS" MACHINE WITH WHICH HE WON THE PAR IS-BORDEAUX AND PARIS-BERLIN RACES AND BEAT THE VANDERBILT RECORD FOR ONE KILOMETRE.

Henri Fournier on his uniquely dampened and racewinning 'Mors Machine', photo taken 1902

Automobiles were initially developed as self-propelled versions of horse drawn vehicles. However, horse drawn vehicles had been designed for relatively slow speeds and their suspension was not well suited to the higher speeds permitted by the internal combustion engine.

In 1901 Mors of Germany first fitted an automobile with shock absorbers. With the advantage of having a dampened suspension system in his 'Mors Machine', Henri Fournier was able to win the prestigegous Paris — Berlin race on June 20, 1901. Fourniers superior time was 11 hrs 46 min 10 sec, while the best competitor was Léonce Girardot in a Panhard at the time 12 hrs 15 min 40 sec.

In 1920, Leyland used torsion bars in a suspension system. In 1922, independent front suspension was pioneered on the Lancia Lambda and became more common in mass market cars from 1932.

Important properties

Citroën BX Hydropneumatic suspension - maximum to minimum demonstration

Spring rate

The spring rate (or suspension rate) is a component in setting the vehicle's ride height or its location in the suspension stroke. Vehicles which carry heavy loads will often have heavier springs to compensate for the additional weight that would otherwise collapse a vehicle to the bottom of its travel (stroke). Heavier springs are also used in performance applications where the loading conditions experienced are more extreme.

Springs that are too hard or too soft cause the suspension to become ineffective because they fail to properly isolate the vehicle from the road. Vehicles that commonly experience suspension loads heavier than normal have heavy or hard springs with a spring rate close to the upper limit for that vehicle's weight. This allows the vehicle to perform properly under a heavy load when control is limited by the inertia of the load. Riding in an empty truck used for carrying loads can be uncomfortable for passengers because of its high spring rate relative to the weight of the vehicle. A race car would also be described as having heavy springs and would also be uncomfortably bumpy. However, even though we say they both have heavy springs, the actual spring rates for a 2,000 lb (910 kg) race car and a 10,000 lb (4,500 kg) truck are very different. A luxury car, taxi, or passenger bus would be described as having soft springs. Vehicles with worn out or damaged springs ride lower to the ground which reduces the overall amount of compression available to the suspension and increases the amount of body lean. Performance vehicles can sometimes have spring rate requirements other than vehicle weight and load.

Mathematics of the spring rate

Spring rate is a ratio used to measure how resistant a spring is to being compressed or expanded during the spring's deflection. The magnitude of the spring force increases as deflection increases according to Hooke's Law. Briefly, this can be stated as

$$F = -kx$$

where

> F is the force the spring exerts
> k is the spring rate of the spring.
> x is the displacement from equilibrium length i.e. the length at which the spring is neither compressed or stretched.

Spring rate is confined to a narrow interval by the weight of the vehicle,load the vehicle will carry, and to a lesser extent by suspension geometry and performance desires.

Spring rates typically have units of N/mm (or lbf/in). An example of a linear spring rate is 500 lbf/in. For every inch the spring is compressed, it exerts 500 lbf. A non-linear spring rate is one for which the relation between the spring's compression and the force exerted cannot be fitted adequately to a linear model. For example, the first inch exerts 500 lbf force, the second inch exerts an additional 550 lbf (for a total of 1050 lbf), the third inch exerts another 600 lbf (for a total of 1650 lbf). In contrast a 500 lbf/in linear spring compressed to 3 inches will only exert 1500 lbf.

The spring rate of a coil spring may be calculated by a simple algebraic equation or it may be measured in a spring testing machine. The spring constant k can be calculated as follows:

$$k = \frac{d^4 G}{8 N D^3}$$

where d is the wire diameter, G is the spring's shear modulus (e.g., about 12,000,000 lbf/in^2 or 80 GPa for steel), and N is the number of wraps and D is the diameter of the coil.

Wheel rate

Wheel rate is the effective spring rate when measured at the wheel. This is as opposed to simply measuring the spring rate alone.

Wheel rate is usually equal to or considerably less than the spring rate. Commonly, springs are mounted on control arms, swing arms or some other pivoting suspension member. Consider the example above where the spring rate was calculated to be 500 lbs/inch, if you were to move the wheel 1 in (2.5 cm) (without moving the car), the spring more than likely compresses a smaller amount. Lets assume the spring moved 0.75 in (19 mm), the lever arm ratio would be 0.75:1. The wheel rate is calculated by taking the square of the ratio (0.5625) times the spring rate. Squaring the ratio is because the ratio has two effects on the wheel rate. The ratio applies to both the force and distance traveled.

Wheel rate on independent suspension is fairly straight-forward. However, special consideration must be taken with some non-independent suspension designs. Take the case of the straight axle. When viewed from the front or rear, the wheel rate can be measured by the means above. Yet because the wheels are not independent, when viewed from the side under acceleration or braking the pivot point is at infinity (because both wheels have moved) and the spring is directly inline with the wheel contact patch. The result is often that the effective wheel rate under cornering is different from what it is under acceleration and braking. This variation in wheel rate may be minimized by locating the spring as close to the wheel as possible.

Roll couple percentage

Roll couple percentage is the effective wheel rate, in roll, of each axle of the vehicle as a ratio of the vehicle's total roll rate. Roll couple percentage is critical in accurately balancing the handling of a vehicle. It is commonly adjusted through the use of anti-roll bars, but can also be changed through the use of different springs.

A vehicle with a roll couple percentage of 70% will transfer 70% of its sprung weight at the front of the vehicle during cornering. This is also commonly known as "Total Lateral Load Transfer Distribution" or "TLLTD".

Weight transfer

Weight transfer during cornering, acceleration or braking is usually calculated per individual wheel and compared with the static weights for the same wheels.

The total amount of weight transfer is only affected by four factors: the distance between wheel centers (wheelbase in the case of braking, or track width in the case of cornering) the height of the center of gravity, the mass of the vehicle, and the amount of acceleration experienced.

The speed at which weight transfer occurs as well as through which components it transfers is complex and is determined by many factors including but not limited to roll center height, spring and damper rates, anti-roll bar stiffness and the kinematic design of the suspension links.

Unsprung weight transfer

Unsprung weight transfer is calculated based on the weight of the vehicle's components that are not supported by the springs. This includes tires, wheels, brakes, spindles, half the control arm's weight and other components. These components are then (for calculation purposes) assumed to be connected to a vehicle with zero sprung weight. They are then put through the same dynamic loads. The weight transfer for cornering in the front would be equal to the total unsprung front weight times the G-Force times the front unsprung center of gravity height divided by the front track width. The same is true for the rear.

Sprung weight transfer

Sprung weight transfer is the weight transferred by only the weight of the vehicle resting on the springs, not the total vehicle weight. Calculating this requires knowing the vehicle's sprung weight (total weight less the unsprung weight), the front and rear roll center heights and the sprung center of gravity height (used to calculate the roll moment arm length). Calculating the front and rear sprung weight transfer will also require knowing the roll couple percentage.

The roll axis is the line through the front and rear roll centers that the vehicle rolls around during cornering. The distance from this axis to the sprung center of gravity height is the roll moment arm length. The total sprung weight transfer is equal to the G-force times the sprung weight times the roll moment arm length divided by the effective track width. The front sprung weight transfer is calculated by multiplying the roll couple percentage times the total sprung weight transfer. The rear is the total minus the front transfer.

Jacking forces

Jacking forces are the sum of the vertical force components experienced by the suspension links. The resultant force acts to lift the sprung mass if the roll center is above ground, or compress it if underground. Generally, the higher the roll center, the more jacking force is experienced.

Travel

Travel is the measure of distance from the bottom of the suspension stroke (such as when the vehicle is on a jack and the wheel hangs freely) to the top of the suspension stroke (such as when the vehicle's wheel can no longer travel in an upward direction toward the vehicle). Bottoming or lifting a wheel can cause serious control problems or directly cause damage. "Bottoming" can be caused by the suspension, tires, fenders, etc. running out of space to move or the body or other components of the car hitting the road. The control problems caused by lifting a wheel are less severe if the wheel lifts when the spring reaches its unloaded shape than they are if travel is limited by contact of suspension members. Many off-road vehicles, such as desert racers, use straps called "limiting straps" to limit the suspensions downward travel to a point within safe limits for the linkages and shock absorbers. This is necessary, since these trucks are intended to travel over very rough terrain at high speeds, and even become airborne at times. Without something to limit the travel, the suspension bushings would take all the force when the suspension reaches "full droop", and it can even cause the coil springs to come out of their "buckets" if they are held in by compression forces only. A limiting strap is a simple strap, often nylon of a predetermined length, that stops the downward movement at a preset point before the theoretical maximum travel is reached. The opposite of this is the "bump-stop", which protects the suspension and vehicle (as well as the occupants) from violent "bottoming" of the suspension, caused when an obstruction (or hard landing) causes the suspension to run out of upward travel without fully absorbing the energy of the stroke. Without bump-stops, a vehicle that "bottoms out" will experience a very hard shock when the suspension contacts the bottom of the frame or body, which is transferred to the occupants and every connector and weld on the vehicle. Factory vehicles often come with plain rubber "nubs" to absorb the worst of the forces, and insulate the shock. A desert race vehicle, which must routinely absorb far higher impact forces, may be provided with pneumatic or hydro-pneumatic bump-stops. These are essentially miniature shock absorbers (dampeners) that are fixed to the vehicle in a location such that the suspension will contact the end of the piston when it nears the upward travel limit. These absorb the impact far more effectively than a solid rubber bump-stop will, essential because a rubber bump-stop is considered a "last-ditch" emergency insulator for the occasional accidental bottoming of the suspension; it is entirely insufficient to absorb repeated and heavy bottomings such as a high-speed off road vehicle encounters.

Damping

Damping is the control of motion or oscillation, as seen with the use of hydraulic gates and valves in a vehicles shock absorber. This may also vary, intentionally or unintentionally. Like spring rate, the optimal damping for comfort may be less than for control.

Damping controls the travel speed and resistance of the vehicle's suspension. An undamped car will oscillate up and down. With proper damping levels, the car will settle back to a normal state in a minimal amount of time. Most damping in modern vehicles can be controlled by increasing or decreasing the resistance to fluid flow in the shock absorber.

Camber control

Camber changes due to wheel travel, body roll and suspension system deflection or compliance. In general, a tire wears and brakes best at -1 to -2° of camber from vertical. Depending on the tire and the road surface, it may hold the road best at a slightly different angle. Small changes in camber, front and rear, can be used to tune handling. Some race cars are tuned with -2~-7° camber depending on the type of handling desired and the tire construction. Oftentimes, too much camber will result in the decrease of braking performance due to a reduced contact patch size through excessive camber variation in the suspension geometry. The amount of camber change in bump is determined by the instantaneous front view swing arm (FVSA) length of the suspension geometry, or in other words, the tendency of the tire to camber inward when compressed in bump.

Roll center height

This is important to body roll and to front to rear roll stiffness distribution. However, the roll stiffness distribution in most cars is set more by the antiroll bars than the RCH. The height of the roll center is related to the amount of jacking forces experienced.

Instant center

Due to the fact that the wheel and tire's motion is constrained by the suspension links on the vehicle, the motion of the wheel package in the front view will scribe an imaginary arc in space with an "instantaneous center" of rotation at any given point along its path. The instant center for any wheel package can be found by following imaginary lines drawn through the suspension links to their intersection point.

A component of the tire's force vector points from the contact patch of the tire through instant center. The larger this component is, the less suspension motion will occur. Theoretically, if the resultant of the vertical load on the tire and the lateral force generated by it points directly into the instant center, the suspension links will not move. In this case, all weight transfer at that end of the vehicle will be geometric in nature. This is key information used in finding the force-based roll center as well.

In this respect the instant centers are more important to the handling of the vehicle than the kinematic roll center alone, in that the ratio of geometric to elastic weight transfer is determined by the forces at the tires and their directions in relation to the position of their respective instant centers.

No-dive and No-squat

Anti-dive and anti-squat are percentages and refer to the front diving under braking and the rear squatting under acceleration. They can be thought of as the counterparts for braking and acceleration as jacking forces are to cornering. The main reason for the difference is due to the different design goals between front and rear suspension, whereas suspension is usually symmetrical between the left and right of the vehicle.

The method of determining the anti-dive or anti-squat depends on whether the suspension linkages react to the torque of braking and accelerating. For example, with inboard brakes and half-shaft driven rear wheels, the suspension linkages do not, but with outboard brakes and a swing-axle driveline, they do.

To determine the percentage of front suspension braking anti-dive for outboard brakes, it is first necessary to determine the tangent of the angle between a line drawn, in side view, through the front tire patch and the front suspension instant center, and the horizontal. In addition, the percentage of braking effort at the front wheels must be known. Then, multiply the tangent by the front wheel braking effort percentage and divide by the ratio of the center of gravity height to the wheelbase. A value of 50% would mean that half of the weight transfer to the front wheels, during braking, is being transmitted through the front suspension linkage and half is being transmitted through the front suspension springs.

For inboard brakes, the same procedure is followed but using the wheel center instead of contact patch center.

Forward acceleration anti-squat is calculated in a similar manner and with the same relationship between percentage and weight transfer. Anti-squat values of 100% and more are commonly used in dragracing, but values of 50% or less are more common in cars which have to undergo severe braking. Higher values of anti-squat commonly cause wheel hop during braking. It is important to note that, while the value of 100%...in either case...means that all of the weight transfer is being carried through the suspension linkage, this does not mean that the suspension is incapable of carrying additional loads (aerodynamic, cornering, etc.) during an episode of braking or forward acceleration. In other words, no "binding" of the suspension is to be implied.

Flexibility and vibration modes of the suspension elements

In modern cars, the flexibility is mainly in the rubber bushings. For high-stress suspensions, such as off-road vehicles, polyurethane bushings are available, which offer far more longevity under greater stresses.

Isolation from high frequency shock

For most purposes, the weight of the suspension components is unimportant, but at high frequencies, caused by road surface roughness, the parts isolated by rubber bushings act as a multistage filter to suppress noise and vibration better than can be done with only the tires and springs. (The springs work mainly in the vertical direction.)

Contribution to unsprung weight and total weight

These are usually small, except that the suspension is related to whether the brakes and differential(s) are sprung.

Space occupied

Designs differ as to how much space they take up and where it is located. It is generally accepted that MacPherson struts are the most compact arrangement for front-engined vehicles, where space between the wheels is required to place the engine.

Force distribution

The suspension attachment must match the frame design in geometry, strength and rigidity.

Air resistance (drag)

Certain modern vehicles have height adjustable suspension in order to improve aerodynamics and fuel efficiency. And modern formula cars, that have exposed wheels and suspension, typically use streamlined tubing rather than simple round tubing for their suspension arms to reduce drag. Also typical is the use of rocker arm, push rod, or pull rod type suspensions, that among other things, places the spring/damper unit inboard and out of the air stream to further reduce air resistance.

Cost

Production methods improve, but cost is always a factor. The continued use of the solid rear axle, with unsprung differential, especially on heavy vehicles, seems to be the most obvious example.

Springs and dampers

Most conventional suspensions use passive springs to absorb impacts and dampers (or shock absorbers) to control spring motions.

Some notable exceptions are the hydropneumatic systems, which can be treated as an integrated unit of gas spring and damping components, used by the French manufacturer Citroën and the hydrolastic, hydragas and rubber cone systems used by the British Motor Corporation, most notably on the Mini. A number of different types of each have been used:

Passive suspensions

Traditional springs and dampers are referred to as passive suspensions — most vehicles are suspended in this manner.

Springs

Pneumatic spring on a semitrailer

- Leaf spring – AKA Hotchkiss, Cart, or semi-elliptical spring
- Torsion beam suspension
- Coil spring
- Rubber bushing
- Air spring

Dampers or shock absorbers

The shock absorbers damp out the (otherwise resonant) motions of a vehicle up and down on its springs. They also must damp out much of the wheel bounce when the unsprung weight of a wheel, hub, axle and sometimes brakes and differential bounces up and down on the springiness of a tire. The regular bumps found on dirt roads (nicknamed "corduroy", but properly corrugations or washboarding) are caused by this wheel bounce.

Semi-active and active suspensions

If the suspension is externally controlled then it is a semi-active or active suspension — the suspension is reacting to what are in effect "brain" signals. As electronics have become more sophisticated, the opportunities in this area have expanded.

For example, a hydropneumatic Citroën will "know" how far off the ground the car is supposed to be and constantly reset to achieve that level, regardless of load. It will *not* instantly compensate for body roll due to cornering however. Citroën's system adds about 1% to the cost of the car versus passive steel springs.

Semi-active suspensions include devices such as air springs and switchable shock absorbers, various self-levelling solutions, as well as systems like Hydropneumatic, Hydrolastic, and Hydragas suspensions. Mitsubishi developed the world's first production semi-active electronically controlled suspension system in passenger cars; the system was first incorporated in the 1987 Galant model. Delphi currently sells shock absorbers filled with a magneto-rheological fluid, whose viscosity can be changed electromagnetically, thereby giving variable control without switching valves, which is faster and thus more effective.

Fully active suspension systems use electronic monitoring of vehicle conditions, coupled with the means to impact vehicle suspension and behavior in real time to directly control the motion of the car. Lotus Cars developed several prototypes, from 1982 onwards, and introduced them to F1, where they have been fairly effective, but have now been banned. Nissan introduced a low bandwidth active suspension in circa 1990 as an option that added an extra 20% to the price of luxury models. Citroën has also developed several active suspension models. A recently publicised fully active system from Bose Corporation uses linear electric motors, i.e. solenoids, in place of hydraulic or pneumatic actuators that have generally been used up until recently. The most advanced suspension system is Active Body Control, introduced in 1999 on the top-of-the-line Mercedes-Benz CL-Class.

Several electromagnetic suspensions have also been developed for vehicles. Examples include the electromagnetic suspension of Bose, and the electromagnetic suspension developed by prof. Laurentiu Encica. In addition, the new Michelin wheel with embedded suspension working on a electromotor is also similar.

With the help of control system, various semi-active/active suspensions realize an improved design compromise among different vibrations modes of the vehicle, namely bounce, roll, pitch and warp modes. However, the applications of these advanced suspensions are constrained by the cost, packaging, weight, reliability, and/or the other challenges.

Interconnected suspensions

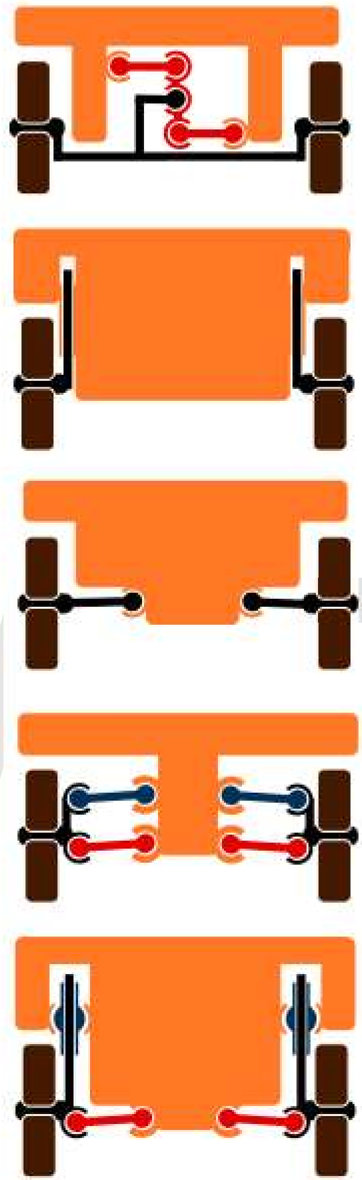
Interconnected suspension, unlike semi-active/active suspensions, could easily decouple different vehicle vibration modes in a passive manner. The interconnections can be realized by various means, such as mechanical, hydraulic and pneumatic. Anti-roll bars are one of the typical examples of mechanical interconnections, while it has been stated that fluidic interconnections offer greater potential and flexibility in improving both the stiffness and damping properties.

Considering the considerable commercial potentials of hydro-pneumatic technology (Corolla, 1996), interconnected hydropneumatic suspensions have also been explored in some recent studies, and their potential benefits in enhancing vehicle ride and handling have been demonstrated. The control system can also be used for further improving performance of interconnected suspensions. Apart from academic research, an Australian company, Kinetic, is having some success (WRC: 3 Championships, Dakar Rally: 2 Championships, Lexus GX470 2004 4x4 of the year with KDSS, 2005 PACE award) with various passive or semi-active systems, which generally decouple at least two vehicle modes (roll, warp (articulation), pitch and/or heave (bounce)) to simultaneously control each mode’s stiffness and damping, by using interconnected shock absorbers, and other methods. In 1999, Kinetic was bought out by Tenneco.

Historically, the first mass production car with front to rear mechanical interconnected suspension was the 1948 Citroën 2CV. The suspension of the 2CV was extremely soft — it had low roll stiffness, but its pitch stiffness was increased by using an interconnected suspension. The leading arm / trailing arm swinging arm, fore-aft linked suspension system together with inboard front brakes had a much smaller unsprung weight than existing coil spring or leaf designs. The interconnection transmitted some of the force deflecting a front wheel up over a bump, to push the rear wheel down on the same side. When the rear wheel met that bump a moment later, it did the same in reverse, keeping the car level front to rear. The 2CV had a design brief to be able to be driven at speed over a ploughed field. It originally featured friction dampers and tuned mass dampers. Later models had tuned mass dampers at the front with telescopic dampers / shock absorbers front and rear.

Some of the last post-war Packard models also featured interconnected suspension. The original Mini and some more recent British Leyland models also featured interlinking, when fitted with Moulton's Hydrolastic or Hydragas suspensions.

Suspension Geometry



Common types seen from behind. From top to bottom: live axle with Watt bar, suspension like on a bike fork, swing axle, double wishbone, MacPherson. Some types are missing because trailing arm links are not presentable in this view and some types use elements which flex to some movements and are stiff to others and flexible elements are omitted for clarity.

Suspension systems can be broadly classified into two subgroups — dependent and independent. These terms refer to the ability of opposite wheels to move independently of each other.

A *dependent suspension* normally has a beam (a simple 'cart' axle) or (driven) live axle that holds wheels parallel to each other and perpendicular to the axle. When the camber of one wheel changes, the camber of the opposite wheel changes in the same way (by convention on one side this is a positive change in camber and on the other side this a negative change). De Dion suspensions are also in this category as they rigidly connect the wheels together.

An *independent suspension* allows wheels to rise and fall on their own without affecting the opposite wheel. Suspensions with other devices, such as sway bars that link the wheels in some way are still classed as independent.

A third type is a *semi-dependent* suspension. In this case, the motion of one wheel does affect the position of the other but they are not rigidly attached to each other. A twist-beam rear suspension is such a system.

Dependent suspensions

Dependent systems may be differentiated by the system of linkages used to locate them, both longitudinally and transversely. Often both functions are combined in a set of linkages.

Examples of location linkages include:

- Satchell link
- Panhard rod
- Watt's linkage
- WOBLink
- Mumford linkage
- Leaf springs used for location (transverse or longitudinal)
    - Fully elliptical springs usually need supplementary location links and are no longer in common use
    - Longitudinal semi-elliptical springs used to be common and still are used in heavy-duty trucks and aircraft. They have the advantage that the spring rate can easily be made progressive (non-linear).
    - A single transverse leaf spring for both front wheels and/or both back wheels, supporting solid axles, was used by Ford Motor Company, before and soon after World War II, even on expensive models. It had the advantages of simplicity and low unsprung weight (compared to other solid axle designs).

In a front engine, rear-drive vehicle, dependent rear suspension is either "live axle" or deDion axle, depending on whether or not the differential is carried on the axle. Live axle is simpler but the unsprung weight contributes to wheel bounce.

Because it assures constant camber, dependent (and semi-independent) suspension is most common on vehicles that need to carry large loads as a proportion of the vehicle weight, that have relatively soft springs and that do not (for cost and simplicity reasons) use active suspensions. The use of dependent front suspension has become limited to heavier commercial vehicles.

A rear independent suspension on an AWD car.

Semi-independent suspension

In a semi-independent suspensions, the wheels of an axle are able to move relative to one another as in an independent suspension but the position of one wheel has an effect on the position and attitude of the other wheel. This effect is achieved via the twisting or deflecting of suspension parts under load. The most common type of semi-independent suspension is the twist beam.

- Twist beam

Independent suspension

The variety of independent systems is greater and includes:

- Swing axle
- Sliding pillar
- MacPherson strut/Chapman strut
- Upper and lower A-arm (double wishbone)

- multi-link suspension
- semi-trailing arm suspension
- swinging arm
- leaf springs
    - Transverse leaf springs when used as a suspension link, or four quarter elliptics on one end of a car are similar to wishbones in geometry, but are more compliant. Examples are the front of the original Fiat 500, the Panhard Dyna Z and the early examples of Peugeot 403 and the back of the AC Ace and AC Aceca.

Because the wheels are not constrained to remain perpendicular to a flat road surface in turning, braking and varying load conditions, control of the wheel camber is an important issue. Swinging arm was common in small cars that were sprung softly and could carry large loads, because the camber is independent of load. Some active and semi-active suspensions maintain the ride height, and therefore the camber, independent of load. In sports cars, optimal camber change when turning is more important.

Wishbone and multi-link allow the engineer more control over the geometry, to arrive at the best compromise, than swing axle, MacPherson strut or swinging arm do; however the cost and space requirements may be greater. Semi-trailing arm is in between, being a variable compromise between the geometries of swinging arm and swing axle.

Armoured fighting vehicle suspension

This Grant I tank's suspension has road wheels mounted on wheel trucks, or *bogies*.

Military AFVs, including tanks, have specialized suspension requirements. They can weigh more than seventy tons and are required to move at high speed over very rough ground. Their suspension components must be protected from land mines and antitank weapons. Tracked AFVs can have as many as nine road wheels on each side. Many wheeled AFVs have six or eight wheels, to help them ride over rough and soft ground.

The earliest tanks of World War I had fixed suspension with no movement whatsoever. This unsatisfactory situation was improved with leaf spring or coil spring suspensions adopted from agricultural, automotive or railway machinery, but even these had very limited travel.

Speeds increased due to more powerful engines, and the quality of ride had to be improved. In the 1930s, the Christie suspension was developed, which allowed the use of coil springs inside a vehicle's armored hull, by changing the direction of force deforming the spring, using a bell crank. Horstmann suspension was a variation which used a combination of bell crank and exterior coil springs, in use from the 1930s to the 1990s.

By World War II the other common type was torsion-bar suspension, getting spring force from twisting bars inside the hull — this had less travel than the Christie-type, but was significantly more compact, allowing more space inside the hull, with consequent possibility to install larger turret rings and thus a heavier main armament. The torsion-bar suspension, sometimes including shock absorbers, has been the dominant heavy armored vehicle suspension since World War II.

Automotive Suspension Design

Automotive suspension design is an aspect of automotive engineering, concerned with designing the suspension for cars and trucks.

The process entails

- selecting appropriate vehicle level targets
- selecting a system architecture
- choosing the location of the 'hard points', or theoretical centres of each ball joint or bushing
- selecting the rates of the bushings
- analysing the loads in the suspension
- designing the spring rates
- designing shock absorber characteristics
- designing the structure of each component so that it is strong, stiff, light, and cheap
- analysing the vehicle dynamics of the resulting design

Since the 1990s the use of multibody simulation and finite element software has made this series of tasks more straightforward.

Vehicle level targets

A partial list would include:

- maximum steady state lateral acceleration (in understeer mode)
- roll stiffness (degrees per g of lateral acceleration)
- ride frequencies
- lateral load transfer percentage distribution front to rear
- Roll moment distribution front to rear
- ride heights at various states of load
- Understeer gradient
- Turning circle
- Ackermann
- Jounce travel
- Rebound travel

Once the overall vehicle targets have been identified they can be used to set targets for the two suspensions. For instance, the overall understeer target can be broken down into contributions from each end using a Bundorf analysis.

System architecture

Typically a vehicle designer is operating within a set of constraints. The suspension architecture selected for each end of the vehicle will have to obey those constraints. For both ends of the car this would include the type of spring, location of the spring, and location of the shock absorbers.

For the front suspension the following need to be considered

- the type of suspension (MacPherson strut or double wishbone suspension)
- type of steering actuator (rack and pinion or recirculating ball)
- location of the steering actuator in front of, or behind, the wheel centre

For the rear suspension there are many more possible suspension types, in practice.

Hardpoints

The hardpoints control the static settings and the kinematics of the suspension.

The static settings are

- Toe
- Camber
- Caster
- Roll center height at design load
- Mechanical (or caster) trail
- Anti-dive and anti-squat
- Kingpin Inclination
- Scrub radius
- Spring and shock absorber motion ratios

The kinematics describe how important characteristics change as the suspension moves, typically in roll or steer. They include

- Bump Steer
- Roll Steer
- Tractive Force Steer
- Brake Force Steer
- Camber gain in roll
- Caster gain in roll
- Roll centre height gain
- Ackerman change with steering angle

- Track gain in roll

The analysis for these parameters can be done graphically, or by CAD, or by the use of kinematics software.

Compliance analysis

The compliance of the bushings, the body, and other parts modify the behaviour of the suspension. In general it is difficult improve the kinematics of a suspension using the bushings, but one example where it does work is the toe control bush used in Twist-beam rear suspensions. More generally, modern cars suspensions include an NVH bush. This is designed as the main path for the vibrations and forces that cause road noise and impact noise, and is supposed to be tunable without affecting the kinematics too much;

Loads

Once the basic geometry is established the loads in each suspension part can be estimated. This can be as simple as deciding what a likely maximum load case is at the contact patch, and then drawing a Free body diagram of each part to work out the forces, or as complex as simulating the behaviour of the suspension over a rough road, and calculating the loads caused. Often loads that have been measured on a similar suspension are used instead - this is the most reliable method.

Detailed design of arms

The loads and geometry are then used to design the arms and spindle. Inevitably some problems will be found in the course of this that force compromises to be made with the basic geometry of the suspension.

Chapter 3

Weight Transfer

Camaro performing a wheelie during drag racing.

A motorcyclist performing a stoppie.

A Toyota MR2 leaning to the outside of a turn.

Weight transfer and **load transfer** are two expressions used somewhat confusingly to describe two distinct effects: the change in load borne by different wheels of even perfectly rigid vehicles during acceleration, and the change in center of mass (CoM) location relative to the wheels because of suspension complience or cargo shifting or sloshing. In the automobile industry, **weight transfer** customarily refers to the change in load borne by different wheels during acceleration. This is more properly referred to as **load transfer**, and that is the expression used in the motorcycle industry, while **weight transfer** on motorcycles, to a lesser extent on automobiles, and cargo movement on either is due to a change in the CoM location relative to the wheels.

Load transfer

In wheeled vehicles, **load transfer** is the measurable change of load borne by different wheels during acceleration (both longitudinal and lateral). This includes braking, and deceleration (which is an acceleration at a negative rate). No motion of the centre of gravity (CoG) relative to the wheels is necessary, and so load transfer may be experienced by vehicles with no suspension at all. Load transfer is a crucial concept in understanding vehicle dynamics. The same is true in bikes, though only longitudinally.

Cause

The major forces that accelerate a vehicle occur at the tires' contact patches. Since these forces are not directed through the vehicle's CoG, one or more moments are generated whose forces are the tyres traction forces at pavement level, the other one (equal but opposed) is the mass inertia located at (CoG) and the arm is the distance from pavement surface to CoG. It is these moments that cause variation in the load distributed between the tires. Often this is interpreted by the casual observer as a pitching or rolling motion of the vehicles body. A perfectly rigid vehicle without suspension that would not exhibit pitching or rolling of the body still undergoes load transfer. However, the pitching and rolling of the body adds some (small) weight transfer due to the (small) CoG horizontal displacement with respect to the wheels axis suspension vertical travel and also due to deformation of the tires i.e. contact patch displacement relative to wheel.

Lowering the CoG towards the ground is one method of reducing load transfer. As a result load transfer is reduced in both the longitudinal and lateral directions. Another method of reducing load transfer is by increasing the wheel spacings. Increasing the vehicle's wheel base (length) reduces longitudinal load transfer while increasing the vehicle's track (width) reduces lateral load transfer. Most high performance automobiles are designed to sit as low as possible and usually have an extended wheel base and track.

Weight transfer

Weight transfer involves the *actual* (relatively small) movement of the vehicle CoG relative to the wheel axes due to displacement of the chassis as the suspension complies, or of cargo or liquids within the vehicle, which results in a redistribution of the total vehicle load between the individual tires.

Center of gravity

Weight transfer occurs as the vehicle's center of gravity (CoG) shifts during automotive maneuvers. Acceleration causes the sprung mass to rotate about a geometric axis resulting in relocation of the CoG. Front-back weight transfer is proportional to the change in the longitudinal location of the center of gravity to the vehicle's wheelbase, and side-to-side weight transfer (summed over front and rear) is proportional to the ratio of the change in the center of gravity's lateral location to the vehicle's track.

Liquids, such as fuel, readily flow within their containers, causing changes in the vehicle's CoG. As fuel is consumed, not only does the position of the CoG change, but the total weight of the vehicle is also reduced.

By way of example, when a vehicle accelerates, a weight transfer toward the rear wheels can occur. An outside observer might witness this as the vehicle visibly leans to the back, or squats. Conversely, under braking, weight transfer toward the front of the car can occur. Under hard braking it might be clearly visible even from inside the vehicle as the nose dives toward the ground (most of this will be due to load transfer). Similarly, during changes in direction (lateral acceleration), weight transfer to the outside of the direction of the turn can occur.

Weight transfer is generally of far less practical importance than load transfer, for cars and SUVs at least. For instance in a 0.9g turn, a car with a track of 1650 mm and a CG height of 550 mm will see a load transfer of 30% of the vehicle weight, that is the outer wheels will see 30% more load than before, and the inners 30% less. Total available grip will drop by around 3% as a result of this load transfer. At the same time, the CG of the vehicle will typically move laterally and vertically, relative to the contact patch by no more than 30 mm, leading to a weight transfer of less than 2%, and a corresponding reduction in grip of 0.01%.

Traction

Load transfer causes the available traction (engineering) at all four wheels to vary as the car brakes, accelerates, or turns. This bias to one pair of tires doing more `work' than the other pair results in a net loss of total available traction. The net loss can be attributed to the phenomenon known as tire load sensitivity.

An exception is during positive acceleration when the engine power is driving two or fewer wheels. In this situation where all the tires are not being utilized load transfer can be advantageous. As such, the most powerful cars are almost never front wheel drive, as the acceleration itself causes the front wheels' traction to decrease. This is why sports cars usually have either rear wheel drive or all wheel drive (and in the all wheel drive case, the power tends to be biased toward the rear wheels under normal conditions).

Rollover

If (lateral) load transfer reaches the tire loading on one end of a vehicle, the inside wheel on that end will lift, causing a change in handling characteristic. If it reaches half the weight of the vehicle it will start to roll over. Some large trucks will roll over before skidding, while passenger vehicles and small trucks usually roll over only when they leave the road. Fitting racing tires to a tall or narrow vehicle and then driving it hard may lead to rollover.

Chapter 4

TorqueFlite

	TorqueFlite
Manufacturer	Chrysler Corporation
Production	1956–
Predecessor	PowerFlite
Class	3- or 4-speed automatic

TorqueFlite (also spelled Torqueflite) was the trademarked name of Chrysler Corporation's three-speed automatic transmission, which was introduced late in the 1956 model year. TorqueFlite was introduced on the heels of the company's two-speed PowerFlite automatic, which made its debut in 1954. In the 1990s, the TorqueFlite name was dropped and the transmissions were referred to by a model number referring to their torque rating and gear set, although some models remained completely unchanged.

History

The first Torqueflites provided three speeds forward plus reverse. Gear ratios were 2.45:1 in first, 1.45 in second, and 1.00 in third. The transmission was controlled by a series of pushbuttons located on the vehicle's dashboard. The buttons were generally at the extreme driver's side end of the dash, i.e., the left in left-hand drive vehicles, and the right in right-hand drive ones. However, this was not always the case; the 1962 Dodge Phoenix, a right-hand drive export model sold in Australia and South Africa, used the U.S. 1962 Plymouth Valiant instrument cluster assembly, into the left end of which were integrated the transmission pushbuttons. Button arrangement varied by vehicle model and year; sequence was Reverse, Neutral, Drive, Second, and First, from top to bottom with vertically-arrayed buttons, from left to right with horizontally-arrayed buttons, and clockwise starting at upper left with clustered buttons.

A parking lock was not provided until the advent of the aluminum-case Torqueflites in 1960 (standard-duty A-904) and 1962 (heavy-duty A-727), at which point a lever was added adjacent to the pushbuttons: Throwing the lever to the "Park" position placed the car into Neutral and engaged a lock pawl on the transmission's output shaft. Throwing the park lever out of "Park" position unlocked the shift buttons so that a driving range could be selected. The buttons were replaced by conventional steering column- or floor-mounted shift levers in all automatic Chrysler-built vehicles for the 1965 model year, though floor levers were available in certain sporty 1964 models.

Like a vehicle with a General Motors Hydramatic, a vehicle with a Torqueflite transmission starts out in first gear when the Drive or Second position is selected. This is in contrast to vehicles with several automatics from Ford and Borg-Warner, which start out in second rather than first if the Second position is selected.

1962 brought the addition of a canister-style fluid filter installed in the cooler line. For 1964, the canister filter was eliminated, and the transmission's internal intake screen was replaced by an efficient Dacron filter. Fluid life starting in 1964 was extended from 12,000 mi (19,000 km) to 50,000 mi (80,000 km), providing justification for the deletion of the drain plug from the oil pan.

For 1966, the twin-cable shift and park control mechanism (a holdover from the push-button operation) was replaced by a solid shift control linkage consisting of a series of pushrods, rotating rods and levers. The rear pump was eliminated, which simplified and cost-reduced the transmission but rendered push-starting impossible; Chrysler engineers reasoned that improved electrical and fuel systems reduced the need to push-start vehicles, and safety concerns weighed against doing so. The gated shift quadrants also permitted the deletion of the reverse safety blocker valve which, in TorqueFlites made through 1965, had shifted the transmission harmlessly into Neutral if the Reverse position were selected with the vehicle moving forward above approximately 3 mph (4.8 km/h).

In 1968, part-throttle downshift functionality was added to A-904 transmissions used with 6-cylinder engines. This feature permitted the transmission to shift from third to second gear in response to moderate accelerator pressure. Previously, an automatic 3-2 downshift occurred only if the driver pushed the accelerator to the floor. This change was made to maintain acceptable in-town performance with taller final-drive ratios in the rear axle — 2.76:1 rear axle gears were being furnished in applications previously equipped with 2.93:1 or 3.23:1 gearsets. Part-throttle downshift functionality was extended to V8 A-904s in 1969, and to most A-727 transmissions in 1970 to 1971.

In 1978, most Torqueflite transmissions gained a lockup torque converter clutch to mechanically connect the converter's impeller and turbine, eliminating slip for better highway fuel economy. This addition required the removal of the torque converter drain plug.

For 1980, a wide-ratio gearset was released for the A904, A998 and A999, with 2.74:1 in first, 1.54 in second, and 1.00 in third.

Torqueflite was an available option or standard equipment, depending on model and year, on all Chrysler products: Plymouth, Dodge, DeSoto, Chrysler and Imperial. It was also used by American Motors beginning in 1972, where it was named **TorqueCommand**, as well as by Jeep, International Harvester, Maserati Quattroporte, Monteverdi and Bristol When installed in Dodge trucks and vans, the transmission was marketed as **LoadFlite**.

In the 1990s, the transmissions were renamed, however the Torqueflite remains the basis of all current Chrysler designed transmissions. Jeep used several other manufacturers' transmissions until 1997, and Mercedes-Benz uses its own design identified by the number "722". Also several of the pickup lines now use transmissions from various sources.

Nomenclature

Torqueflite transmissions and transaxles made through 1991 were assigned arbitrary designations consisting of the letter "A" followed by three digits. 1992 and later units have four-character designations in which the first through fourth characters indicate, respectively, the number of forward speeds, torque capacity, drive type or transaxle orientation, and control system:

Forward speeds	Torque capacity	Drive type	Control
3 or 4	1 (low) to 9 (high)	R (Rear wheel) T (Transverse) A (All-wheel)	H (Hydromechanical) E (Electronic)

Technology

Torqueflites use a torque converter and the **Simpson Gearset**, two identical planetary gearsets sharing a common sun gear. Chrysler Corporation licensed this gearset from Simpson in 1955.

Rear-wheel drive transmissions

A488

The original TorqueFlite was designated **A488**, with a cast iron case and no parking pawl.

A500

The **A500**, later 40RH/42RH (hydraulic) and 40RE/42RE/44RE (electronic), was an A904 derivative used in trucks and vans. Introduced in the 1989 model year on a limited basis, it was the first light-duty Chrysler four-speed automatic and was placed behind the 3.9 L and 5.2 L engines for light-duty purposes. A tailshaft overdrive unit was bolted to the rear of the case to provide a total of four forward speeds, and was replaced by the 42RLE in 2004.

Gear ratios:

1	2	3	4	R
2.74	1.54	1.00	0.69	2.21

Applications:

- 1989-2001 Dodge Ram pickup 150/1500 V6/V8(2WD)
- 1989-2003 Dodge Ram Van B150/B250 V6/V8
- 1989-2003 Dodge Dakota
- 1993-2004 Jeep Grand Cherokee I6
- 1996-1998 Jeep Grand Cherokee 5.2 V8

A518

The **A518**, later 46RH (hydraulic controlled governor pressure) and 46RE (electronic controlled governor pressure), is an A727 derivative with overdrive. Starting in the early 1990s, it was used in trucks and vans. The overdrive fourth gear ratio is 0.69:1.

Gear ratios:

1	2	3	4	R
2.45	1.45	1.00	0.69	2.35

Applications:

- Dodge Ram pickup and vans 1500/2500/3500 V8 engines (DGT)
- Dodge Dakota *R/T* (1998-2003)
- Jeep Grand Cherokee 1998 5.9L
- Jeep Grand Cherokee 1993-1995 5.2 V8

A618

The **A618**, later 47RH (hydraulic controlled governor pressure) and 47RE (electronic controlled governor pressure), is a heavier-duty version of A518. It was used in trucks and vans starting in the mid-1990s. While currently used with some internal changes when coupled to the 5.9 L Cummins Turbo-Diesel and the 8.0 L V-10 applications, it's still a 727 with overdrive and stronger internal parts. It has an input torque rating of 450 lb·ft (610 N·m).

Gear ratios:

1	2	3	4	R
2.45	1.45	1.00	0.69	2.21

Applications:

- Dodge Ram pickups 2500/3500 ISB Diesel and iron V-10 (DGP)
- Dodge Ram SRT-10 (DGP)f

A727

The A488 was replaced in 1962 with the **A727** (later 36RH and 37RH), with an aluminum case to reduce weight by about 60 lb (27 kg). The A727 incorporated a parking pawl and various internal improvements, and used a 10.75 in (27.3 cm) or 11.75 in (29.8 cm) torque converter. The heavier-duty A727 Torqueflites became — and remain — popular for drag racing and monster truck applications because of their controllability and strength.

- 1962-1978 361 , 383 , 400 B-Motor V8
- 1962-1978 413 , 426 wedge , 440 RB-V8
- 1964-1965 426 Hemi Super Stock
- 1966-1971 426 "Street" Hemi
- 1962-1966 318 "A" "Poly" V8
- 1968-1973 340
- 1971-1978 360
- H.D. 225 Slant Six (Police , Taxi , Light-Duty Pickups , "A" Van , "B" Van)

was known as "A-727-RG" (Raised-deck "G" Motor)

- 1972-c.1978 AMC 304 , 360 , 401 V8 "Torque-Command 8"

A904

For standard-duty applications in smaller and lighter vehicles with 6-cylinder or small V8 engines, the compact **A904** (later 30RH) was introduced in 1960. This transmission used a 10.75 in (27.3 cm) torque converter. There was also a smaller version of this transmission used in the Dodge Colt/Plymouth Champ cars made by Mitsubishi in Japan. This smaller transmission used a 10 in (25 cm) torque converter.

Uses:

- 1960-1976 170 , 198 , 225 Slant Six
- 1964-1969 273 LA-V8
- 1967-1978 318 LA-V8
- 1975-1978 360 2Bbl LA-V8
- 1972-c.1978 AMC I-6 "Torque-Command 6"

A998

The **A998** (later, 31RH) was a medium-duty, wide-ratio version of the small-frame A904 transmission for use with medium-power V8 engines and the 3.9 L V6 engine.

The 998 was equipped with four direct friction plates.

These automatics had lower first and second gear ratios to allow the lower-powered engines to provide better acceleration without sacrificing highway fuel economy.

A999

The **A999** (later 32RH) was a heavier-duty, wide-ratio version of the small-frame A904 transmission for use with medium-power V8 engines and the 3.9 L V6 engine.

The 999 was equipped with four or five direct friction plates.

These automatics had lower first and second gear ratios to allow the lower-powered engines to provide better acceleration without sacrificing highway fuel economy.

Uses:

- Jeep Wrangler TJ's with the 4.0 straight 6

30RH

A renamed light-duty A904.

31RH

A renamed medium-duty A998.

32RH

A renamed heavier medium-duty A999.

40RH

A renamed light-duty A500. A904 with overdrive and hydraulic control.

42RH

A renamed medium-duty A500. A998 with overdrive and hydraulic control.

44RE

A renamed heavy-duty A500. A999 with overdrive and electrical control.

46RH

A renamed A518. A727 with overdrive and hydraulic control.

Applications:

- 1994-1995 Dodge Ram 2500/3500 V8
- 1995 (Jeep Grand Cherokee 5.2)

46RE

A renamed second-generation A518. A727 with overdrive and electrical control.

Applications:

- 1996 Dodge Dakota V8
- 1996-2002 Dodge Ram 1500/2500/3500 V8
- 1998-2000 Dodge Durango 5.9L V8 (4WD or 2WD)
- 1998 Jeep Grand Cherokee 5.9L V8 (4WD or 2WD)

47RH

A renamed A618 and hydraulic control.

Applications:

- 1994-1995 Dodge Ram 2500/3500 Diesel/V10

47RE

A renamed second-generation A618. A heavy-duty A727 with overdrive and electrical control.

Applications:

- 1996-2002 Dodge Ram 2500/3500 Diesel/V10

48RE

The **48RE** is an electronically-governed, four-speed heavy-duty overdrive automatic transmission, stronger than its predecessor, the 47-series.

Gear ratios:

1	2	3	4	R
2.45	1.45	1.00	0.69	2.21

Applications:

- 2003-2004 Dodge Ram 2500/3500 ISB Diesel
- 2003-2004 Dodge Ram 2500/3500 HO ISB Diesel
- 2004-2007 Dodge Ram 2500/3500 600/610 Diesel
- 2004-2006 Dodge Ram SRT-10

Front-wheel drive transaxles

The A404, A413, A470, and A670 are front wheel drive transaxle derivatives of the A904 Torqueflite.

In the late 1970s, Chrysler designed the **A404** TorqueFlite three-speed automatic transaxle for its front wheel drive Dodge Omni and Plymouth Horizon subcompact cars. This transaxle would be upgraded in the 1980s into the **A413** and **A670** units, which were progressively heavier-duty, for Chrysler's K-cars and their derivatives, including the minivans. The four-speed Ultradrive electronic four-speed automatic transaxle would eventually replace it, but the three-speed lasted for more than a decade after the 1989 debut of the four-speed unit.

A404

The light-duty A404 was used with the smallest straight-4 engines from Chrysler, commonly the 1.7 L Volkswagen unit.

A413 or 31TH

The A404 was strengthened to become the **A413** (later **31TH**) in 1981. This was used with Chrysler's 2.2 and 2.5 L K-car engines. It was available both with and without a lockup torque converter. This transmission was also used in the Dodge Neon from 1995-2001. The A413 is broadly similar in concept to Ford's *ATX* three-speed unit.

A415

The **A415** was developed for the 1.6 L Simca 1100 engine, but was not released for series production.

A470

The **A470** was a strengthened version of the transaxle used with the 2.6 L *Mitsubishi Astron engine* in the K-cars from 1981-1985 and minivans from 1984 through 1987.

A670

The highest-specification three-speed transaxle was the **A670**. It was used with the 3.0 L *Mitsubishi* V6 engine in Chrysler's cars and minivans from 1987-2000.

Gear ratios:

1	2	3	R	Final
2.69	1.55	1.00	2.10	3.02

Chapter 5

Automotive Hemming & Automotive Aerodynamics

Automotive Hemming

Hemming (Automotive) Hemming is a technology used by the automotive industry to join inner and outer closure panels together (hoods, doors, tailgates, etc.). It is the process of bending/folding the flange of the outer panel over the inner one. The accuracy of the operation affects significantly the appearance of the car's outer surfaces and is therefore a critical factor in the final quality of a finished vehicle.

Hemming Processes

Press Hemming

Hemming presses are widely used in automotive manufacturing for hemming of sheet-metal body components. The process uses traditional hydraulically operated 'stamping presses' to hem closure parts and being the last forming process in stamping, it determines the external quality of automotive outer parts such as doors, hood and trunk-lid.

Hemming press features and benefits

- Die storage systems
- Fully automatic die-changing systems
- Pressing capacity typically 150 or 180 tons
- Large panel size capacity
- More than one part can be produced on same line

Hemming Press Limitations

- Restricted to flat un-complicated panel profiles
- High Cost

Table Top Hemming

Tabletop hemming machines are utilised for the manufacture of medium to high production volumes, with the ability to achieve cycle times as low as 15 seconds.

Table Top features and benefits

- Optimum panel quality guaranteed through the hemming principle of the closed ring (

Table Top Limitations

- Dedicated to one panel

Robot (Roller Hemming)

Robot hemming uses a standard Industrial Robot integrated with a roller hemming head to provide a flexible solution to closure manufacture. The flange of the outer panel is bent over the inner panel in progressive steps by means of the roller hemming head. The process allows the advantage of using the robot controlled hemming head to hem several different components in a single cell. Minor changes and modifications to panel hemming conditions can also be accommodated allowing a quick and cost-effective reaction.

The robot can also be used for other tasks for example, by equipping it with a tool changing system. This will allow it to also operate dispensing equipment for adhesives and sealants, or a gripper which will enable it to carry out panel manipulation within the assembly cell.

Robot Hemming features and benefits

- The ideal solution for low to medium volume production demands
- Flexibility as robot can hem various panels and can perform other tasks with economical implementation of panel changes
- Simple and quiet in operation
- Low cost simple hem roller tooling and use of standard Industrial robot
- Reduced mechanical effort for tryout
- Flexible production with regard to different types and variants

Automotive Aerodynamics

A truck with added bodywork on top of the cab to reduce drag.

Automotive aerodynamics is the study of the aerodynamics of road vehicles. The main concerns of automotive aerodynamics are reducing drag (though drag by wide wheels is dominating most cars), reducing wind noise, minimizing noise emission, and preventing undesired lift forces and other causes of aerodynamic instability at high speeds. For some classes of racing vehicles, it may also be important to produce desirable downwards aerodynamic forces to improve traction and thus cornering abilities.

An aerodynamic automobile will integrate the wheel arcs and lights in its shape to have a small surface. It will be streamlined, for example it does not have sharp edges crossing the wind stream above the windshield and will feature a sort of tail called a fastback or Kammback or liftback. Note that the Aptera 2e, the Loremo, and the Volkswagen 1-litre car try to reduce the area of their back. It will have a flat and smooth floor to support the Venturi effect and produce desirable downwards aerodynamic forces. The air that rams into the engine bay, is used for cooling, combustion, and for passengers, then reaccelerated by a nozzle and then ejected under the floor. For mid and rear engines air is decelerated and pressurized in a diffuser, loses some pressure as it passes the engine bay, and fills the slipstream. These cars need a seal between the low pressure region around the wheels and the high pressure around the gearbox. They all have a closed engine bay floor. The suspension is either streamlined (Aptera) or retracted. Door handles, the antenna, and roof rails can have a streamlined shape. The side mirror can only have a round fairing as a nose. Air flow through the wheel-bays is said to increase drag (German source) though race cars need it for brake cooling and a lot of cars emit the air from the radiator into the wheel bay.

Automotive aerodynamics differs from aircraft aerodynamics in several ways. First, the characteristic shape of a road vehicle is much less streamlined compared to an aircraft. Second, the vehicle operates very close to the ground, rather than in free air. Third, the operating speeds are lower (and aerodynamic drag varies as the square of speed). Fourth, a ground vehicle has fewer degrees of freedom than an aircraft, and its motion is less affected by aerodynamic forces. Fifth, passenger and commercial ground vehicles have very specific design constraints such as their intended purpose, high safety standards (requiring, for example, more 'dead' structural space to act as crumple zones), and certain regulations. Roads are also much worse (smoothness, debris) than the average airstrip. Lastly, car drivers are vastly under-trained compared to pilots, and usually will not drive to maximize efficiency.

Automotive aerodynamics is studied using both computer modelling and wind tunnel testing. For the most accurate results from a wind tunnel test, the tunnel is sometimes equipped with a rolling road. This is a movable floor for the working section, which moves at the same speed as the air flow. This prevents a boundary layer forming on the floor of the working section and affecting the results. An example of such a rolling road wind tunnel is Wind Shear's Full Scale, Rolling Road, Automotive Wind Tunnel built in 2008 in Concord, North Carolina.

Drag coefficient

Drag coefficient (C_d) is a commonly published rating of a car's aerodynamic smoothness, related to the shape of the car. Multiplying C_d by the car's frontal area gives an index of total drag. The result is called *drag area*, and is listed below for several cars. The width and height of curvy cars lead to gross overestimation of frontal area. These numbers use the manufacturer's frontal area specifications from the

Mayfield Company Homepage.

Some examples:

Drag area (C_d x Ft^2)	**Year Automobile**
3.95	1996 GM EV1
5.10	1999 Honda Insight

5.40	1989 Opel Calibra
5.54	1980 Ferrari 308 GTB
5.61	1993 Mazda RX-7
5.61	1993 McLaren F1
5.63	1991 Opel Calibra
5.64	1990 Bugatti EB110
5.71	1990 Honda CRX
5.74	2002 Acura NSX
5.76	1968 Toyota 2000GT
5.88	1990 Nissan 240SX
5.86	2001 Audi A2 1.2 TDI 3L
5.92	1994 Porsche 911 Speedster
5.95	1994 McLaren F1
6.00	1970 Lamborghini Miura S
6.00	1992 Subaru SVX
6.06	2003 Opel Astra Coupe Turbo
6.08	2008 Nissan GTR
6.13	1991 Acura NSX
6.15	1989 Suzuki Swift GT
6.17	1995 Lamborghini Diablo
6.24	2004 Toyota Prius
6.27	1986 Porsche 911 Carrera
6.27	1992 Chevrolet Corvette
6.35	1999 Lotus Elise
6.77	1995 BMW M3
6.79	1993 Corolla DX
6.81	1989 Subaru Legacy
6.96	1988 Porsche 944 S
7.02	1992 BMW 325I
7.10	Saab 900
7.13	2007 SSC Ultimate Aero
7.48	1993 Chevrolet Camaro Z28
7.57	1992 Toyota Camry
8.70	1990 Volvo 740 Turbo
8.71	1991 Buick LeSabre Limited
9.54	1992 Chevy Caprice Wagon
10.7	1992 Chevrolet S-10 Blazer
11.63	1991 Jeep Cherokee
13.10	1990 Range Rover Classic

13.76	1994 Toyota T100 SR5 4x4
14.52	1994 Toyota Land Cruiser
17.43	1992 Land Rover Discovery
18.03	1992 Land Rover Defender 90
18.06	1993 Hummer H1
20.24	1993 Land Rover Defender 110
26.32	2006 Hummer H2

Relationship to velocity

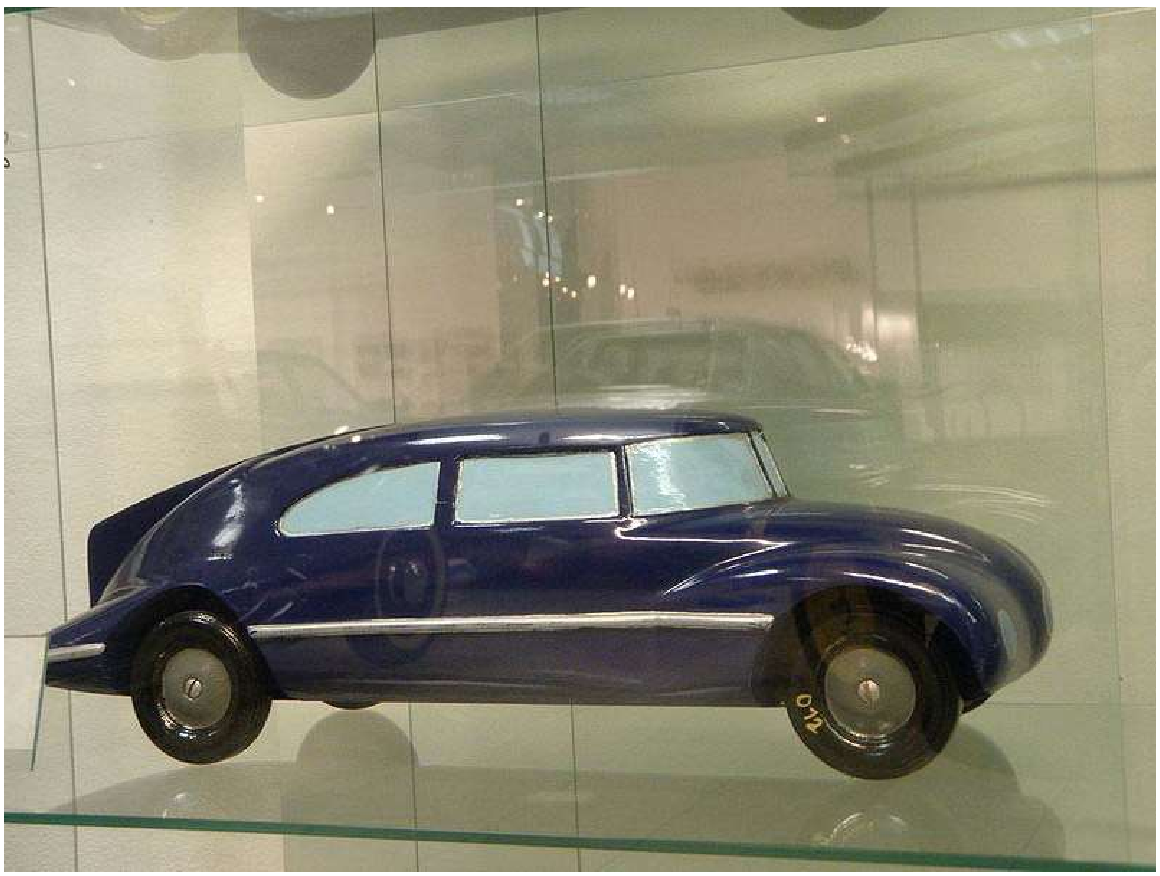
The frictional force of aerodynamic drag increases significantly with vehicle speed. As early as the 1920s engineers began to consider automobile shape in reducing aerodynamic drag at higher speeds. By the 1950s German and British automotive engineers were systematically analyzing the effects of automotive drag for the higher performance vehicles. By the late 1960s scientists also became aware of the significant increase in sound levels emitted by automobiles at high speed. These effects were understood to increase the intensity of sound levels for adjacent land uses at a non-linear rate. Soon highway engineers began to design roadways to consider the speed effects of aerodynamic drag produced sound levels, and automobile manufacturers considered the same factors in vehicle design.

Downforce

Downforce describes the downward pressure created by the aerodynamic characteristics of a car that allows it to travel faster through a corner by holding the car to the track or road surface. Some elements to increase vehicle downforce will also increase drag. It is very important to produce a good downward aerodynamic force because it affects the car’s speed and traction.

Chapter 6

Automobile Drag Coefficient



Tatra T77 maquette by Paul Jaray, 1933

The **drag coefficient** is a common metric in automotive design pertaining to aerodynamic effects. As aerodynamic drag increases as the square of speed, a low value is preferable to a high one. With about 60% of the power required to cruise at highway speeds being used to overcome aerodynamic effects minimizing drag translates directly into improved fuel efficiency.

For the same reason aerodynamics are of increasing concern to truck designers, where greater surface area presents substantial potential savings in fuel costs.

Reducing drag

Reducing drag is also a factor in sports car design, where fuel efficiency is less of a factor, but where low drag helps a car achieve a high top speed. However, there are other important aspects of aerodynamics that affect cars designed for high speed, including racing cars. Notably, it is important to minimize lift, hence increasing downforce, to avoid the car becoming airborne. Increasing the downforce pushes the car down onto the race track—allowing higher cornering speed. It is also important to maximize aerodynamic stability: some racing cars have tested well at particular "attack angles", yet performed catastrophically, i.e. flipping over, when hitting a bump or experiencing turbulence from other vehicles (most notably the Mercedes-Benz CLR). For best cornering and racing performance, as required in Formula One cars, downforce and stability are crucial and these cars must attempt to maximize downforce and maintain stability while attempting to minimize the overall C_d value.

Typical drag coefficients

The average modern automobile achieves a drag coefficient of between 0.30 and 0.35. SUVs, with their typically boxy shapes and larger frontal area, typically achieve a C_d of 0.35–0.45. A very gently inclined windshield gives a lower drag coefficient but has safety disadvantages, including reduced driver visibility. Certain cars can achieve figures of 0.25–0.30, although sometimes designers deliberately increase drag to reduce lift.

Some examples of $\mathbf{C_d}$ follow. Figures given are generally for the basic model. Some "high performance" models may actually have higher drag, due to wider tires and extra spoilers.

Production cars

C_d	Automobile	Year
0.7 to 1.1	typical values for a Formula One car (downforce settings change for each circuit)	
0.74	Legends car	
0.7	Caterham Seven	
0.6 +	a typical truck	
0.57	Hummer H2	2003
0.54	Mercedes Benz G-Class	
0.51	Citroën 2CV	1948
0.48	Volkswagen Beetle (original design)	1938
0.48	Rover Mini	1998
0.48	Volkswagen Cabriolet (Rabbit Convertible)	1979–1993
0.47	Lancia Aprilia	1937
0.46	Ford Mustang (coupe)	1979
0.45	Range Rover Classic	1990
0.45	Dodge Viper RT/10	1996
0.44	Ford Mustang (fastback)	1979
0.44	Peugeot 305	1978
0.44	Peugeot 504	1968
0.44	Toyota Truck	1990
0.43	TVR 3000S	1978-79
0.425	Duple 425 coach (named for its low C_d by coach standards)	1985
0.42	Lamborghini Countach	1974
0.42	Triumph Spitfire Mk IV	1971
0.42	Plymouth Duster	1994
0.41	Smart Roadster	2003
0.41	Volvo 740 (sedan)	1982
0.405	Subaru Forester	1997-2002
0.40	Ford Escape Hybrid	2005
0.40	Nissan Skyline GT-R R32	1989
0.40	Chevrolet Astro	1995-2005
0.39	Ford Aerostar	1995
0.39	Honda Odyssey	1994-98

Production cars (continued)

C_d	Automobile	Year
0.315	Saturn SL1	1996-1999
0.31	Audi A4 B5	1995
0.31	BMW 7-series	2009
0.31	Buick Park Avenue	1996
0.31	Cadillac CTS-V	2005
0.31	Cadillac CTS	2004
0.31	Citroën AX	1986
0.31	Citroën GS	1970
0.31	Eagle Vision	1995
0.31	FIAT Coupé	1995
0.31	Ford Falcon	1995
0.31	Ford Thunderbird	1989-1997
0.304	Ford Probe	1988-1992
0.31	Holden Commodore	1998
0.31	Honda Civic (Sedan)	2006
0.31	Honda Civic (Hatchback)	1992-1995
0.31	Infiniti G37 (Coupe)	2008-2011
0.31	Kia Rio (Sedan)	2001
0.310	Lamborghini Diablo	1990
0.31	Lexus LFA (wing retracted)	2010
0.31	Mazda RX-7 FC3S	1986
0.31	Mazda RX-7 FD R1(R2)	1993
0.31	Mazda RX-8	2004
0.31	Mazda MX-6	1992–1997
0.31	Nissan Tiida / Versa	2004
0.31	Peugeot 307	2001
0.31	Porsche 997 Turbo/GT3	2006
0.31	Renault 25	1984

0.39	Chevrolet Tahoe	2006
0.39	Dodge Durango	2004
0.39	Ford Escort 5 Door	1981-1984
0.39	Triumph Spitfire	1964
0.385	Nissan 280ZX	1978
0.38	Smart Roadster Coupé	2003
0.38	Smart ForTwo	1998
0.38	Lexus GX	2003
0.38	Mazda Miata	1989
0.38	Subaru Forester	2009
0.38	VW NewBeetle without wing or spoiler 0.39	2003
0.374	Ford Capri Mk III	1978
0.372	Ferrari F50	1996
0.37	BMW Z3 M coupe	1999
0.37	Jaguar XJ (X300/X308)	
0.37	Renault Twingo	
0.37	Volkswagen Tiguan	2008
0.36	Alfa Romeo 33	1983
0.36	Cadillac Escalade hybrid	2008
0.36	Cadillac Fleetwood	1996
0.36	Volkswagen Jetta	1985-1992
0.36	Citroën CX (named after the term for C_d)	1974
0.36	Citroën DS	1955
0.36	Chrysler Sebring	1996
0.36	Ferrari Testarossa	1986
0.36	Ford Escort	1997-2002
0.36	Ford Mustang	1999
0.36	Honda Civic	2001–2005
0.36	Opel GT	1969
0.36	Subaru Impreza WRX	2010
0.36	Saturn SW	1996-2001
0.36	Toyota Celica Convertible	1994-1999
0.355	NSU Ro 80	1967
0.31	Saab Sonett III	1970
0.31	Saturn SC2	2001
0.31	Scion xA	2004
0.31	Toyota Avalon	1995–2000
0.31	Toyota Corolla	1998-2002
0.32	Toyota Paseo	1995-1999
0.31	Toyota RAV4	2006
0.31	Toyota Supra (N/A; without factory wing)	1993
0.31	Volkswagen GTI Mk IV	1997
0.30	Audi 100	1983
0.30	Alfa Romeo 164 Sedan	1988
0.30	Ford Taurus	1996-1999
0.30	Honda Accord Sedan	2003, 2005–2007
0.30	Honda NSX	2002
0.30	Honda CRX DX/Si	1988
0.30	Honda Odyssey	2005
0.30	Hyundai Sonata	2006
0.30	Koenigsegg CCX	2006
0.30	Mitsubishi Eclipse	2000
0.30	Nissan 180SX	1989
0.30	Nissan 300ZX	1983
0.30	Nissan 350Z Coupe Base and Enthusiast models	2003–2008
0.30	Nissan 370Z Coupe (0.29 with sport package)	2009
0.30	Renault 19 16V	1991
0.30	Saab 92	1947
0.30	Toyota Sienna	2003–2009
0.30	Toyota Corolla	2003-2008
0.295	Ford Falcon	1998

0.35	Aston Martin Vanquish	2004
0.35	BMW Z4 M coupe	2006
0.35	BMW M3 Convertible	2005
0.35	Dodge Viper GTS	1996
0.35	Honda Del Sol	1992–1997
0.35	Jaguar XKR	2005
0.35	Lexus GX	2010
0.35	Lexus RX	2003–2009
0.35	MINI Cooper	2008
0.35	Nissan Cube	2009
0.35	Renault Clio (Mk 2)	2002
0.35	SSC Ultimate Aero	2007–present
0.35	Tesla Roadster	2008
0.35	Toyota MR-2	1998
0.35	Toyota Sequoia	2007
0.35	Toyota Previa	1991-1997
0.35	Volvo 940 (sedan)	1990
0.348	Toyota Celica Supra (Mk 2)	1982
0.342	Toyota Celica (Liftback Model)	1982
0.34	Subaru Impreza WRX (4 Door)	2009
0.34	Aston Martin DB9	2004
0.34	Chevrolet Caprice	1994
0.34	Chevrolet Tahoe hybrid	2008
0.34	Chevrolet C6 Corvette Z06	2005–present
0.34	Ferrari F40	1987
0.34	Ferrari 360 Modena	1999
0.34	Ferrari F430 F1	2004
0.34	Ford Sierra	1982
0.34	Ford Puma	1997
0.34	Geo Metro (Hatchback)	1995-1997
0.34	Honda Prelude	1988
0.34	Mercedes-Benz SL (Roof Down)	2001
0.34	Nissan Altima	1993-1997
0.34	Peugeot 106	1991

0.291	Toyota Avalon	2005
0.29	Alfa Romeo 155	1992
0.29	BMW 1-Series (116i Sportshatch)	2008
0.29	Pontiac Firebird Trans Am (with optional W62 Aero Package and N89 Turbo Cast rims)	1984
0.29	BMW 8-Series	1989
0.29	Chevrolet Corvette	2005
0.29	Chevrolet Corvette C5 Z06	2002
0.29	Daewoo Espero	1990
0.29	Dodge Charger Daytona	1969
0.29	Eagle Talon	1990s
0.29	Ford Escape	2010
0.29	Ford Focus C-Max	2003
0.29	Honda Accord Hybrid	2005, 2007
0.29	Honda Accord Coupe	2003, 2005–2007
0.29	Honda CRX HF	1988
0.29	Infiniti G35 Sedan	2008
0.29	Lancia Dedra	1990
0.29	Lexus LS 400	1990
0.29	Lotus Elite	1958
0.29	Lotus Europa	1966
0.29	Mazda Millenia	1995
0.29	Mazda RX-7 FC3S Aero Package	1986
0.29	Mazda 3	2010
0.29	Mazda RX-7 FD	1993
0.29	Mercedes-Benz SL (Roof Up)	2001
0.29	Mercedes-Benz	2001

0.34	Saturn SL2	1991-1995
0.34	Subaru Legacy Wagon	1993-1999
0.34	Toyota Supra (with factory 3 piece turbo wing)	1989–1990
0.34	Toyota Corolla (Wagon)	1993-1997
0.338	Chevrolet Camaro	1995
0.33	Audi A3	2006
0.33	Acura Integra	1993-2001
0.33	Citroën SM	1970
0.33	Honda Civic Hatchback	1988-1991
0.33	Dodge Charger	2006
0.33	Ford Crown Victoria	1992
0.33	Ford Fusion	2010
0.33	Ford Escort ZX2	1998-2003
0.33	Honda Accord Sedan	2002
0.33	Lamborghini Murcielago	2001
0.33	Lexus RX	2010
0.33	Mazda RX-7 FC3C	1987
0.33	Nissan 200SX Coupe	1995-1998
0.33	Peugeot 206	1998
0.33	Peugeot 309	1986
0.33	Renault Modus	2004
0.33	Subaru Impreza WRX STi	2004
0.33	Saturn SL2	1999
0.33	Toyota Corolla	1993-1997
0.33	Toyota Supra (without wing)	1989–1990
0.329	Chevrolet Corsica	1989-2006
0.324	Cobalt SS Supercharged	2005
0.321	Toyota Matrix	2003-2008
0.32	Volkswagen Golf MK3	1991
0.32	AMC Pacer	1975–
	W203 C-Class Coupe	
0.29	Nissan 350Z Coupe Track and Grand Touring	2007–2008
0.29	Nissan Versa	2007–2008
0.29	Peugeot 308	2007
0.29	Peugeot 407	2004
0.29	Peugeot 607	1999
0.29	Porsche Boxster	2005
0.29	Subaru XT	1985
0.29	Subaru SVX	1992
0.29	Toyota Echo	2000-2005
0.29	Toyota Yaris	2007
0.29	Toyota Camry]	1996–2001
0.29	Toyota Prius	2001
0.29	Volvo C70	2000
0.288	Chrysler Concorde	1998–2001
0.286	Chevrolet Corvette C6	2006
0.284	Volkswagen Passat CC	2008
0.28	Audi A2 1.4 TDI	2000
0.28	Citroën XM	1989
0.28	Citroën C4	2004
0.28	Lexus IS	2006–present
0.28	Lexus LS400	1998
0.28	Mitsubishi Diamante	1995
0.28	Porsche 997 Carrera (with optional automatic spoiler, PDK transmission 0.30)	2004
0.28	Renault 25 TS	1984
0.28	Honda Civic Hybrid	2003-2005
0.28	Rumpler-Tropfenwagen	1921
0.28	Saab 9-3	2003

		1980
0.32	Ferrari California	2008
0.32	Buick Riviera	1995
0.32	BMW M3 Coupe	2005
0.32	Dodge Avenger	1995
0.32	Ford Taurus	1992-1995
0.32	Geo Metro (Sedan)	1995-1997
0.32	Honda Accord (Coupe)	2002
0.32	Honda NSX	1990
0.32	Honda Civic (Coupe)	1992-1995
0.32	Honda Civic (Hatchback DX)	1996-2000
0.32	Honda Civic (Sedan EX)	1996-2000
0.32	Mazdaspeed3	2007
0.32	McLaren F1	1992
0.32	Mercedes-Benz 190E 2.5-16/2.3-16	
0.32	Nissan Altima	1998-2001
0.32	Nissan 240SX Coupe	1995-1998
0.32	Nissan 300ZX	1989
0.32	Nissan Maxima	1997
0.32	Porsche 997 GT2	2008–present
0.32	Peugeot 406	1995
0.32	Peugeot 806	1994
0.32	Scion xB	2008
0.32	Suzuki Swift	1991
0.32	Toyota Celica	1994
0.32	Toyota Celica	2000-2005
0.32	Toyota Supra (N/A with wing and turbo models)	1993
0.32	Toyota Supra (with factory turbo wing)	1987–1988
0.32	Toyota Tercel Sedan	1995-2000

0.28	Toyota Camry / Lexus ES	2001
0.28	Opel Astra Coupe Turbo	2003
0.28	Hyundai Elantra	2011
0.28	Opel Omega sedan	1986
0.27	Nissan GTR	2008
0.27	Mazda Mazda6	2009
0.27	Audi A2 1.6 FSI	2003
0.27	Honda Civic Hybrid	2006-
0.27	Hyundai Genesis	2009
0.27	Infiniti G35 Coupe (0.26 with "aero package")	2003–2007
0.27	Lexus GS	2005
0.27	Mazda6 (sedan and hatchback)	2008
0.27	Mercedes-Benz W203 C-Class Sedan	2001
0.27	Nissan GT-R	2007-2010
0.27	Toyota Camry Hybrid	2007
0.27	Tucker Torpedo	1948
0.27	Volkswagen Passat B5 (sedan)	1997
0.27	Mercedes-Benz S Class (0.268 with Sport Package)	2000–2005
0.27	Opel Insignia	2008–present
0.26	Opel Insignia - EcoFlex	2009–present
0.26	BMW E90 (0.26-0.30)	2009
0.26	Chevrolet Volt	2010
0.26	Hotchkiss Gregoire	1951
0.26	Lexus LS 430	2001–2006

0.32	Volkswagen GTI Mk V	2006
	(0.25 with air suspension)	
0.26	Lexus LS 460	2006
0.26	Mercedes-Benz W221 S-Class	2006
0.26	Mercedes-Benz W211 E-Class	2002-09
0.26	Nissan GT-R	2010-present
0.26	Opel Calibra (8 valve version)	1989
0.26	Toyota Prius	2004–2009
0.25	Audi A2 1.2 TDI	2001
0.25	Honda Insight	1999, 2003, 2005
0.25	Toyota Prius	2010
0.24	Mercedes E 220 CDI Blue Efficiency European version only, other E-Class Coupe 0.28 (0.25 sedan)(	2009
0.212	Tatra T77A	1935
0.195	General Motors EV1	1996

Concept/experimental cars

C_d	Automobile	Year
0.39	Porsche 918 Concept	2010
0.27	Avion	1986
0.26	Alfa Romeo Disco Volante	1952
0.25	Dymaxion Car	1933
0.25	SmILE (an experimental car)	1996
0.22	Citroën ECO 2000 Concept	1981
0.22	BMW Vision EfficientDynamics Concept	2009

0.20	Loremo Concept	2006 20XX (Planned production)
0.20	Opel Eco Speedster Concept	2003
0.19	Alfa Romeo B.A.T. 7 Concept	1954
0.19	Dodge Intrepid ESX Concept	1995
0.19	Mercedes-Benz Bionic Concept(based on the boxfish)	2005
0.186	Schlör's Göttinger Ei	1939
0.186	Volkswagen XL1	2011
0.168	Daihatsu UFE-III Concept	2005
0.16	General Motors Precept Concept (5 seats)	2000
0.16	Edison2 Very Light Car, Automotive X Prize winner	2010
0.159	Volkswagen 1-litre car Concept	2002 2013 (Planned production)
0.157	Li-ion Motors Wave II, Automotive X Prize winner	2010
0.15	Aptera 2 Series 2e	2011 (Planned production)
0.147	JCB Dieselmax land speed record holder	2006
0.146	Urbee Production vehicle	2010
0.14	Fiat Turbina Concept	1954
0.137	Ford Probe V Concept	1985
0.125	Sunraycer, solar race car	1987
0.12	Reflex 1000, solar cycle	1996
0.117	Summers Brothers Goldenrod Bonneville race car	1965
0.08	Fortis Saxonia (Shell Eco-marathon) Concept	2007
0.075	PAC-Car II (Shell Eco-marathon) Concept	2005
0.07	Nuna, World Solar Challenge winner	2001–2007

Drag area

While designers pay attention to the overall shape of the automobile, they also bear in mind that reducing the frontal area of the shape helps reduce the drag. The combination of drag coefficient and area - drag area - is represented as $\mathbf{C_dA}$ (or $\mathbf{C_xA}$), a multiplication of the C_d value by the area.

The term *drag area* derives from aerodynamics, where it is the product of some reference area (such as cross-sectional area, total surface area, or similar) and the drag coefficient. In 2003, *Car and Driver* magazine adopted this metric as a more intuitive way to compare the aerodynamic efficiency of various automobiles.

Average full-size passenger cars have a drag area of roughly 8.50 sq ft (0.790 m^2). Reported drag areas range from the 1999 Honda Insight at 5.10 sq ft (0.474 m^2) to the 2003 Hummer H2 at 26.3 sq ft (2.44 m^2). The drag area of a bicycle is also in the range of 6.5–7.5 sq ft (0.60–0.70 m^2).

Automobile examples of $\mathbf{C_dA}$

$\mathbf{C_dA}$	**Automobile model**
2.50 sq ft (0.232 m^2)	1986 Twike
2.69 sq ft (0.250 m^2)	2009 Loremo
3.00 sq ft (0.279 m^2)	2011 Volkswagen XL1
3.95 sq ft (0.367 m^2)	1996 GM EV1
5.10 sq ft (0.474 m^2)	1999 Honda Insight
5.40 sq ft (0.502 m^2)	1989 Opel Calibra
5.71 sq ft (0.530 m^2)	1990 Honda CR-X Si
5.74 sq ft (0.533 m^2)	2002 Acura NSX
5.76 sq ft (0.535 m^2)	1968 Toyota 2000GT
5.80 sq ft (0.539 m^2)	1986 Toyota MR2
5.81 sq ft (0.540 m^2)	1989 Mitsubishi Eclipse GSX
5.86 sq ft (0.544 m^2)	2001 Audi A2 1.2 TDI 3L
5.88 sq ft (0.546 m^2)	1990 Nissan 240SX hatchback / 200SX / 180SX
5.92 sq ft (0.550 m^2)	1994 Porsche 911 Speedster
5.95 sq ft (0.553 m^2)	1990 Mazda RX7
6.00 sq ft (0.557 m^2)	1992 Subaru SVX
6.00 sq ft (0.557 m^2)	1970 Lamborghini Miura
6.08 sq ft (0.565 m^2)	2008 Nissan GTR
6.13 sq ft (0.569 m^2)	1991 Acura NSX
6.17 sq ft (0.573 m^2)	1995 Lamborghini Diablo
6.24 sq ft (0.580 m^2)	2004 Toyota Prius
6.27 sq ft (0.583 m^2)	1986 Porsche 911 Carrera

6.27 sq ft (0.583 m^2) 1992 Chevrolet Corvette
6.35 sq ft (0.590 m^2) 1999 Lotus Elise
6.37 sq ft (0.592 m^2) 2000 Vauxhall VX220 N/A
6.40 sq ft (0.595 m^2) 1990 Lotus Esprit
6.41 sq ft (0.596 m^2) 2003 Smart Roadster Coupé
6.54 sq ft (0.608 m^2) 1991 Saturn Sports Coupe
6.57 sq ft (0.610 m^2) 1985 Chevrolet Corvette
6.63 sq ft (0.616 m^2) 2001 Audi A2
6.63 sq ft (0.616 m^2) 1989 Ford Thunderbird
6.66 sq ft (0.619 m^2) 1996 Citroën Saxo
6.77 sq ft (0.629 m^2) 1995 BMW M3
6.79 sq ft (0.631 m^2) 1993 Toyota Corolla DX
6.80 sq ft (0.632 m^2) 2007 BMW 335i Coupe
6.81 sq ft (0.633 m^2) 1991 Subaru Legacy
6.90 sq ft (0.641 m^2) 1993 Saturn Wagon
6.93 sq ft (0.644 m^2) 1982 Delorean DMC-12
6.94 sq ft (0.645 m^2) 2003 Smart Roadster
6.96 sq ft (0.647 m^2) 1988 Porsche 944 S
6.96 sq ft (0.647 m^2) 1995 Chevrolet Lumina LS
7.02 sq ft (0.652 m^2) 1992 BMW 325I
7.04 sq ft (0.654 m^2) 1991 Honda Civic EX
7.06 sq ft (0.656 m^2) 2004 Vauxhall VX220 Turbo
7.10 sq ft (0.660 m^2) 1995 Saab 900
7.14 sq ft (0.663 m^2) 1995 Subaru Legacy L
7.20 sq ft (0.669 m^2) 1995 Nissan Maxima GLE
7.34 sq ft (0.682 m^2) 2001 Honda Civic
7.39 sq ft (0.687 m^2) 1994 Honda Accord EX
7.48 sq ft (0.695 m^2) 1993 Chevrolet Camaro Z28
7.57 sq ft (0.703 m^2) 1992 Toyota Camry
7.69 sq ft (0.714 m^2) 1994 Chrysler LHS
7.72 sq ft (0.717 m^2) 1993 Subaru Impreza
8.02 sq ft (0.745 m^2) 2005 Bugatti Veyron
8.70 sq ft (0.808 m^2) 1990 Volvo 740 Turbo
8.70 sq ft (0.808 m^2) 1992 Ford Crown Victoria
8.71 sq ft (0.809 m^2) 1991 Buick LeSabre Limited
9.54 sq ft (0.886 m^2) 1992 Chevrolet Caprice Wagon
10.7 sq ft (0.99 m^2) 1992 Chevrolet Blazer
11.6 sq ft (1.08 m^2) 2005 Ford Escape Hybrid

11.7 sq ft (1.09 m^2)	1993 Jeep Grand Cherokee
16.8 sq ft (1.56 m^2)	2006 Hummer H3
17.4 sq ft (1.62 m^2)	1995 Land Rover Discovery
26.5 sq ft (2.46 m^2)	2003 Hummer H2

Selected photographs

0.57 - 2003 Hummer H2


Total Travel
Total Travel
LLZ 4067


TRANS AM

Chapter 7

Car Audio

Car audio/video (car AV), mobile audio, 12-volt and other terms are used to describe the sound or video system fitted in an automobile. While 12-volt audio and video systems are also used, marketed, or manufactured for marine, aviation, and buses, here we focuses on cars as the most common application. From the earliest days of radio, enthusiasts had adapted domestic equipment to use in their cars. In the 1960s, tape players using reel to reel equipment, Compact Cassettes, and then 8-track cartridges were introduced for in-car use.

A stock car audio system refers to the OEM application that the vehicle's manufacturer specified to be installed when the car was built. A large after market industry exists where the consumer can at their desire replace many or all components of the stock system. In modern cars, the primary control device for an audio system is commonly referred to as a head unit, and is installed in the center of the dash panel between the driver and the passenger. In older vehicles that had audio components as an option, such devices were mounted externally to the top of or underneath the dash. Car speakers often use space-saving designs such as mounting a tweeter directly over a woofer or using non-circular cone shapes. Subwoofers are a specific type of loudspeaker for low frequency reproduction. Extremely loud sound systems in automobiles, which have been nicknamed "boom cars", may violate the noise ordinance of some municipalities.

Motorcycles have been utilized with similar equipment since they also have the so-called "car audio" experience. Even pedal bicycles, as well as homemade boomboxes have utilized sealed lead-acid batteries (or 12V power supplies) for applications outside of motor vehicle use, likewise the store displays which mount in demo models prior to aftermarket purchases for installation.

History

1930s

Early 1970s tractor with a radio/8-track system

From the earliest days of radio, enthusiasts had adapted domestic equipment to use in their cars. The commercial introduction of the fitted car radio came in the 1930s from the Galvin Manufacturing Corporation. Galvin Manufacturing was owned and operated by Paul V. Galvin and his brother Joseph E. Galvin. The Galvin brothers purchased a battery eliminator business in 1928 and the corporation's first product was a battery eliminator that allowed vacuum tube battery-powered radios to run on standard household electric current. In 1930, the Galvin Corporation introduced one of the first commercial car radios, the Motorola model 5T71, which sold for between $110 and $130 (*2009: $1,700*) and could be installed in most popular automobiles. Founders Paul Galvin and Joe Galvin came up with the name 'Motorola' when his company started manufacturing car radios. A number of early companies making phonographs, radios, and other audio equipment in the early 20th century used the suffix "-ola," the most famous being Victrola; RCA made a "radiola"; there was also a company that made jukeboxes called Rock-Ola, and a film-editing device called a Moviola. The Motorola prefix "motor-" was chosen because the company's initial focus was in automotive electronics.

In Germany Blaupunkt fitted their first radio to a Studebaker in 1932 and in the United Kingdom Crossley offered a factory fitted wireless in their 10 hp models from 1933. The early car radio receivers used the battery voltage (6.3 volts at the time) to run the vacuum tube filaments, and generated the required high voltage for the plate supply using a vibrator to drive a step-up transformer. The receivers required more stages than the typical home receiver in order to ensure that enough gain was available to allow the AGC to mask signal fading as the car was driven. When cars switched to 12-volt batteries, the same arrangement was used, with tubes with 12-volt heaters. In 1952 Blaupunkt became the first maker to offer FM receivers.

1950s

A common feature of modern car radios is the "seek" function which allows tuning from one station to the next at the push of a button. This was a popular option on some Ford products in the 1950s. It was known as the "Town & Country" radio since it used a pair of switches marked "Town" and "Country." Pressing the Town button actuated a motor to rotate the tuning mechanism while the receiver sensitivity was reduced so that only local (stronger) signals would be received. When a station was tuned, the motor stopped. Pressing the Country button had the same effect except that full sensitivity was enabled so that the very next available station would be selected. In addition, for repeated seeking operations, pressing a foot switch on the driver's floor up to the left where the "dead pedal" is located on modern cars would reactivate the Seek at whatever sensitivity was last selected.

1960s-1970s

The introduction of semiconductors (transistors) allowed the output stage to change to a transistor, which soon lead to the elimination of the vibrator, and the use of "space charge" tubes that only required 12 volts on their plates without a high voltage plate power supply (typical example was the 6GM8/ECC86). Advances in electronics allowed additions to the basic radio and Motorola offered 16 2/3 rpm disc players fitted to some Chryslers known as "Hiway HI FI" from as early as 1956 and ran through 1958. Records were produced under license by Comumbia "Special Products division and sold exclusively through Chrysler dealers. The 45 rpm record player was introduced in 1959 and ran through the early 60"s under the RCA and ARC brand. Earl "Mad Man Muntz" introduced the "4 track" tape player in the early 60's using a contiuous loop cartidge and was the first commercially available "car stereo. Tape players using reel to reel equipment followed, but their bulk ensured limited popularity. This changed in 1964 when Philips launched the Compact Cassette. During the '60s Lear invented and introduced the 8track cartridge in competition with the cassette system. Other early manufacturers and enthusiasts began building extra audio amplifiers to run on 12 volts (the standard voltage in automotive electrical systems). Jim Fosgate, later to become the founder of Rockford Fosgate, was one such pioneer. The company *a/d/s* also brought an amplifier to market in 1978.

1980s-1990s

In 1983, Zed Audio became the first company to build a 200 watt per channel car amplifier, which was invented by company founder Steven Mantz. At first, speakers from the home audio and professional markets were simply installed into vehicles. However, they were not well suited to the extremes of temperature and vibration which are a normal part of the environment of an automobile. Different manufacturing techniques, and different component materials were used in construction to adapt to these conditions.

Car audio competitions started in the early 1980s. The first known occurred in 1981 in Bakersfield, CA and evolved into an annual event, The Summertime Sound Off, which at its height drew upwards of 300 contestants and continued into the 1990s. Like the Summertime Sound Off, some competitions during the 1980s were judged based on sound and installation quality, particularly those hosted in California. But most were simply held to find the loudest and/or most outrageous installations. Perhaps the most well known vehicle of this time was the Wayne Harris modified 1960 Cadillac Hearse; featuring three 24-inch subwoofers as well as eight 12-inch subwoofers. During the late '80s, several interests in the car stereo industry promoted the formation of sanctioning organizations to provide common rules and to move the focus to sound quality.

The most important of these were CAN (formed by Alpine) and NACA (supported by shop owners and amp manufacturers). Both organizations sanctioned countrywide regional events and hosted National Championship events in the late 1980s. They merged to form IASCA in 1990. Despite the move to "quality" based judging, volume was still a significant portion of most early 1990s competitions. Since then, the two styles—SPL vs. sound quality—have become almost mutually exclusive. The loudness competitions have become known as dB drag racing. Currently, MEASQ conducts Sound Quality Competitions nationally in Australia. This back to basics competition format was developed by Marc Rushton, the founder of one of the largest enthusiast organizations known as Mobile Electronics Australia.

Common components and terms

Stock unit

A *stock* car audio system refers to the OEM application that the vehicle's manufacturer specified to be installed when the car was built and nowadays at least includes a CD-radio, with MP3 player and an aux-in. A large after market industry exists where the consumer can at their desire replace or complement many or all components of the stock system (i.e. kits to include a USB port and bluetooth to the stock radio-CD).

Head unit

A Panasonic single DIN head unit, combining radio, CD and MP3

In modern cars, the primary control device for an audio system is commonly referred to as a head unit, and is installed in the center of the dash panel between the driver and the passenger. In older vehicles that had audio components as an option, such devices were mounted externally to the top of or underneath the dash.

The headunit itself is usually a multi-purpose device that houses multiple types of components in its housing. The most common components are a radio receiver/tuner usually with AM and FM bands, and a small amplifier for driving an audio signal to speakers. Other possible components include various media devices, such as (in older vehicles) a tape player (either 8-track or cassette), CD player, DVD player, Minidisc, USB flash memory, and even a hard disk drive typically used in notebook computing. Many head units also feature a DSP component, and equalization component (such as bass and treble controls), or a control interface for another feature on the car (such as a back-up/parking camera, navigation system, trip odometer, etc).

Due to auto manufacturing differences over the years, aftermarket headunit products are manufactured in multiple form factors. The primarily used size is mostly referred to by its legacy name of DIN, which refers to ISO 7736. DIN headunits come as single DIN or double DIN. A third less common standard is used mostly by Chrysler group and for a time Mitsubishi in their OEM devices.

Speakers

A set of speaker drivers removed from a passenger vehicle.

Car **speakers** are largely functionally identical to any other loudspeaker design with key components specialized for use in mobile environments, and generally serve an identical purpose. One major key design difference is mult-axial mounting of different types of loudspeakers in the same footprint, such as a tweeter directly mounted over a woofer. Another key difference is non-circular cone shapes, such as square, oval, or even triangular. Both of these features reflect a significant reduction in space and size that a speaker may occupy in a vehicle cabin.

Material construction may also include more exotic and hearty components more suitable to mobile use. Marine speakers may have plating for corrosion resistance. Cones may be coated with a substance to resist expansion and contraction under high vehicle cabin temperatures, known to reach 140 °F (60 °C) in the sun. Subwoofers may also be found in mobile audio applications where a cabin speaker may lack the desired low frequency response on its own.

Before stereo radio was introduced, the most common speaker location was in the middle of the dashboard pointing through perforations towards the front windshield. In most modern applications, speakers are mounted certain common locations including the front deck (or dash), the rear deck (or parcel shelf), the kick panel (located in the footwell below the A-pillar,) or the doors. In the case of subwoofers, mountings are usually under the seat or in the trunk. Each position has certain strengths and limitations from both a quality of sound, and a vehicle manufacturing perspective.

5.1 and even 7.1 channel surround sound systems, as well as THX II Certified, are now being integrated into some cars by both aftermarket enthusiasts and car manufacturers themselves. These systems include the full complement of front left, right and center speakers along with rear right and left surround speakers.

Amplifiers

A car audio amplifier.

Blaupunkt Class T amplifier

Basically a mobile audio amplifier, a car 'amp' is a term used to refer to a dedicated electronic amplifier separated from the other components of the system. Though most head units have an amplifier, some do not, or lack the desired power or additional features (e.g., equalization controls or crossover systems). External amplification is available and most often used when existing amplification is insufficient. External amplifiers can be mounted in a different part of the car than the "head unit"; in many cases, an additional amp is mounted in the trunk. This is usually the case when powering a subwoofer, where desired wattage may be several multiples more compared to other cabin speakers.

Though less common, OEM external amplification can be found in 'premium' audio packages, or in luxury cars. More common is aftermarket amplification installed later to satisfy the expansion of an existing system in some way. During operation, it is common for a vehicle's charging system to fluctuate, so a regulated amplifier will maintain its power output regardless of voltage fluctuation. Amplifiers rated at 100 watts at 14.4 volts can not be regarded equal as to an amplifier that can maintain 100 watts at 12 volts. Outside of certain standards, it is not uncommon for manufacturers to list a 14.4 rating and not post a 12 volt value.

Subwoofers

Subwoofers are a specific type of loudspeaker for low frequency reproduction. Mobile 'subs' are not very different from any other application of sub in terms of construction. However it is more common in aftermarket that visual aesthetics take on a more significant role in design than other types of sub drivers, including high contrast paint schemes, grill covers, translucent or refractive materials. Typical subwoofer drivers range in size from an 8" diameter to 10", 12" or 15"; more rarely, some car systems may have 18", 21", 22", 24" or even 32" subwoofers.

A subwoofer is used when existing low frequency production is unsatisfactory, either in frequency range or in volume. Design goals have led to subwoofer, both driver's alone and whole packages, with some extreme difference from one another. Space conscious design has reduced some driver depth to 2" or less, or enclosure depth to 3". Pure loudness through increasing sound pressure has led to some drivers with excursions as great as 4" and vented components to cool the "motor" of the speaker. Quality and clarity has led to driver enclosures being tuned by construction to resonate or neutralize certain frequencies.

Capacitors

Capacitors are used to store energy for the amplifier to draw on demand. They come in many different sizes ranging from 0.5 farad to well over 100 farads and their intended function is to temporarily cover the short-burst electrical demands of a car audio system that have exceeded the general electrical capabilities of the vehicle. There is little evidence to suggest they impart any benefit to the system, however, due to their low energy storage (compared with the battery) and exponential nature of capacitor voltage decay.


A powerful after-market audio system installation in a Toyota

Damping

Sound deadening material is often used in the door cavities and boot/trunk area to damp excess vibration of the panels in the car in response to loud subwoofer bass tones, especially the boot/trunk. The most common type of deadening is either butyl or rubberized asphalt, a product which has an adhesive quality and can be applied by simply pressing it into place with a roller and using a heat gun (or hair dryer). Other types of deadening can be sprayed on, but they are less common because of the additional installation difficulties.

Uniden BCT-15 radio scanner installed with aftermarket head unit

Other components

Other components that make up high-end car audio installations may include:

- Multiple-CD Changer
- amplifiers
- audio processors
- cables
- crossovers
- equalizers
- mobile video (VCRs, television, DVD and navigation)

- Controls, including on steering wheel interface, as well as remote controls
- Car computer, fully functional computer (i.e. Internet, Music, games) that is operable from the interface.
- Gaming consoles – passenger entertainment

Legal problems

Extremely loud sound systems in automobiles may violate the noise ordinance of some municipalities. Some cities have even outlawed so called "boom cars", vehicles containing loud stereo systems that emit low frequency sound, usually with an intense amount of bass. A number of organizations and websites are dedicated to lobbying for tougher restrictions on boom cars, citing that they disturb the peace and cause documented health problems. Noise Free America, a 501(c)(3) non-profit group, cites boom cars as one of the most problematic sources of noise pollution. In 2007, the U.S. Department of Justice issued a guide to police officers on how to deal with problems associated with boom cars.

Chapter 8

Automotive Navigation System

A taxi equipped with GPS navigation device

An **automotive navigation system** is a satellite navigation system designed for use in automobiles. It typically uses a GPS navigation device to acquire position data to locate the user on a road in the unit's map database. Using the road database, the unit can give directions to other locations along roads also in its database. Dead reckoning using distance data from sensors attached to the drivetrain, a gyroscope and an accelerometer can be used for greater reliability, as GPS signal loss and/or multipath can occur due to urban canyons or tunnels.

Some sorts can be taken out of the car and used hand-held while walking.

History

Automotive navigation systems were the subject of extensive experimentation, including some efforts to reach mass markets, prior to the availability of commercial GPS.

Most major technologies required for modern automobile navigation were already established when the microprocessor emerged in the 1970s to support their integration and enhancement by computer software. These technologies subsequently underwent extensive refinement, and a variety of system architectures had been explored by the time practical systems reached the market in the late 1980s. Among the other enhancements of the 1980s was the development of color displays for digital maps and of CD-ROMs for digital map storage.

However, there is some question about who made the first *commercially available* automotive navigation system. There seems to be little room for doubt that Etak was first to make available a digital system that used map-matching to improve on dead reckoning instrumentation. Etak's systems, which accessed digital map information stored on standard cassette tapes, arguably made car navigation systems practical for the first time. However, Japanese efforts on both digital and analog systems predate Etak's founding.

Steven Lobbezoo developed the first commercially available satellite navigation system for cars. It was produced in Berlin from start 1984 to January 1986. Publicly presented first at the Hannover fair in 1985 in Germany, the system was shown in operation on the evening news (item in the Hannover fair) from the first German television channel in that year. It used a modified IBM PC, a large disc for map data and a flat screen, built into the glove compartment. It was called Homer (after the device from a James Bond movie).

Alpine claims to have created the first automotive navigation system in 1981. However, according to the company's own historical timeline, the company claims to have *co*-developed an analog automotive navigation product called the Electro Gyrocator, working with Honda. This engineering effort was abandoned in 1985. Although there are reports of the Electro Gyrocator being offered as a dealer option on the Honda Accord in 1981, it's not clear whether an actual product was released, whether any customers took delivery of an Electro Gyrocator-equipped Accord, or even whether the unit appeared in any dealer showrooms; Honda's own official history appears to pronounce the Electro Gyrocator as not practical.

Honda claims to have created the first navigation system starting in 1983, and culminating with general availability in the 1990 Acura Legend. The original analog Electro Gyrocator system used an accelerometer to navigate using inertial navigation, as the GPS system was not yet generally available. However, it appears from Honda's concessions in their own account of the Electro Gyrocator project that Etak actually trumped Honda's analog effort with a truly practical digital system, albeit one whose effective range of operation was limited by the availability of appropriately digitized street map data.

[...] progress in digital technology would not stop simply because Honda had turned its attention to analog. In 1985, for example, the U.S. company ETAK introduced its own digital map navigation system. Although the system's effective range-the area of geographical coverage-was limited, the announcement was a dour one for Nakamura and his staff. Therefore, ultimately the development of a practical analog system was shelved. The staff experienced indescribable feelings of disappointment. The development of [Honda's] digital map navigation system resumed in 1987, following a three-year hiatus.

Both Mitsubishi Electric and Pioneer claim to be the first with a GPS-based auto navigation system, in 1990. Also in 1990, a draft patent application was filed within Digital Equipment Co. Ltd. for a multi-function device called PageLink that had real-time maps for use in a car listed as one of its functions.

Magellan, a GPS navigation system manufacturer, claims to have created the first GPS-based vehicle navigation system in the U.S. in 1995.

In 1995, Oldsmobile introduced the first GPS navigation system available in a production car, called GuideStar. There also was an Oldsmobile navigation system available as an option as early as 1994 called the Oldsmobile Navigation/Information System. It was an option on the Oldsmobile Eighty Eight.

However it was not until 2000 that the United States made a more accurate GPS signal available for civilian use.

Technology

Visualization

Navigation systems may (or may not) use a combination of any of the following:

- top view for the map
- top view for the map with the map rotating with the automobile (so that "up" on the map always corresponds to "forward" in the vehicle)
- bird's-eye view for the map or the next curve
- linear gauge for distance, which is redundant if a rotating map is used
- numbers for distance
- schematic pictograms
- voice prompts

Road database

Contents

The road database is a vector map of some area of interest. Street names or numbers and house numbers are encoded as geographic coordinates so that the user can find some desired destination by street address.

Points of interest (waypoints) will also be stored with their geographic coordinates. Point of interest specialties include speed cameras, fuel stations, public parking, and "parked here" (or "you parked here").

Contents can be produced by the user base as their cars drive along existing streets (Wi-Fi) and communicating via the internet, yielding a free and up-to-date map.

Map formats

Formats are almost uniformly proprietary; there is no industry standard for satellite navigation maps, although NAVTEQ are currently trying to address this with S-Dal (see below).

The map data vendors such as Tele Atlas and NAVTEQ create the base map in a standard format GDF, but each electronics manufacturer compiles it in an optimized, usually proprietary format. GDF is not a CD standard for car navigation systems. GDF is used and converted onto the CD-ROM in the internal format of the navigation system.

CARiN

CARiN Database Format (CDF) is a proprietary navigation map format created by Philips Car Systems (this branch was sold to Mannesman VDO, VDO/Dayton in 1998, to Siemens VDO in 2002, and Continental in 2007.) and is used in a number of navigation-equipped vehicles. The 'CARiN' portmanteau is derived from **Car** **I**nformation and **N**avigation.

S-Dal

This is a proprietary map format published by NAVTEQ, who released it royalty free in the hope that it would become an industry standard for digital navigation maps. Vendors currently using this format include:

- Microsoft
- Magellan
- Pioneer
- Panasonic
- Clarion

- InfoGation

The format has not been very widely adopted by the industry.

Physical Storage Format

The Physical Storage Format (PSF) initiative is an industry grouping of car manufacturers, navigation system suppliers and map data suppliers whose objective is the standardization of the data format used in car navigation systems, as well as allow a map update capability. Standardization would improve interoperability, specifically by allowing the same navigation maps to be used in navigation systems from 19 manufacturers. Companies involved include BMW, Volkswagen, Daimler, Renault, ADIT, Aisin AW, Alpine Electronics, Navigon, Bosch, DENSO, Mitsubishi, Harman Becker, Panasonic, PTV, Continental AG, Clarion, NAVTEQ, Tele Atlas and Zenrin.

Media

The road database may be stored in solid state read-only memory (ROM), optical media (CD or DVD), solid state flash memory, magnetic media (hard disk), or a combination. A common scheme is to have a base map permanently stored in ROM that can be augmented with detailed information for a region the user is interested in. A ROM is always programmed at the factory; the other media may be preprogrammed, downloaded from a CD or DVD via a computer or wireless connection (bluetooth, Wi-Fi), or directly used utilizing a card reader.

Some navigation device makers provide free map updates for their customers. These updates are often obtained from the vendor's website, which is accessed by connecting the navigation device to a PC.

Real-time data

Some newer systems can not only give precise driving directions, they can also receive and display information on traffic congestion and suggest alternate routes. These may use either TMC, which delivers coded traffic information using radio RDS, or by GPRS/3G data transmission via mobile phones.

One key type of real-time data is traffic information, which includes:

- Real-time data about free/full parkings;
- Nearest public transport lines and prices, to go to a destination, when there is a jam.

Other real-time data includes weather broadcasting, etc.

Integration and other functions

- The color LCD screens on some automotive navigation systems can also be used to display television broadcasts or DVD movies.
- A few systems integrate (or communicate) with mobile phones for hands-free talking and SMS messaging (i.e., using Bluetooth or Wi-Fi).
- Automotive navigation systems can include personal information management for meetings, which can be combined with a traffic and public transport information system.

Controversy

Safety features

Vehicles produced by Subaru and Lexus, as well as Lexus' parent company, Toyota, lock out many of the features when the vehicle is in motion. The manufacturers claim this is a safety feature to avoid the driver being distracted. Many users have complained that passengers are not able to enter destinations while in motion, even though it is safe to do so. Additionally, drivers have complained that it is often more dangerous to pull off a highway and stop than it would be to enter a destination into the system.

Misdirection

A number of road accidents in the UK have been attributed to misdirection by satellite navigation systems. On May 11, 2007, a driver followed satellite navigation instructions in the dark and her car was hit by a train on a rail crossing that was not shown on the system. In Exton, Hampshire, the County Council erected a sign warning drivers to ignore their "sat nav" system and to take another route, because the street was too narrow for vehicular traffic and property damage resulted from vehicles getting stuck.

On March 25, 2009, a man drove down a steep mountain path and almost off of a cliff after he was allegedly directed by his portable GPS system. He was finally stopped by a wire fence.

Misdirection can also occur when a road is altered either permanently or temporarily, such as during road re-construction.

GPS vs speed camera accuracy

In July 2007, an Australian man successfully overturned a speeding conviction after evidence from a GPS navigational track proved that he did not exceed the speed limit.

Other functions

- Golf Carts may have integrated GPS rangefinders tailored to specific golf courses, providing interactive course maps and live readings of distance measurements to the green.
- Many systems can give information on nearby points of interest (POIs), such as restaurants, cash machines and gas stations. Some navigation devices use this feature to store the location of known speed traps or speed cameras, and can alert the driver in much the same way as a radar detector. GPS may also be integrated into actual radar detection devices to enhance accuracy, and in some cases, implement a logic system where the system only alerts if the driver is traveling above the speed limit or in the direction to be 'caught.' Unlike radar detectors, GPS-based speed trap warnings are currently legal in many countries.
- Some systems feature internet connectivity, either via Bluetooth to a mobile phone (in which case the device can typically also be used for hands-free calling), or with a built in GSM SIM card. This connectivity can be used for up-to-date traffic information, to find fuel prices, as well as to search for local distances. Such devices include the TomTom LIVE series, and the Garmin nüvi 1690.
- The radio dispatching of taxicabs have been phased out in several countries in favor of GPS technology plus some form of mobile networking with on board computers. The central dispatch computer keeps track of all vehicles in its fleet, and automatically selects the nearest cab to respond to a passenger request.
- Advanced car security vehicle tracking systems can relay the vehicle's location via cellular phone services in case of loss or theft. The technology can also be used to manage fleet vehicles, in which case it's known as automatic vehicle location.
- A very basic form of GPS navigation is used on public buses in Taipei, where the location and sequence of bus stops for a particular route are programmed. The computer announces the approaching and upcoming bus stops and repeats the information on a dot-matrix display, all without intervention from the driver. This service was once provided based on tire revolutions and odometer mileage, which is not nearly as reliable as a GPS enabled system.

Retrofitting of GPS

A vehicle can be retrofitted with a GPS navigation device unit if it did not originally have one. There are three approaches that can be taken here:

Portable GPS

This type of GPS navigation device is not permanently integrated into the vehicle, having only a simple bracket to mount the device on the surface of the dashboard and powered via the car cigarette lighter. This class of GPS unit does not require professional installation and can typically be used as handheld device, too.

Benefits of this type of GPS unit include low cost as well as the ability to move them easily to other vehicles. Their portability means they are easily stolen if left inside the vehicle. Furthermore, not having a compass, accelerometer or inputs from the vehicle's speed sensors, means that they cannot navigate as accurately by dead reckoning as some built-in devices when there's no GPS signal. More modern portable devices such as the TomTom 920, have an inbuilt accelerometer to try to address this.

A portable automotive navigation system kit generally includes:

- Mini-USB sync cable
- AC adaptor
- Car charger
- Car mount kit
- Pouch
- Wrist band
- External antenna (optional by model)
- Stylus
- Battery pack
- Document kit
- SD card with preload map (sometimes capable of shuffling MP3 playlists)
- Companion CD-ROM
- Navigation software CD-ROM

Early Factory Navigation System (as fitted to 1997 UK Specification Ford Mondeo)

Original factory equipment

Many vehicle manufacturers offer a GPS navigation device as an option in their vehicles. Customers whose vehicles did not ship with GPS can therefore purchase and retrofit the original factory-supplied GPS unit. In some cases this can be a straightforward "plug-and-play" installation if the required wiring harness is already present in the vehicle. However, with some manufacturers, new wiring is required, making the installation more complex.

Modern Factory Navigation System (as fitted to a 2009 U.S. Honda Accord)

The primary benefit of this approach an integrated and factory-standard installation. Many original systems also contain a gyrocompass or accelerometer and may accept input from the vehicle's speed sensors, thereby allowing them to navigate via dead reckoning when a GPS signal is temporarily unavailable. However, the costs can be considerably higher than other options. In some cases, it may even be more economical to buy a similar vehicle that already has a factory-fitted GPS.

Aftermarket

A number of manufacturers supply aftermarket GPS navigation devices that can be integrated permanently into the vehicle. A typical location for such an installation is the DIN slot for the radio/tape/CD. However, in extreme cases, the dashboard may also be remodeled to accommodate the unit.

This approach can be considered a tradeoff between the previous two options. Benefits include a more secure and better cosmetic finish than a portable device, and lower cost compared to the installation of an original factory-supplied GPS.

Alternatives

Smartphones with GPS, and other navigation devices, may also be used without installing in a car.

SMS

Establishing points of interest in real-time and transmitting them via GSM cellular telephone networks using the Short Message Service (SMS) is referred to as Gps2sms. Some vehicles and vessels are equipped with hardware that is able to automatically send an SMS text message when a particular event happens, such as theft, anchor drift or breakdown. The receiving party (e.g., a tow truck) can store the waypoint in a computer system, draw a map indicating the location, or see it in an automotive navigation system.

Example systems

Navigon

- Acer e300 series
- Clarion

- EB street director
- Garmin
- Gizmondo
- Hertz Neverlost
- iGo (software)
- MapmyIndia
- Kenwood DNX-5120
- Magellan Navigation
- Master Navigator Software (Sapper Oy)
- Mio Technology
- Navigon
- Navmii
- NDrive
- Navman iCN series
- Ovi Maps
- Pioneer
- TomTom
- VDO Dayton
- Wayfinder Navigator
- Sygic Mobile Maps/Tele Atlas
- Mireo
- Teletype Software
- VIETMAP

Chapter 9

I-Drive

iDrive is a computer system which is used to control most secondary vehicle systems in many current BMW cars. iDrive's user interface consists of a LCD panel mounted in the dashboard and a controller knob mounted on the center console.

iDrive allows the driver and front-seat passenger (in recent cars it is available to back-seat passengers as well) to control such amenities as the climate (air conditioner and heater), the audio system (radio and CD player), the navigation system and communication system.

iDrive Generations

iDrive (1st Gen)

Debuted in September 2001 with the 7-Series and was based on Microsoft Windows CE for Automotive.
This can easily be seen when the system reboots or restarts after a software crash displaying a "Windows CE" logo.

iDrive Business (M-ASK)

M-ASK stands for MMI Audio System controller and is manufactured by Becker. This is a limited version of the iDrive computer with a small 6.6" display and is only found on 5th, 6th and 7th-series, and the X5 or X6, without the navigation option.

In addition it can optionally be ordered in Europe on the 1-series and 3-series as "Business navigation", which has basic navigation abilities. Early versions of the Business navigation could only display directional arrows, but the latest version can also display 2D maps. iDrive Business Navigation uses a different map DVD then iDrive Professional Navigation. In addition because only one optical drive is available you cannot use both navigation and listen to a CD simultaneously.

When iDrive Professional is ordered the M-ASK system is replaced by either the CCC or CIC in addition to a larger display.

iDrive Business is available on the following cars;

- iDrive Business Navigation (optional)
  - 1-Series E81/E82/E87/E88
  - 3-Series E90/E91/E92/E93
- iDrive Business (default when navigation is not ordered)
  - 5-Series E60/E61
  - 6-Series E63/E64
  - 7-Series E65/E66/E67/E68
  - 7-Series F01/F02
  - X5 E70
  - X6 E71

Note that the above list can vary depending on the region. For instance North American 7-series come by default with CCC or CIC.

iDrive Professional Navigation (CCC)

iDrive Controller on BMW X5

iDrive controller on BMW 530d

Debuted in 2003 with the E60/E61 5-Series and is based on Wind River VxWorks, a real-time operating system. CCC stands for Car Communication Computer and uses a larger 8.8" wide-screen display. It was available on the following cars as an option;

- 1-Series E81/E82/E87/E88 manufactured until March 2007
- 3-Series E90/E91/E92/E93 manufactured until March 2007
- 5-Series E60/E61 manufactured until March 2007
- 6-Series E63/E64 manufactured until March 2007
- 7-Series E65/E66/E67/E68 from September 2004

CCC based systems use a map DVD from Navteq in a dedicated DVD drive.

CCC - update 1

This is a minor update to iDrive Professional debuted in March 2007. It adds additional programmable buttons in the dashboard to directly access frequent functions and it removes the haptic feedback from the iDrive controller. It is available on the following cars as an option;

- 1-Series E81/E82/E87/E88 manufactured between March 2007 and September 2008
- 3-Series E90/E91/E92/E93 manufactured between March 2007 and September 2008
- 5-Series E60/E61 manufactured between March 2007 and March 2010
- 6-Series E63/E64 manufactured between March 2007 and September 2009
- X5 E70
- X6 E71

CCC - update 2

This is a minor update debuted in September 2008 to iDrive Professional equipped cars that did not get the new CIC based system. These cars get the new iDrive controller that is also used on cars with CIC. The actual iDrive computer (CCC) remains the same. This update is available on the following cars;

- 5-Series E60/E61 manufactured from September 2008
- 6-Series E63/E64 manufactured from September 2008

iDrive Professional Navigation (CIC)

Debuted in September 2008 with F01/F02 7-Series. CIC stands for Car Infotainment Computer and is manufactured by Becker, utilizing the QNX operating system. It is available on the following cars as an option;

- 1-Series E81/E82/E87/E88 manufactured from September 2008
- 3-Series E90/E91/E92/E93 manufactured from September 2008
- 5-Series F07/F10/F11 manufactured from September 2009
- 6-Series E63/E64 manufactured from September 2009
- 7-Series F01/F02 manufactured from September 2008

The CIC system is a major update to iDrive, replacing the display, computer and the controller. The display is of a higher resolution, and is generally more responsive than CCC, to address one of the common complaints of iDrive. Internet access is also supported.

CIC-based systems use maps from TeleAtlas which are installed on an internal 2.5" 40GB Hard Disk Drive (HDD). This HDD can also store up to 8GB of music files for playback. For facilitating the uploading of music files to the HDD, a USB port is provided in the glove box.

Following 2009 LCI production, all CIC-based iDrive systems will support DVD video. This, however, is only operational when the vehicle is in the "Park" position.

Rationale

The design rationale of iDrive is to replace a confusing array of controls for the above systems with an all-in-one unit. The controls necessary for vehicle control and safety, such as the headlights and turn signals, are still located in the immediate vicinity of the steering column. iDrive also allows the On-Board Diagnostics computer to provide detailed information to the driver and service technicians in plain-text, rather than limited and confusing symbology, such as a "Check Engine" light.

Since the climate, audio, navigation and communication systems are adjusted only occasionally, they were moved into an easy-to-use, central location. However, iDrive was filled with controversy and many disapproved of it, as it was considered to be difficult to use .

Controversy and Critics

iDrive has caused significant controversy among users, the automotive media, and critics. Many reviewers of BMWs in (automobile) magazines disapprove of the system. Criticisms of iDrive include its steep learning curve and its tendency to cause the driver to look away from the road too much . Most users report that they adapt to the system after about one hour of practice, and the advent of voice controls has reduced the learning curve greatly.

A new iDrive system (CIC) was introduced in September 2008 to address most of the complaints.

Influence

Despite the criticisms of iDrive, the concept of a computer-oriented interface has grown in the luxury segment of the industry:

- MMI, Audi
- Comand APS, Mercedes-Benz
- Remote Touch, Lexus

As such, the significance of iDrive in auto history is predicated more on its pioneering value as a first mover into a new feature space than on the success of its application or particular interpretation of how to execute the idea in design. Generally speaking, the single touch-point for an increasingly broad array of controls is becoming a standard functionality and, like other features that were once only found in luxury vehicles (power windows, air conditioning, air bags) this single touch-point, if it remains a strong selling feature, will likely trickle down to higher-production, more affordable model lines.

How It Works

The *iDrive* M-ASK and CCC systems are based around the points of a compass (north, south, east, west) with each direction corresponding with a specific area. These areas are also colour coded providing identification as to which part of the system is currently being viewed.

- North (blue) for communication
- East (green) for navigation (In some models without navigation, this option is replaced by the On Board Computer)
- South (yellow) for entertainment
- West (red) for climate control

Also, at the iDrive home screen, the control knob can be pushed downwards to provide access to the car's control panel (iMenu), which gives access to a variety of operational parameters:

- date/time settings
- System language localization (generally, English (US/UK) and native language of the vehicle's location is provided.)
- Bluetooth settings
- Flat tire sensor settings,
- lighting behavior, etc.
- custom steering wheel buttons
- Power Output (BMW M series, for example, 400 hp, 500 hp).

Starting in 2007, perhaps in response to critics, iDrive added programmable buttons (6 USA/Japan, 8 in Europe) to the dashboard, breaking tradition of having the entire system operated via the control knob. Each button can be programmed to instantly access any feature within iDrive (such as a particular navigation route, or your favorite radio station). In addition, a dedicated AM/FM button, and a Mode button (to switch between entertainment sources) were added (only USA)

iDrive is controlled by manipulating the control knob. This can be pushed north, south, east, west; pushed inwards (down), nudged left and right, or rotated left and right. The control knob contains an element of 'force feedback' so the knob can not be rotated further than there are options on the screen. It will also kick back slightly as it scrolls through options. This makes it easier to use while driving and keeping your eyes on the road.

From the home screen, each option can be reached by pushing the control knob in the desired direction. From any other screen, pushing the knob in the desired direction and holding in place for a few seconds will jump to that new area. (For example, in the *Entertainment* screen, pushing the control knob to the right for a few seconds before letting it go will jump straight to the *Navigation* area). The iDrive system includes a button marked *Menu* behind the control knob which provides quick access to the home screen.

iDrive is unique among its competitors by using a widescreen display that is split into a 2/3 main window, and 1/3 "Assistance Window". This allows the driver to use any function or menu, while simultaneously maintaining secondary information. For example, if the driver is not in the Navigation menu, he can still see a map on the assistance window. Other information that can be displayed includes navigation route directions and a trip computer.

The latest generation of the BMW iDrive in the 2009 BMW 7-Series features a large 10.2 inch high resolution LCD panel with a 1280x480 resolution. It has a full featured web browser that connects to the internet via BMW ConnectedDrive using EDGE.

Chapter 10

Multi Media Interface

the MMI controls (to the rear of the gear lever) on a left-hand drive Audi Q7

The Audi **Multi Media Interface**, commonly abbreviated to **MMI**, is an in-car user interface system developed by Audi, and implemented in most of its latest series of cars/automobiles since 2004.

Concept

MMI consists of a single interface, which controls a variety of devices and functions of the car, thus minimizing the vast array of buttons and dials normally found on a dashboard. The system consists of the MMI terminal and the MMI display screen.

Like in the mentioned iDrive the central element of the MMI terminal is the control dial. This dial can be rotated, to navigate up and down through menus, and pressed to activate a selected highlighted function. Four or eight function buttons surround the control dial (dependent on MMI specification installed in the car), which can be used to call up a corresponding on-screen menu. The MMI screen is available as a 5-inch monochrome black & red or 7-inch 16:9 full colour display, depending on the variation of MMI fitted in the car. MMI uses Media Oriented Systems Transport (MOST) technology to interconnect the various systems. Harman Becker manufactures the system, utilizing QNX Neutrino's Real Time Operating System (RTOS) software.

Variations

a right-hand drive 2005 Audi A6 (C6), showing the Multi Media Interface (MMI) controls

a left-hand drive 2007 Audi S6 (C6), showing the MMI controls, and the display screen in the dashboard

On the A6 and S6, MMI comes in a choice of 3 systems, **MMI Basic**, **MMI Basic Plus** and **MMI** . The features of the 3 varieties are as follows:

- **MMI basic**
    - 5-inch monochrome display (red and black)
    - optional CD-ROM based satellite navigation (with single country street-level maps)
    - radio tuner (with RDS Traffic Programme (TP))
    - single CD player
- **MMI basic plus** - all features of MMI basic, plus:
    - DSP 10-speaker sound system
    - ability to store (TIM) RDS Traffic Announcement messages (TA)
- **MMI** - the features of MMI basic plus, and the addition of:
    - 7-inch 16:9 full-colour display
    - 6 CD Changer

- optional DVD-ROM based satellite navigation (with Europe-wide/United States-wide street-level maps, and TMC)
- optional TV Tuner

For the current A8 and S8 and Q5, the MMI only comes as a complete "one size fits all" package.

On the current Q7, it is available in two specifications, the standard **MMI** (with 8 speakers, monochrome display, and radio/CD player, and 4 function keys), and the optional **MMI High** (7" hi-res colour monitor, double tuner extended radio, DSP sound system, and separate CD changer - but NO navigation, which is an extra option).

The latest version, due to appear in 2010 on the new A8, can recognize handwriting inputs for the phone and navigation system.

Functions

MMI operates a large number of in car entertainment components, car electronics, and other functions. The list below indicates the scope of systems controllable by MMI. However, depending on the actual car model, along with which version was specified (MMI basic, MMI High, etc), only some, and not all functions will be applicable or available.

- Satellite Navigation, including traffic management (TMC)
- Radio tuner
- CD Changer
- TV Tuner
- Telephone & Directory
- heating, ventilation, air conditioning / Climate Control, and seat heating
- Car Setup (e.g. central locking and convenience function (coming home/leaving home, power sunroof and windows) options, global audio settings, suspension settings etc.)
- Driver Information (e.g. fuel economy statistics (often encompassed by "trip computer" functions), battery level, tire-pressure monitoring, etc.)
- User Manual (full on-board car user manual, displayed on screen)

Cars

Audi models featuring MMI are:

- A1
- A4 (B8) 2008 onwards
- A5
- A6 (C6) 2005 onwards
- S6 (C6) 2006 onwards

- A8 (D3) from the 2005 facelift onwards
- S8 (D3) 2006 onwards
- Q5
- Q7

Criticisms

While intuitive and user-friendly, MMI can be difficult to operate when driving. A sequence of menus may need to be accessed in order to change a particular setting, such as radio station, rather than having a dedicated button designated to such a function. This can make changing a setting both time-consuming and arguably hazardous under certain circumstances, where the driver is distracted from the road. It must be said, however, that this concern can also apply to other dashboard interfaces and even conventional dashboards.

Software Updates

- The MMI systems firmware can be updated, either by a dealer, or by a more recent release of navigation software. Bug-fixes, and enhancements can be added in this process, and on first installing a new navigation DVD, the firmware version is updated and system altered.
- MMI featuring DVD based navigation has a DVD disc drive located in the boot/trunk. This is used exclusively for navigation and contains the navigation software DVD.

Verify that the software level in 07 - Display control unit is 1070. If this is not the case, contact the Audi Technical Assistance Center for further instruction.

Version History

European / ROW (Rest of the World) versions:

- 0890 (0.8.90) -
- 1190 (1.1.90) -
- 1200 (1.2.00) -
- 2120 (2.1.20) - {Update CD p/n 4E0 906 961 L}
- 3460 (3.4.60) - {Update CD p/n 4E0 906 961 T}
- 4220 (4.2.20) - {Update CD p/n 4E0 906 961 AA}
- 5150 (5.1.50) - {Update CD p/n 4F0 906 961 AB}
- 5170 (5.1.79) -
- 5570 (5.5.70) - {Update CD set p/n 4L0 998 961 (A6/A8/Q7) or p/n 8K0 998 961 (A4 B8/A5)}

North America versions:

- 0600 (0.6.00) -

- 1190 (1.1.90) -
- 2750 (2.7.50) - version 2750 and below have to be upgraded to 3360 before upgrading to a higher version
- 3310 (3.3.10) -
- 3360 (3.3.60) - {Update CD p/n 4F0 906 961AB}
- 4140 (4.1.40) - {Update CD p/n 4L0 906 961 H}
- 4610 (4.6.10) - {Update CD set p/n 4F0 998 961}

Pseudo-MMI

Certain Audi cars have a "pseudo" type of MMI. These are the A3, A4 (B6 and B7), the TT and the R8 - when fitted with the RNS-E DVD based "Audi Navigation Plus" system. Whilst appearing to be a similar layout, and operating in a similar manner, these two systems are very different, are unable to share mapping discs or software, and are not able to control non-ICE functions (such as Climate, convenience or suspension settings).

Competing Technologies

Other car manufacturers use similar technologies in their car, including BMW with its iDrive system and Mercedes-Benz with its COMAND system; Lexus uses a mouse-based Remote Touch system; Ford uses a product called Sync.

Chapter 11

Subwoofer

a 12" subwoofer driver without an enclosure

A **subwoofer** (or simply "sub") is a woofer, or a complete loudspeaker typically between 8" and 21" in diameter, which is dedicated to the reproduction of low-pitched audio frequencies (the "bass"). The typical frequency range for a subwoofer is about 20–200 Hz for consumer products, below 100 Hz for professional live sound, and below 80 Hz in THX-approved systems. Because of their limited frequency range, most subwoofers are used to augment the output of loudspeakers covering higher frequency bands.

Subwoofers are made up of one or more woofers in a well-braced wood or plastic loudspeaker enclosure, in one of a variety of designs, including bass reflex (with a port or tube in the enclosure), infinite baffle, horn-loaded, and bandpass designs, each of which has advantages and disadvantages in efficiency, size, distortion, cost, and power handling. Passive subwoofers have a subwoofer driver and enclosure and they are powered by an external amplifier. Active subwoofers include a built-in amplifier.

The first subwoofers were developed in the 1960s to add bass response to home stereo systems. Subwoofers came into greater popular consciousness in the 1970s with the introduction of Sensurround in movies such as *Earthquake*, which produced loud low-frequency sounds through large subwoofers. With the advent of the compact cassette and the compact disc in the 1980s, the easy reproduction of deep *and* loud bass was no longer limited by the ability of a phonograph record stylus to track a groove, and producers could add more low frequency content to recordings. As well, during the 1990s, DVDs were increasingly recorded with "surround sound" processes that included a Low Frequency Effects (LFE) channel, which could be heard using the subwoofer in home theater systems. During the 1990s, subwoofers also became increasingly popular in home stereo systems, custom car audio installations, and in PA systems. By the 2000s, subwoofers became almost universal in sound reinforcement systems in nightclubs and concert venues.

History

The very first subwoofer was developed during the 1960s by Ken Kreisel, the former president of the Miller & Kreisel Sound Corporation in Los Angeles. When Kreisel's business partner, Jonas Miller, who owned a high-end audio store in Los Angeles, told Kreisel that some purchasers of the store's high-end electrostatic speakers had complained about a lack of bass response in the electrostatics, Kreisel designed a powered woofer that would reproduce only those frequencies that were too low for the electrostatic speakers to convey. Infinity's full range electrostatic speaker system that was developed during the 1960s also used a woofer to cover the lower frequency range that its electrostatic arrays did not handle adequately.

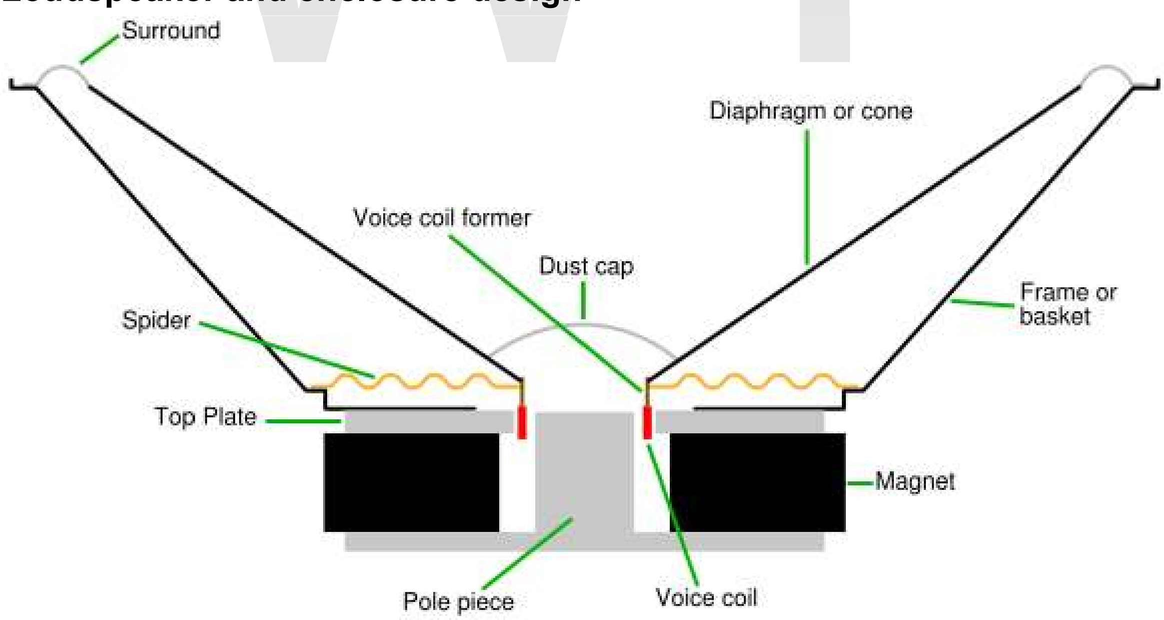
The first use of a subwoofer in a recording session was in 1973 for mixing the Steely Dan album *Pretzel Logic* when recording engineer Roger Nichols arranged for Kreisel to bring a prototype of his subwoofer to Village Recorders. Further design modifications were made by Kreisel over the next ten years, and in the 1970s and 1980s by engineer John P. D'Arcy; record producer Daniel Levitin served as a consultant and "golden ears" for the design of the crossover network (used to partition the frequency spectrum so that the subwoofer would not attempt to reproduce frequencies too high for its effective range, and so that the main speakers would not need to handle frequencies too low for their effective range).

Subwoofers received a great deal of publicity in 1974 with the movie *Earthquake* which was released in Sensurround. Initially installed in 17 U.S. theaters, the Sensurround system used large subwoofers which were driven by racks of 500 watt amplifiers which were triggered by control tones printed on one of the audio tracks on the film. Four of the subwoofers were positioned in front of the audience under (or behind) the film screen and two more were placed together at the rear of the audience on a platform. Powerful noise energy in the range of 17 Hz to 120 Hz was generated at the level of 110–120 decibels of sound pressure level, abbreviated dB(SPL). The new low frequency entertainment method helped the film become a box office success. More Sensurround systems were assembled and installed. By 1976 there were almost 300 Sensurround systems leapfrogging through select theaters. Other films to use the effect include the WW II naval battle epic *Midway* in 1976 and *Rollercoaster* in 1977.

For owners of 33 rpm LPs and 45 singles, loud *and* deep bass was limited by the ability of the phonograph record stylus to track the groove. Some hi-fi aficionados solved the problem by using reel-to-reel tape players which were capable of delivering accurate, naturally deep bass from acoustic sources, or synthetic bass not found in nature. With the popular introduction of the compact cassette and the CD, it became possible to add more low frequency content to recordings, and satisfy a larger number of consumers. Home subwoofers grew in popularity, as they were easy to add to existing multimedia speaker setups and they were easy to position or hide.

Construction and features

Loudspeaker and enclosure design



Cross-section of a subwoofer drive unit. *Image not to scale.*

Subwoofers use speaker drivers (woofers) typically between 8" and 21" in diameter. Some uncommon subwoofers use larger drivers, and single prototype subwoofers as large as 60" have been fabricated. On the smaller end of the spectrum, subwoofer drivers as small as 4" may be used, depending on the design of the loudspeaker enclosure, the desired sound pressure level, the lowest frequency targeted and the level of permitted distortion. The most common subwoofer driver sizes used for sound reinforcement are 10-, 12-, 15- and 18-inch models. The largest available sound reinforcement subwoofers, 21" drivers, are less commonly seen.

The efficiency of a speaker driver is given by:

$$\eta_0 = \left(\frac{4\pi^2 F_s^3 V_{as}}{c^3 Q_{es}} \right) \times 100\ \%$$

Where the variables are Thiele/Small parameters. Deep low frequency extension is a common goal for a subwoofer and small box volumes are also considered desirable. Hoffman's Iron Laws therefore mandate low efficiency under those constraints, and indeed most subwoofers require considerable power, much more than other individual drivers.

So for the example of a sealed speaker box, the box volume to achieve a given Q_{ts} is proportional to Vas:

$$V_b = \frac{V_{as}}{\alpha} \text{ Where: } \alpha = \frac{Q_{tc}}{Q_{ts}}^2 - 1$$

Therefore a decrease in box volume and the same F_3 will decrease the efficiency of the sub woofer. Similarly the F_3 of a speaker is proportional to Fs:

$$F_c = \frac{(Q_{tc} F_s)}{Q_{ts}}$$

As the efficiency is proportional to Fs^3, small improvements in low frequency extension with the same driver and box volume will result in very significant reductions in efficiency. For these reasons, subwoofers are typically very inefficient at converting electrical energy into sound energy. This combination of factors accounts for the higher power output of subwoofer amplifiers, and the requirement for greater power handling for subwoofer drivers. Enclosure variations (e.g., bass reflex designs) are sometimes used for subwoofers to increase the efficiency of the driver/enclosure system, helping to reduce the amplifier power requirement.

Subwoofer mounted in a sealed enclosure

Subwoofers have been designed using a number of enclosure approaches: bass reflex, acoustic suspension, infinite baffle, horn loaded, tapped horn, transmission line and bandpass. Each enclosure type has advantages and disadvantages in efficiency increase, bass extension, cabinet size, distortion, and cost. Subwoofers are typically constructed by mounting one or more woofers in a cabinet of medium-density fibreboard (MDF), oriented strand board (OSB), plywood, plastic or other dense materials. Because of the high power they use, subwoofers often require strong internal crossbracing to add strength and reduce box resonances.

There is a great deal of variety in the size of enclosures and, in the case of bass reflex systems, vent designs. When two or more subwoofers are placed in the same enclosure, they work together to move a greater mass of air, resulting in lower frequency extension. For example, if a single 12" subwoofer enclosure can go down to 40 Hz, a larger enclosure with four of these 12" drivers may be able to go to 30 Hz.

The smallest subwoofers are typically those designed for home theater users with limited space. The largest common subwoofer enclosures are those used for concert sound reinforcement systems or nightclub sound systems. An example of a large concert subwoofer enclosure is the 1980s-era ElectroVoice MT-4 "Bass Cube" system, which used four 18" drivers. An example of a subwoofer that uses a bass horn is the Bassmaxx B-Two, which loads an 18" driver onto an 11-foot (3.4 m) long folded horn. Folded horn-type subwoofers can typically produce a deeper range with greater efficiency than the same driver in an enclosure that lacks a horn. Some experimental fixed-installation subwoofer horns have been constructed using brick and concrete to produce a very long horn that allows a very deep sub-bass extension.

Subwoofer output level can be increased by increasing cone surface area or by increasing cone excursion. Since large drivers require undesirably large cabinets, most subwoofer drivers have large excursions. Unfortunately, high excursion, at high power levels, tends to produce more distortion from inherent mechanical and magnetic effects in electro-dynamic drivers (the most common sort). The conflict between assorted goals can never be fully resolved; subwoofer designs are necessarily compromises. Hoffman's Iron Law (the efficiency of a woofer system is directly proportional to its cabinet volume and to the cube of its cutoff frequency) applies to subwoofers just as to all loudspeakers.

Frequency range and frequency response

The typical frequency range for a subwoofer is between 20–200 Hz. Professional concert sound system subwoofers typically operate below 100 Hz, and THX-approved systems in movie theaters operate below 80 Hz. The frequency response specification of a speaker "attempts to describe the range of frequencies or musical tones a speaker can reproduce, measured in Hertz" Subwoofers vary in terms of the range of pitches that they can reproduce, depending on a number of factors such as the size of the cabinet and the construction and design of the enclosure and driver(s). Specifications of frequency response depend wholly for relevance on an accompanying amplitude value—measurements taken within a wider amplitude range will give any loudspeaker a wider frequency response. For example, the JBL 4688 TCB Subwoofer System, a now-discontinued system which was designed for movie theaters, had a frequency response of 23–350 Hz when measured within a 10-decibel boundary (0 dB to -10 dB) and a narrower frequency response of 28–120 Hz when measured within a six-decibel boundary (±3 dB).

As well, subwoofers vary in regards to the sound pressure levels achievable and the distortion levels they can produce over their range. The Abyss subwoofer, for example can reproduce pitches from 18 Hz (which is about the pitch of the lowest rumbling notes on a huge pipe organ with 32-foot (9.8 m) bass pipes) to 120 Hz (±3 dB). Nevertheless, even though the Abyss subwoofer can go down to 18 Hz, its lowest frequency and maximum SPL with a limit of 10% distortion at 2 meters in a large room is 35.5 Hz at 79.8 dB. This means that a person choosing a subwoofer needs to consider more than just the lowest pitch that that sub can reproduce.

Amplification

'Active subwoofers' include their own dedicated amplifiers within the cabinet. Some also include user-adjustable equalization that allows boosted or reduced output at particular frequencies; these vary from a simple "boost" switch, to fully parametric equalizers meant for detailed speaker and room correction. Some such systems are even supplied with a calibrated microphone to measure the subwoofer's in-room response, so the automatic equalizer can correct the combination of subwoofer, subwoofer location, and room response to minimize effects of room modes and improve low frequency performance.

'Passive subwoofers' have a subwoofer driver and enclosure, but they do not include an amplifier. They sometimes incorporate internal passive crossovers, with the filter frequency determined at the factory. These are generally used with third-party power amplifiers, taking their inputs from active crossovers earlier in the signal chain. While few high-end home-theater systems use passive subwoofers, this format is still popular in the professional sound industry. Using a passive subwoofer adds flexibility for the user, because the user can select which type of amplifier (Class AB or Class D, for example); brand of amplifier; or features (e.g., limiting to prevent distortion) that they want to use with their speaker or speakers.

Equalization

Equalization can be used to adjust the in-room response of a subwoofer system. Designers of active subwoofers sometimes include a degree of corrective equalization to compensate for known performance issues (e.g., a steeper than desired low end roll-off rate). In addition, many amplifiers include an adjustable low-pass filter, which prevents undesired higher frequencies from reaching the subwoofer driver. For example, if a listener's main speakers are usable down to 80 Hz, then the subwoofer filter can be set so the subwoofer only works below 80. Realizable filter behavior does not permit such sharp cutoffs, so some overlap is to be expected and must be compensated for. Digital crossover filters can produce sharper and more precise cutoff characteristics than analog filters. The crossover section may also include a high-pass "infrasonic" filter which prevents the subwoofer driver from attempting to reproduce frequencies below its safe capabilities.

Some systems use parametric equalization in an attempt to correct for room frequency response irregularities. Equalization is often unable to achieve flat frequency response at all listening locations in part because of the resonance (i.e., standing wave) patterns at low frequencies in nearly all rooms. Careful positioning of the subwoofer within the room can also help flatten the frequency response. Multiple subwoofers can manage a flatter general response since they can often be arranged to excite room modes more evenly than a single subwoofer, allowing equalisation to be more effective.

Phase control

Changing the relative phase of the subwoofer with respect to the woofers in other speakers may or may not help to minimize unwanted destructive acoustic interference in the frequency region covered by both subwoofer and main speakers. It may not help at all frequencies, and may create further problems with frequency response, but is even so generally provided as an adjustment for subwoofer amplifiers. Phase control circuits may be a simple polarity reversal switch or a more complex continuously variable circuits.

Continuously variable phase control circuits are common in subwoofer amplifiers, and may be found in crossovers and as do-it-yourself electronics projects. Phase controls allow the listener to change the arrival time of the subwoofer sound waves relative to the same frequencies from the main speakers (i.e., at and around the crossover point to the subwoofer). A similar effect can be achieved with the delay control on many home theater receivers. The subwoofer phase control found on many subwoofer amplifiers is actually a polarity inversion switch. It allows users to reverse the polarity of the subwoofer relative to the audio signal it is being given. This type of control allows the subwoofer to either be in phase with the source signal, or 180 degrees out of phase.

Back panel of a Polk subwoofer. Notice consumer line-level and speaker-level inputs, the polarity switch and the crossover frequency control.

Servo subwoofers

Some active subwoofers use a servo feedback mechanism based on cone movement which modifies the signal sent to the voice coil. The servo feedback signal is derived from a comparison of the input signal to the amplifier versus the actual motion of the cone. The usual source of the feedback signal is a few turns of voice coil attached to the cone or a microchip-based accelerometer placed on the cone itself. An advantage of a well-implemented servo subwoofer design is reduced distortion making smaller enclosure sizes possible. The primary disadvantages are cost and complexity.

Servo controlled subwoofers are not the same as Servodrive subwoofers whose primary mechanism of sound reproduction avoids the normal voice coil and magnet combination in favor of a high-speed belt-driven servomotor. The Servodrive design increases output power, reduces harmonic distortion and virtually eliminates the loss of loudspeaker output that results from an increase in voice coil impedance due to overheating of the voice coil (called *power compression*.) This feature allows high power operation for extended periods of time. Intersonics was nominated for a TEC Award for its Servo Drive Loudspeaker (SDL) design in 1986 and for the Bass Tech 7 model in 1990.

Applications

Home audio

The use of a subwoofer augments the bass capability of the main speakers, and allows them to be smaller without sacrificing low frequency capability. A subwoofer does not necessarily provide superior bass performance in comparison to large conventional loudspeakers on ordinary music recordings due to the typical lack of very low frequency content on such sources. However, there are recordings with substantial low frequency content that most conventional loudspeakers are ill-equipped to handle without the help of a subwoofer, especially at high playback levels, such as music for pipe organs with 32' bass pipes (16 Hz), very large bass drums on symphony orchestra recordings and electronic music with extremely low synth bass parts.

Low frequencies are not easily localized; hence many stereo and multichannel audio systems feature only one subwoofer channel and a single subwoofer can be placed off-center without affecting the perceived sound stage, since the sound produced is difficult to localize. The intention in a system with a subwoofer is often to use small main ("satellite") speakers (of which there are two for stereo and five or more for surround sound or movie tracks) and to hide the subwoofer elsewhere (e.g. behind furniture or under a table), or to augment an existing speaker to save it from having to handle woofer-destroying low frequencies at high levels.

Some users add a subwoofer because high levels of low bass are desired, even beyond what is in the original recording, as in the case of house music enthusiasts. Thus, subwoofers may be part of a package that includes satellite speakers, may be purchased separately, or may be built into the same cabinet as a conventional speaker system. For instance, some floor standing tower speakers include a subwoofer driver in the lower portion of the same cabinet. Physical separation of subwoofer and "satellite" speakers not only allows placement in an inconspicuous location, but since sub-bass frequencies are particularly sensitive to room location (due to room resonances and reverberation 'modes'), the best position for the subwoofer is not likely to be where the "satellite" speakers are located.

The 1987 Bose Acoustimass 5 stereo bass driver contained one six-inch (152 mm) driver per channel and provided crossover filtering for its two satellites

For greatest efficiency and best coupling to the room's air volume, subwoofers can be placed in a corner of the room, far from large room openings, and closer to the listener. This is possible since low bass frequencies have a long wavelength; hence there is little difference between the information reaching a listener's left and right ears, and so they cannot be readily localized. All low frequency information is sent to the subwoofer. However, unless the sound tracks have been carefully mixed for a single subwoofer channel, it's possible to have some cancellation of low frequencies if bass information in one channel is out of phase with another.

The physically separate subwoofer/satellite arrangement has been popularized by multimedia speaker systems such as Bose Acoustimass Home Entertainment Systems, Polk Audio RM2008 Series and Klipsch Audio Technologies ProMedia. Low-cost "home theater in a box" systems advertise their integration and simplicity.

Particularly among low cost "Home Theater in a Box" systems and with "boom boxes", however, inclusion of a subwoofer may be little more than a marketing device. It is unlikely that a small woofer in an inexpensively-built compact plastic cabinet will have better bass performance than well-designed conventional (and typically larger) speakers in a plywood or MDF cabinet. Mere use of the term "subwoofer" is no guarantee of good or extended bass performance. Many multimedia "subwoofers" might better be termed "bass drivers" as they are too small to produce deep bass.

Further, poorly designed systems often leave everything below about 120 Hz (or even higher) to the subwoofer, meaning that the subwoofer handles frequencies which the ear can use for sound source localization, thus introducing an undesirable subwoofer "localization effect". This is usually due to poor crossover designs or choices (too high crossover point or insufficient crossover slope) used in many computer and home theater systems; localization also comes from port noise and from typically large amounts of harmonic distortion in the subwoofer design. Home subwoofers sold individually usually include crossover circuitry to assist integration into an existing system.

Car audio

A number of subwoofers in a car hatchback

Automobiles are well suited to the "hidden" subwoofer approach due to space limitations in the passenger compartments. It is not possible, in most circumstances, to fit such large drivers and enclosures into doors or dashboards, so subwoofers are installed in the trunk or back seat space. Some car audio enthusiasts compete to produce very high sound pressure levels in the confines of their vehicle's cabin; sometimes dangerously high. The "SPL wars" have drawn much attention to subwoofers in general, but subjective competitions in sound quality ("SQ") have not gained equivalent popularity. Top SPL cars are not able to play normal music, or perhaps even to drive normally as they are designed solely for competition. Many subwoofers are capable of generating high levels in cars due to the small volume of a typical car interior. High sound levels can cause hearing loss and tinnitus if one is exposed to them for an extended period of time.

A homemade car audio subwoofer speaker box with a 15 inch Boss Audio subwoofer and an empty space for a second driver

In the 2000s, several car audio manufacturers have produced subwoofers using non-circular shapes from manufacturers, including Kicker, Sony, Bazooka, and X-Tant. These shapes typically carry some sort of distortion penalties. In situations of limited mounting space they provide a greater cone area and assuming all other variables are constant, greater maximum output. An important factor in the "square sub vs round sub" argument is the effects of the enclosure used. In a sealed enclosure, the maximum displacement is determined by

$$V_{\mathrm{d}} = x_{\max} \times S_{\mathrm{d}}$$

where

- V_d stands for volume of displacement (in m^3)
- x_{max} to the amount of linear excursion the speaker is mechanically capable of (in m)
- S_d to the cone area of the sub woofer (in m^2).

These are some of the Thiele/Small parameters which can either be measured or found with the driver specifications.

Cinema sound

After the introduction of Sensurround, movie theater owners began installing permanent subwoofer systems. Dolby Stereo 70 mm Six Track was a six channel film sound format introduced in 1976 that used two subwoofer channels for stereo reproduction of low frequencies. In 1981, Altec introduced a dedicated cinema subwoofer model tuned to 20 Hz: the 8182. Starting in 1983, THX certification of the cinema sound experience quantified the parameters of good audio for watching films, including requirements for subwoofer performance levels and enough isolation from outside sounds so that noise did not interfere with the listening experience. This helped provide guidelines for multiplex cinema owners who wanted to isolate each individual cinema from its neighbors, even as louder subwoofers were making isolation more difficult. Specific cinema subwoofer models appeared from JBL, Electro-Voice, Eastern Acoustic Works, Kintek, Meyer Sound Laboratories and BGW Systems in the early 1990s. In 1992, Dolby Digital's six-channel film sound format incorporated a single low-frequency effects (LFE) channel, the "point one" in 5.1 surround sound.

Tom Horral, a Boston-based acoustician, blames subwoofers for louder cinema sound in general. He says that before subwoofers made it possible to have loud, relatively undistorted bass, movie sound levels were limited by the distortion in less capable systems at low frequency and high levels.

Sound reinforcement

Each stack of speakers in this sound reinforcement setup consists of two EAW SB1000 direct radiating subwoofers (each contains two 18" drivers) and two EAW KF850 full range cabinets for the mid and high frequencies.

Professional audio subwoofers must be capable of very high output levels. This is reflected in the design attention given in recent years to the subwoofer applications for sound reinforcement, public address systems, dance club systems and concert systems. Consumer applications (as in home use) are considerably less demanding due to much smaller listening space and lower playback levels. Subwoofers are now almost universal in professional sound applications such as live concert sound, churches, nightclubs, and theme parks. Movie theatres certified to the THX standard for playback always include high capability subwoofers. Some professional applications require subwoofers designed for very high sound levels, using multiple 12", 15", 18" or 21" drivers. Drivers as small as 10" are occasionally used, generally in horn loaded enclosures.

The number of subwoofer enclosures used in a concert depends on a number of factors, including the size of the venue, whether it is indoors or outdoors, the amount of low-frequency content in the band's sound, the desired volume of the concert, and the design and construction of the enclosures (e.g., direct-radiating versus horn-loaded. A small bar may use a single direct-radiating 15-inch sub cabinet. A large dance club may have a row of four or five twin 18-inch subwoofer cabinets, or more). In the largest stadium venues, there may be a very large number of subwoofer enclosures. For example, the 2009–2010 U2 360° Tour uses 24 Clair Brothers BT-218 subwoofers (a double 18" box) around the perimeter of the central circular stage, and 72 proprietary Clair Brothers cardioid S4 subwoofers placed underneath the ring-shaped "B" stage which encircles the central main stage.

The main speakers may be 'flown' from the ceiling of a venue on chain hoists, and 'flying points' (i.e., attachment points) are built into many professional loudspeaker enclosures. Subwoofers can be flown or stacked on the ground near the stage. There can be more than 50 double-18-inch cabinets in a typical concert system. Just as consumer subwoofer enclosures can be made of Medium-density fibreboard (MDF), Oriented strand board (OSB), plywood, plastic or other dense material, professional subwoofer enclosures can be built from the same materials. MDF is commonly used to construct subwoofers for permanent installations as its density is relatively high and weatherproofing is not a concern. Other permanent installation subwoofers have used very thick plywood: the Altec 8182 (1981) used 7-ply 28 mm birch-faced oak plywood. Touring subwoofers are typically built from 18–20 mm thick void-free Baltic birch (Betula pendula or Betula pubescens) plywood from Finland, Estonia or Russia; such plywood affords greater strength for frequently transported enclosures. Not naturally weatherproof, Baltic birch is coated with carpet, thick paint or spray-on truck bedliner to give the subwoofer enclosures greater durability.

Touring subwoofer cabinets are typically designed with features that facilitate moving the enclosure (e.g., wheels, a "towel bar" handle and recessed handles), a protective grill for the speaker (in direct radiating-style cabinets), metal or plastic protection for the cabinets to protect the finish as the cabinets are being slid one on top of another, and hardware to facilitate stacking the cabinets (e.g., interlocking corners) and for "flying" the cabinets from stage rigging.

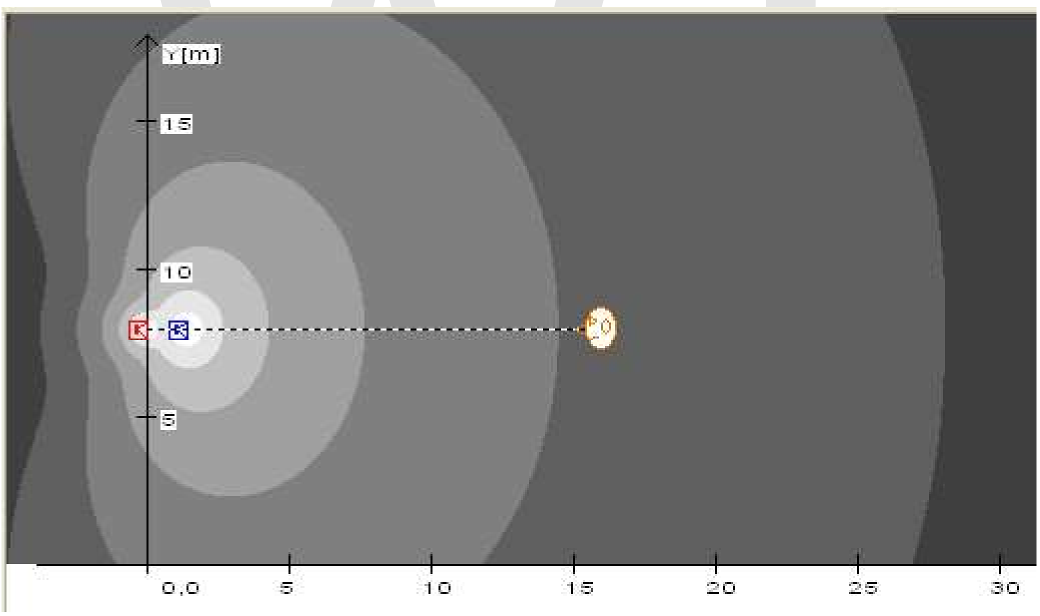
Full-range system

In professional concert sound system design, subwoofers can be incorporated seamlessly with the main speakers into a stereo or mono full-range system by using an active crossover. Such a system receives its signal from the main mono or stereo mixing console mix bus and amplifies all frequencies together in the desired balance. If the main sound system is stereo, the subwoofers can also be in stereo. Otherwise, a mono subwoofer channel can be derived within the crossover from a stereo mix, depending on the crossover make and model.

Aux-fed subwoofers

Instead of being incorporated into a full-range system, concert subwoofers can be supplied with their own signal from a separate mix bus on the mixing console; often one of the auxiliary sends ("aux" or "auxes") is used. This configuration is called "aux-fed subwoofers", and has been observed to significantly reduce low frequency "muddiness" that can build up in a concert sound system which has on stage a number of microphones each picking up low frequencies and each having different phase relationships of those low frequencies. The aux-fed subs method greatly reduces the number of sources feeding the subwoofers to include only those instruments that have desired low frequency information; sources such as kick drum, bass guitar, samplers and keys. This simplifies the signal sent to the subwoofers and makes for greater clarity and low punch. Aux-fed subs can even be stereo, if desired, using two auxiliary mix buses.

Directional bass



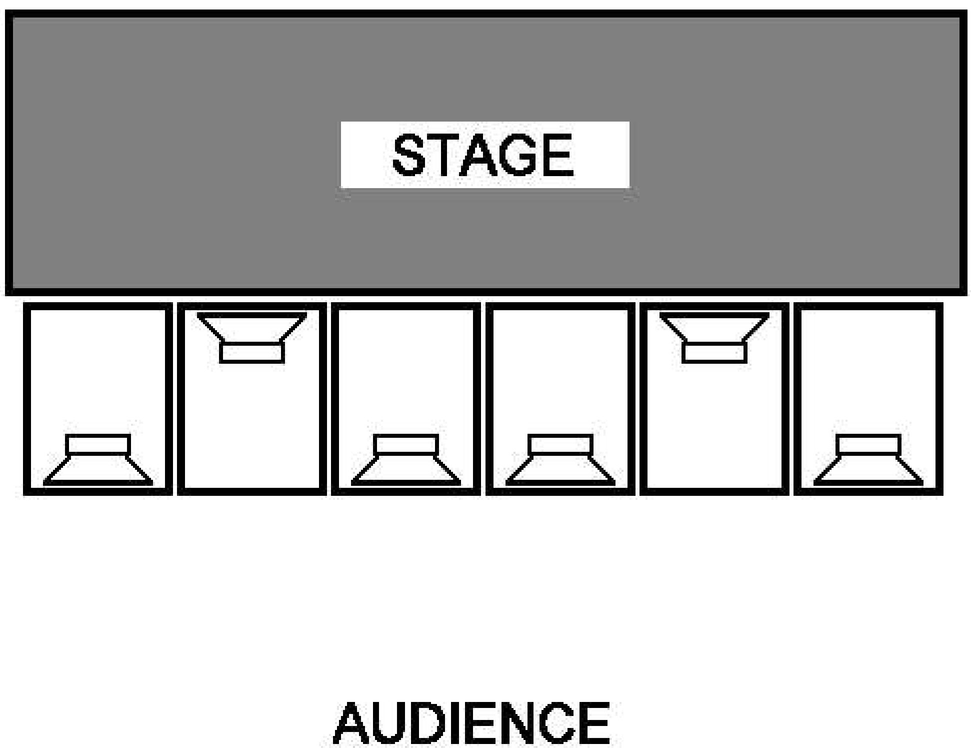
Cardioid dispersion pattern of two end-fire subwoofers placed one in front of the other. The enclosure nearest the listener is delayed by a few milliseconds.

In order to keep low frequency energy focused on the audience area and not on the stage, and to keep low frequencies from bothering people outside of the event space, a variety of techniques have been developed in concert sound to turn the naturally omnidirectional radiation of subwoofers into a more directional pattern. These techniques include setting up subwoofers in a vertical array; using combinations of delay and polarity inversion; and setting up a delay-shaded system.

Vertical array

Stacking or rigging the subwoofers in a vertical array focuses the low frequencies forward to a greater or lesser extent depending on the physical length of the array. Longer arrays have a more directional effect at lower frequencies. The directionality is more pronounced in the vertical dimension, yielding a radiation pattern that is wide but not tall. This helps reduce the amount of low frequency sound bouncing off the ceiling indoors and assists in mitigating external noise complaints outdoors.

Rear delay array

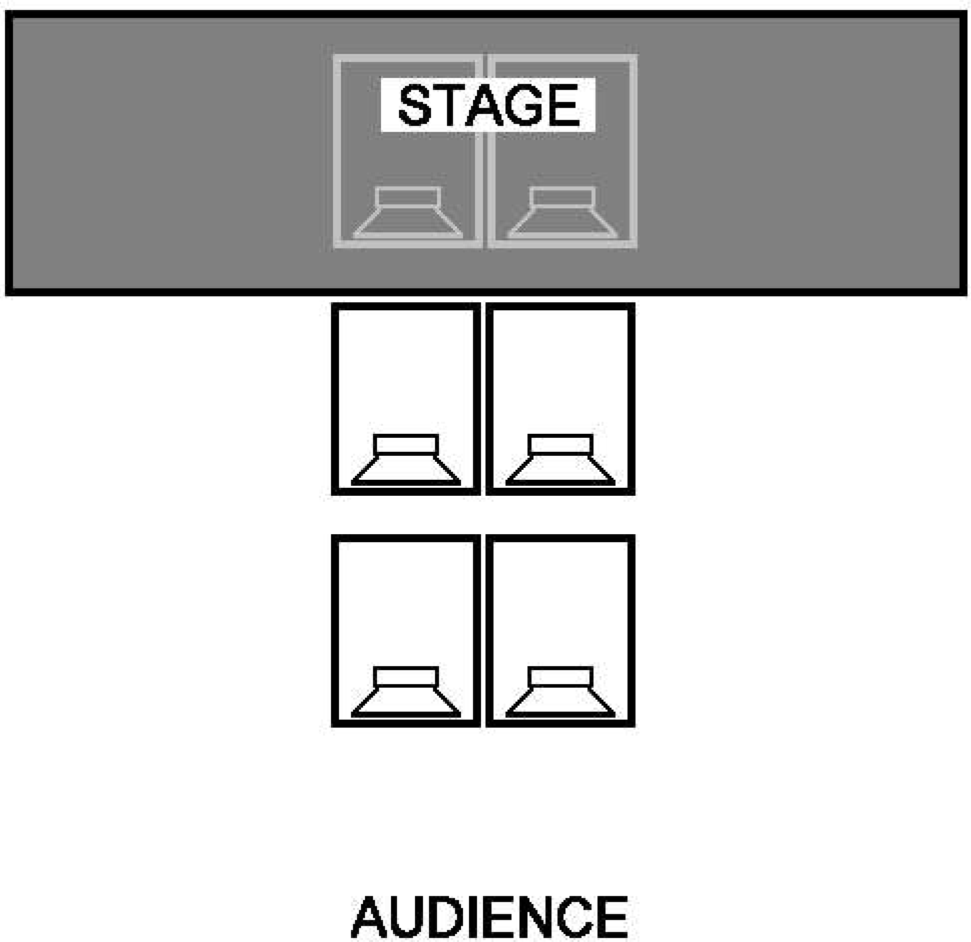


CSA: Six subwoofers arranged for less bass energy on stage. Signal going to the reversed enclosures is delayed a few milliseconds.

Another cardioid subwoofer array pattern can be used horizontally, one which takes few channels of processing and no change in required physical space. Often called "cardioid subwoofer array" or "CSA", though the pattern of all directional subwoofer methods is cardioid, the method inverts the polarity of one out of every three subwoofers across the front of the stage, and delays those enclosures for maximum cancellation of the target frequency on stage. Polarity inversion can be implemented electronically, or by physically placing the enclosure to face rearward. This method reduces forward output relative to a tight-packed, flat-fronted array of subwoofers, but can solve problems of unwanted low frequency energy coming into microphones on stage. Compared to the end-fire array, this method has less on-axis energy but more even pattern control throughout the audience, and more predictable cancellation rearward. The effect spans a range of slightly more than one octave.

A second method of rear delay array combines end-fire topology with polarity reversal, using two subwoofers positioned front to back, the drivers spaced one-quarter wavelength apart, the rear enclosure inverted in polarity and delayed by a few milliseconds for maximum cancellation on stage of the target frequency. This method has the least output power directed toward the audience, compared to other directional methods.

End-fire array



End-fire array using three rows of subwoofers. Each row is delayed a few milliseconds more than the previous row.

The end-fire subwoofer method, also called "forward steered arrays", places subwoofer drivers co-axially in one or more rows, using destructive interference to reduce emissions to the sides and rear. This can be done with separate subwoofer enclosures positioned front to back with a spacing between them of one-quarter wavelength of the target frequency, the frequency that is least wanted on stage or most desired in the audience. Each row is delayed beyond the first row by an amount related to the speed of sound in air; typically a few milliseconds. The arrival time of sound energy from all the subwoofers is near-simultaneous from the audience's perspective, but is canceled out to a large degree behind the subwoofers because of offset sound wave arrival times. Directionality of the target frequency can achieve as much as 25 dB rear attenuation, and the forward sound is coherently summed in line with the subwoofers. The positional technique of end-fire subwoofers came into widespread use in European live concert sound in 2006.

The end-fire array trades a few decibels of output power for directionality, so it requires more enclosures for the same output power as a tight-packed, flat-fronted array of enclosures. Sixteen enclosures in four rows were used in 2007 at one of the stages of the Ultra Music Festival, to reduce low frequency interference to neighboring stages. Because of the physical size of the end-fire array, few concert venues are able to implement it. The output pattern suffers from comb-filtering off-axis, but can be further shaped by adjusting the frequency response of each row of subwoofers.

Delay-shaded array

A long line of subwoofers placed horizontally along the front edge of the stage can be delayed such that the center subs fire several milliseconds prior to the ones flanking them, which fire several milliseconds prior to *their* neighbors, continuing in this fashion until the last subwoofers are reached at the outside ends of the subwoofer row. This method helps to counteract the extreme narrowing of horizontal dispersion pattern seen with a horizontal subwoofer array. Such delay shading can be used to virtually reshape a loudspeaker array.

Directional enclosure

Some subwoofer enclosure designs rely on drivers facing to the sides or to the rear in order to achieve a degree of directionality. End-fire drivers can be positioned within a single enclosure that houses more than one driver.

Bass instrument amplification

In rare cases, sound reinforcement subwoofer enclosures are also used for bass instrument amplification by electric bass players and synth bass players. For most bands and most small- to mid-size venues (e.g., nightclubs and bars), standard bass guitar speaker enclosures or keyboard amplifiers will provide sufficient sound pressure levels for onstage monitoring.Since a regular electric bass has a low "E"

(41 Hz) as its lowest note, most standard bass guitar cabinets are only designed with a range that goes down to about 40 Hz. However, in some cases, performers wish to have extended sub-bass response that is not available from standard instrument speaker enclosures, so they use subwoofer cabinets. Just as some electric guitarists add huge stacks of guitar cabinets mainly for show, some bassists will add immense subwoofer cabinets with 18" woofers mainly for show, and the extension sub cabinets will be operated at a lower volume than the main bass cabinets.

Bass guitar players who may use subwoofer cabinets include performers who play with extended range basses that include a low "B" string (about 31 Hz); bassists who play in styles where a very powerful sub-bass response is an important part of the sound (e.g., funk, Latin, gospel, R & B, etc.); and/or bass players who perform in stadium-size venues or large outdoor venues. Keyboard players who use subwoofers for on-stage monitoring include electric organ players who use bass pedal keyboards (which go down to a low "C" which is about 33 Hz) and synth bass players who play rumbling sub-bass parts that go as low as 18 Hz. Of all of the keyboard instruments that are amplified onstage, synthesizers can produce some of the lowest pitches, because unlike a traditional electric piano or electric organ, which have as their lowest notes a low "A" and a low "C", respectively, a synth does not have a fixed lowest octave. A synth player can add lower octaves to a patch by pressing an "octave down" button, which can produce pitches that are at the limits of human hearing.

Several concert sound subwoofer manufacturers suggest that their subs can be used for bass instrument amplification. Meyer Sound suggests that its 650-R2 Concert Series Subwoofer, a 14-square-foot (1.3 m^2) enclosure with two 18-inch drivers, can be used for bass instrument amplification. While performers who use concert sound subwoofers for onstage monitoring may like the powerful sub-bass sound that they get onstage, sound engineers may find the use of large subwoofers (e.g., two 18" drivers) for onstage instrument monitoring to be problematic, because it may interfere with the "Front of House" sub-bass sound.

Bass shakers

Since much very low bass is felt, sub-bass can be 'augmented' using tactile transducers. Unlike a typical subwoofer driver, which produces audible vibrations, tactile transducers produce low-frequency vibrations that are designed to be felt by individuals who are touching the transducer or indirectly through a piece of furniture or a wooden floor. Tactile transducers have recently emerged as a device class, called variously "bass shakers", "butt shakers" and "throne shakers". They are attached to a seat, for instance a drummer's stool ("throne") or gamer's chair, car seat or home theater seating, and the vibrations of the driver are transmitted to the body then to the ear in a manner similar to bone conduction. They connect to an amplifier like a normal subwoofer. They can be attached to a large flat surface (for instance a floor or platform) to create a large low frequency conduction area, although the transmission of low frequencies through the feet is not as efficient as the seat.

The advantage of tactile transducers used for low frequencies is that they allow a listening environment that is not filled with loud low frequency waves. This helps the concert drummer to monitor his or her kick drum performance without "polluting" the stage with powerful low frequency waves from a 15" subwoofer monitor. By not having a subwoofer monitor, a bass shaker also enables a drummer to lower the sound pressure levels that he is exposed to during a performance. For home cinema or videogame use, bass shakers help the user avoid disturbing others in nearby apartments or rooms, because even powerful sound effects such as explosion sounds in a war videogame or the simulated rumbling of an earthquake in an adventure film will not be heard by others. However, some critics argue that the felt vibrations are disconnected from the auditory experience, and they claim that that music is less satisfying with the "butt shaker" than sound effects. As well, critics have claimed that the bass shaker itself can rattle during loud sound effects, which can distract the listener.

World record claims

With varying measures upon which to base claims, several subwoofers have been said to be the world's largest, loudest or lowest.

Matterhorn

The Matterhorn is a subwoofer model completed in March 2007 by Danley Sound Labs in Gainesville, Georgia after a U.S. military request for a loudspeaker that could project infrasonic waves over a distance. The Matterhorn was designed to reproduce a continuous sine wave from 15 to 20 Hz, and generate 94 dB at a distance of 250 meters (820 ft), and more than 140 dB for music playback measured at the horn mouth. It can generate a constant 15 Hz sine wave tone at 140 dB for 24 hours a day, seven days a week with extremely low harmonic distortion. The subwoofer has a flat frequency response from 15 to 80 Hz, and is down 3 dB at 12 Hz. It was built within an intermodal container 20 feet (6.1 m) long and 8 by 8 feet (2.4 × 2.4 m) square. The container doors swing open to reveal a tapped horn driven by 40 long-throw 15-inch speaker drivers each powered by its own 1000-watt amplifier. The manufacturer claims that 53 13-ply 18 mm 4-by-8-foot (1.2 × 2.4 m) sheets of plywood were used in its construction, though one of the fabricators wrote that double-thickness 26-ply sheets were used for convenience. A diesel generator is housed within the enclosure to supply electricity when external power is unavailable. Of the constant tone output capability, designer Tom Danley wrote that the "target 94 dB at 250 meters is not the essentially fictional 'burst' or 'peak SPL' nonsense in pro sound, or like the 'death burp' signal used in car sound contests." At the annual National Systems Contractors Association (NSCA) convention in March 2007, the Matterhorn was barred from making any loud demonstrations of its power because of concerns about damaging the building of the Orange County Convention Center. Instead, using only a single 20 amp electrical circuit for safety, visitors were allowed to step inside the horn of the subwoofer for an "acoustic massage" as the fractionally powered Matterhorn reproduced low level 10–15 Hz waves.

Royal Device custom installation

Another subwoofer claimed to be the world's biggest is a custom installation in Italy made by Royal Device primarily of bricks, concrete and sound-deadening material consisting of two subwoofers embedded in the foundation of a listening room. The horn-loaded subwoofers each have a floor mouth that is 2.2 square meters (24 sq ft), and a horn length that is 9.5 meters (31 ft), in a cavity 1 meter (3 ft 3 in) under the floor of the listening room. Each subwoofer is driven by eight 18-inch subwoofer drivers with 100 millimeters (3.9 in) voice coils. The designers assert that the floor mouths of the horns are additionally loaded acoustically by a vertical wooden horn expansion and the room's ceiling to create a 10 Hz "full power" wave at the listening position.

Concept Design 60-inch

A single 60-inch (1,500 mm) diameter subwoofer driver was designed by Richard Clark and David Navone with the help of Dr. Eugene Patronis of Georgia Institute of Technology. The driver was intended to break sound pressure level records when mounted in a road vehicle, calculated to be able to achieve more than 180 dBSPL. It was built in 1997, driven by DC motors connected to a rotary crankshaft somewhat like in a piston engine. The cone diameter was 54 inches (1,400 mm) and was held in place with a 3-inch (76 mm) surround. With a 6-inch (150 mm) peak-to-peak stroke, it created a one-way air displacement of 6,871 cubic inches (112,600 cm^3). It was capable of generating 5–20 Hz sine waves at various DC motor speeds—not as a response to audio signal—it could not play music. The driver was mounted in a stepvan owned by Tim Maynor but was too powerful for the amount of applied reinforcement and damaged the vehicle. MTX's Loyd Ivey helped underwrite the project and the driver was then called the MTX "Thunder 1000000" (one million). Still unfinished, the vehicle was entered in an SPL competition in 1997 at which a complaint was lodged against the computer control of the DC motor. Instead of using the controller, two leads were touched together in the hope that the motor speed was set correctly. The drive shaft broke after one positive stroke which created an interior pressure wave of 162 dB. The Concept Design 60-inch was not shown in public after 1998.

MTX Jackhammer

The largest production subwoofer intended for use in automobiles is the MTX Jackhammer by MTX Audio which has a 22-inch (560 mm) diameter cone. The Jackhammer can take a total of 6000 watts sent to dual voice coils moving within a 900-ounce (26 kg) strontium ferrite magnet. The Jackhammer weighs 369 pounds (167 kg) and has an aluminum heat sink. The Jackhammer has been featured on the television show Pimp My Ride.

Chapter 12

Kenwood DNX-5120

The **Kenwood DNX-5120** Navigation Receiver is a "full-featured Entertainment and Navigation system with USB Direct Control for iPods or other portable music devices." It features built-in Garmin GPS navigation and includes maps of the United States, Canada, and Puerto Rico. Other prominent features include a 6.1" LCD touchscreen, variable-color illumination of the front panel controls, and two RCA 2V Preouts for system expansion. The majority of this post also applies to the DNX-5220 which is the european equivalent model.

General features

- in-dash DVD/CD player with internal amplifier (22 watts RMS/50 peak x 4 channels)
- fits double-DIN (4" tall) dash openings with surrounds available for many cars such as VW/Seat/Skoda etc.
- 6.1" LCD 16:9 touchscreen display with a TFT active matrix system (resolution of 480 x 234 with 336,960 total pixels - 480H x 234V x RGB). The screen is non-glare and smudge-resistant.
- Front-loading disc-slot.
- Built-in Garmin Navigation Board with USA, Canada, PR, Alaska and Hawaii Mapping - turn-by-turn navigation with spoken street names, and over 6 million of Points of Interest (maps use built-in memory and do not require a disc or other media to be inserted to use). The Garmin navigation interface is very similar to that of other Garmin devices such as the Garmin nuvi. (5120)
- Built-in Garmin Navigation Board with European map - Garmin North Europe City Navigator - turn-by-turn directions with spoken street names with full postcode lookup, traffic avoidance and mapping. (5220)
- Advanced GUI with Variable Illumination and Customizable Start-up
- USB Direct Control - allows connection of a thumb drive, hard drive, or other USB storage device

- iPod Ready - allows direct, speedy control of an iPod, allowing access to music and video (claimed to be the fastest Access to iPod Audio/Video) (requires optional KCA-iP300V cable)
- 2 2V RCA Preouts (F,R/Sub)
- Front Aux Input
- Rear audio/video input
- Rear reverse camera input (if desired, the unit can automatically switch to the rear camera when the car is put into reverse)
- Bluetooth Hands-Free Unit Ready (Requires Optional KCA-BT200 unless the unit model name has 'BT' suffix)
- Satellite Radio Ready (Requires Optional CA-SR20V + Sirius SC-C1 Tuner or KCA-XM100V + XM Mini Tuner) (5120 only)
- HD Radio Ready (requires optional HD radio adapter) (5120 Only, 5220 allows for European DAB connection)
- live traffic and weather data available with optional TMC receiver (5120)
- Built in TMC traffic using RAC traffic data (5220)
- plays DVD-Video, DVD-R/RW, DVD+R/RW, DVD-/+R DL, CD-Audio, CD-R/RW, CD-ROM, DTS-CD, and VCD discs
- plays AAC-LC (.M4a), MP3, WMA, JPEG, MPEG (MPEG1 or MPEG2) files
- allows viewing of JPEGs on CD, DVD, or USB
- 3-band EQ with six preset tone curves - the EQ may be set individually for different audio or video sources
- outputs: 4-channel preamp outputs (front, rear), A/V output, standard speaker outputs
- compatible with most factory steering wheel audio controls (adapter required)
- New units come with a 1 year warranty if purchased from an authorized Kenwood dealer
- Display has adjustable brightness and automatically dims with the vehicle headlights are turned on (if the unit is installed properly by connecting the dimmer wire lead to the vehicle dimmer wire) or at a specified time of day determined by the GPS (if installed)
- Allows Customized Background images
- The unit includes 3 buttons in the front of the unit labeled "NAV," SRC," and "FNC." The unit also includesa rotary-dial along the left edge of the screen which can be pressed or turned.
- Button illumination can be manipulated to preset or custom colors.
- The unit may be programmed security code. Once the unit has been programmed with a security code, the code must be entered to use the unit after it has been disconnected from power.
- The front and rear channels may be independently set to separate sources ("Dual Zone"). Volume can be adjusted for each zone independently.
- The GPS antenna includes an attached 16.5' cable
- Using an optional FM Traffic Receiver, the navigation system can display and utilize traffic information in select cities. (5220 built in)
- Optional remote control is available

- Advanced Crossover system allows tailoring of system with selectable crossover points for all channels

Firmware and Map Software

- Kenwood released an update to the DNX-5120/DNX-5220 firmware on April 5, 2010. The current firmware version is 3.1, and the firmware can be downloaded from Kenwood's website here.
- Kenwood released an update to the DNX-5120/DNX-5220 firmware on February 26, 2009. The current firmware version is 2.4.0, and the firmware can be downloaded from Kenwood's website here.
- Garmin released an update to the Navigation software for the DNX-5120 on January 26, 2009. The current map firmware version is 2.60, and the firmware can be downloaded here.
- Garmin released the 2009 map update called "City Navigator North America NT 2009", which can be ordered from the Garmin website here. The updates come on DVD media which is inserted into the DNX-5120 unit which automatically updates after the required activation (an activation code must be entered by entering information into the appropriate fields on the Garmin activation webpage. The map update process takes over one hour to complete.
- Garmin has released the 2010 map update named "City Navigator North America NT 2010", which can be ordered from the Garmin website here.
- Users of the optional KCA-BT200 bluetooth module (released in cooperation with Parrot) may download and install the latest firmware, version 1.70 using the links at the bottom of the page here.
- The BT200 firmware has been updated to version 3.12 and can be downloaded here.

Issues, tips, and workarounds

USB support

According to the Kenwood website, the DNX-5120 has the following limitations on files and folders stored on USB devices:

- Maximum number of folder layers: 8
- Maximum number of folders (per device): 126
- Maximum number of files (per folder): 255
- Maximum number of files (per device): 15000
- Maximum number of files per playlist: 7000

Folders outside of this limit are inaccessible and appear in the folder list, but they cannot be selected. This limitation does not appear to apply to iPods.

In addition to data volume limitations, there are also hardware compatibility limitations for USB devices used with the DNX5120:

- Utilizes standard USB 1.1 and USB 2.0 connection types
- Data transfer Speeds of up to 12Mbps
- USB class Mass storage class (MSC device)
- USB subclass SCSI
- Can operate on a maximum supply of 500 mA

Some users have also had issues with the USB device being recognized on startup. If the device is attached when the car is turned on, the device is sometimes not recognized.

Another issue with USB playback is that the device currently does not allow fast-forward or rewind of the current playing track (this is possible during playback on other media, such as CD or DVD). Full tracks may be advanced or reviewed; however, the seeking is not enabled through the currently playing track.

It should also be noted the maximum drive size is 32gb, formated with FAT32. Unlike the documentation states, the unit displays files in the order they were written to the drive, not alphabetical as Kenwood claims.

Album Art

Album art for MP3 and WMA files will be displayed on the DNX-5120 if the album art files are embedded as ID3 metadata tags on the audio files. A jpeg picture file in the folder with the audio files is not required.. Many music organization or mp3 tag editing software packages can encode the album art this way, and users have reported that MediaMonkey and Tagclinic as working solutions.

Video Size and Framerate

According to the Kenwood website, the DNX-5120 has the following size and bitrate limitations on video file playback

- For MPEG1: Picture size of 352 × 240 or 352 × 288; Max bitrate of 1.5 Mbit/s.
- For MPEG2: Picture size of 720 × 480 or 720 × 576; Max bitrate of 2.0 Mbit/s.

However, users have found the following limitations to be more accurate:

- For MPEG2: 3000 kbit/s ("at 3500 I started studdering").
- CBR vs VBR seems to make a difference. 720x480 @ 3 kbit/s CBR "worked fine." 480x480 @ 5 kbit/s CBR "worked fine too".

Safe Mode for navigation and viewing video

Because of traffic safety laws that have been adapted by most of the continental United States, the DNX-5120 includes a safe mode feature which disables on-screen video as well as access to manually entering destinations in the navigation source unless the vehicle's parking brake is engaged.

Custom backgrounds

You can customize the DNX-5210 with your own wallpaper / image by entering the "User Interface" option in the Setup menu. All you need to do is put the image you would like to use on a USB flash drive and plug it into the 5210's USB port, the image must be JPEG and stored in a folder on the drive. The DNX-5120 will not warp images to meet the resolution size of the screen. It will, however, raster the image to meet either the vertical or horizontal screen resolution; whichever is closest to the images' size ratio. In order to meet the full resolution of the screen an image will need to be manually resized to 480x250 pixels. Although the actual resolution is 480 x 234, if you load a graphic at the exact resolution, you will see bars at the top and bottom of the screen.

To display your background image only and none of the user interface buttons, select the audio source you wish to listen to. Then press the src button on the left hand side of the head unit. Now press and hold the select source soft button in the top left hand of the screen. Your user interface should disappear and all that will be displayed will be your background image. To get your user interface buttons back, simply tap the screen anywhere.

USB Hubs

USB Hubs cannot be used with the DNX-5120. However, a USB Hub can be used to allow the connection of an iPod as well as a USB storage device simultaneously, however the DNX-5120 will not actively read data from multiple devices at the same time..

HD radio presets

When using the HD Radio adapter (KTC-HR200), some users have reported that the radio presets are not saved when the car is turned off and back on again. Kenwood attributes this problem to outdated software that can not be updated at home. Unit can be sent in to a service center to be updated and resolve preset loss problem..

Mini-USB port

The mini-USB port found on the back of the DNX-5120 is used to connect the GTM-10 FM receiver navigation traffic module. The mini usb at the rear of the device can be used as an efficient way to upload custom maps to the garmin system. This can only be done using the mapsource software from Garmin

Settings Amnesia

Setting data loss can occur on navigation and main unit software if the power level drops too low or is interrupted when the unit is in a certain state. This can be caused when starting your engine - particularly Diesels. The settings for the main unit software and sound stage settings can be memorised and reset when this happens. If this happens to the navigation module, it will revert the user back to the initial setup, i.e. country and language selection and your recent finds etc will be lost. - there are no options to store preferences in a backup file for this part. The Navigation or Main Unit software can lock up independently. i.e. menu or display frozen but playback or navigation continues. To avoid this every happening, simply turn the unit off before you start the engine. -Its the hesitation on startup for the glow-plugs heating that tends to make this worse on Diesels.

5120 and 5220 Differences

The majority of the system is the same, the firmware is identical and the connections are the same across these models. The largest noticeable difference is that XM Radio is not available in the UK or Europe, instead the 'equivalent' system for these services is DAB (digital audio broadcasting). This leads to different hardware requirements because DAB is land-based like FM rather than satellite based which would have been far better. The 5220 has FM traffic built-in to the navigation module, but are otherwise the same.

Custom Points of Interest

You can use Garmin POI editor to enter custom POI's or convert them from those used by TOMTOM etc. Its possible to convert complete police cash point databases that warn you for zones and particular cameras.

Chapter 13

FM Transmitter

Belkin TuneCast transmitter, for use with any device which has a 3.5mm headphone jack. Frequency range is 88.1 - 88.3 - 88.5 - 88.7 MHz

Belkin TuneCastII FM Transmitter with a modified antenna connected to a fifth generation iPod video.

An **FM transmitter** is a portable device that plugs into the headphone jack or proprietary output port of a portable audio or video device, such as a portable media player, CD player, or satellite radio system. The sound is then broadcast through the transmitter, and plays through an FM broadcast band frequency. Purposes for an FM transmitter include playing music from a device through a car stereo, or any radio.

The FM-transmitter plugs into the audio output of audio devices and converts the audio output into an FM radio signal, which can then be picked up by appliances such as car or portable radios. Most devices on the market typically have a short range of up to 30 feet (9 meters) with any average radio (up to about 75 feet (23 meters) with a very good radio under perfect conditions) and can broadcast on any FM frequency from 76.0 to 108.0 MHz (or 88.1 to 107.9 in the US). Some lower-cost transmitters are hard-wired to the 87.7–91.9 MHz band allocated to educational broadcasts in the United States, or a certain other smaller range of frequencies.

FM transmitters are usually battery driven, but some use the cigarette lighter socket in cars, or draw their power from the device itself. They are typically used with portable audio devices such as CD or MP3 players, but are also used to broadcast other outputs (such as that from a computer sound card) throughout a home or other building.

Limitations

- The relatively low power output of FM transmitters sometimes makes it unsuitable for use in some large urban areas because of the number of other radio signals. This is compounded by the fact that strong FM signals can bleed over into neighboring frequencies making the frequencies unusable with the transmitter. Removing a car's radio antenna has been found to significantly improve transmitter reception.
- Some models which connect via ports other than the headphone jack have no means of controlling the volume, which can force the sound to transmit out from the device harshly (causing over modulation, audio distortion and possible radio interference), or too low. In theory a device could use an automatic level control or audio limiter circuit to overcome this problem although there are few (if any) devices with such a facility available out on the market yet.

European legality of FM transmitters

The European Union's Radio Spectrum body the ERO (European Radiocommunications Office) has recently introduced a recommendation document (Table/Annex 13) for Member States to include Transmitters in the FM Band for Music Devices. The underlying specification suggests that the radio transmitter will only emit a maximum of 50 nanowatts Effective radiated power. It is not known what the current "iTrip" device emits although it is known that some devices supposedly manufactured to the US "FCC Part 15" standard emit considerably more. It also has to be ratified and entered into law in each European State, meaning that consultation will normally take place with the users of the spectrum in each country, a protracted and sometimes lengthy process. Until the recommendation is put in place and the law in the country of residence changed, an FM transmitter remains illegal to operate in many EU countries. Due to the minuscule range of these devices the existing legislation is rarely enforced against end users, although retailers in some jurisdictions have been threatened with prosecution.

Within the European Radiocommunications Office in the case the of the Members States that also belong to the European Union the situation is as follows. In 2006, the legislative powers for harmonisation of the technical conditions for use of spectrum for a wide variety of short-range devices, including applications such as alarms, local communications equipment, door openers and medical implants were transferred from the EU Member States to the European Union by Decision of the European Commission 2006/771/EC. Therefore European States no longer have legislative powers in this field, but the powers to police and impose sanctions for non-respect of this EU acts remain in the hands of the Member States. Following the recommendation of the European Radiocommunications Office, by Decision of the

European Commission 2009/381/CE amending Decision 2006/771/EC on harmonisation of the radio spectrum for use by short-range devices , in the frequencies of 87,5-108 MHz, it is allowed to use micro FM transmitters of less than 50 nanowatts Effective radiated power. Since then, these FM transmitters are automatically allowed to enter and being marketed in the territory of the European Union for the use of consumers, as long as they have the CE mark. For countries that belong to the European Radiocommunications Office but are not Member States of the European Union, national law applies and reference has to be made to legal procedures of each country.

UK legality developments

Regulations to legalise the use of certain types of FM transmitter came into force on 8 December 2006. From the end of 2006 the iTrip and other FM transmitters can be used without licence in the United Kingdom. To be legal, it must carry a CE mark which indicates their approval for sale in the European Union. Some FM transmitters have been manufactured for sale and use specifically in the US. These devices do not carry a CE mark and will remain illegal to use in the UK.

The new Regulations set out the technical specifications for legal devices. This is to minimise the risk of interference to other radio devices. In particular, the Regulations set a 50 nanoWatts power limit for legal devices, which limits the distance at which they can broadcast to up to 8 metres.

The changes to the Wireless Telegraphy Act 1949 were announced in a statement from Ofcom.

Use of FM transmitters is now governed by Wireless Telegraphy Exemption Regulations

Models

There are several universal models, as well as those specifically designed for and by certain leading brands; for instance, Griffin Technology manufactures the iTrip which can exclusively be used on iPods. Other examples of FM transmitters are Whole House FM Transmitter, Arkon's SoundFeeder, My FM Station's models, or Belkin's FM TuneCast. Belkin manufactures a premium FM transmitter for iPods called the TuneBase FM with ClearScan. This device mounts an iPod on a sturdy flexible arm (which encases the fm transmitter and power connectors) and allows the iPod to be charged from a car cigarette lighter or power outlet.

Fourth-generation iPod with iTrip.

Most electronic retail stores sell several different models of FM transmitter, including generic brands, which may vary greatly in price, even though quality of audio is indistinguishable. However, the signal strength varies. Even though several models of MP3 player have built-in FM receivers; other models have had built-in FM transmitters to eliminate the need for a separate device. Some cheaper brand units can exhibit very poor audio quality with sibilance (distorted T and S sounds) and poor stereo imaging.

Chapter 14

Telematics

Telematics typically is any integrated use of telecommunications and informatics, also known as ICT (Information and Communications Technology). Hence the application of telematics is with any of the following:

Lexus Gen V navigation system

- The technology of sending, receiving and storing information via telecommunication devices in conjunction with effecting control on remote objects.

- The integrated use of telecommunications and informatics, for application in vehicles and with control of vehicles on the move.
- Telematics includes but is not limited to Global Positioning System technology integrated with computers and mobile communications technology in automotive navigation systems.
- Most narrowly, the term has evolved to refer to the use of such systems within road vehicles, in which case the term **vehicle telematics** may be used.

In contrast *telemetry* is the transmission of measurements from the location of origin to the location of computing and consumption, especially without effecting control on the remote objects. Telemetry is typically applied in testing of flight objects.

Although the majority of devices that integrate telecommunications and information technology are not vehicles but rather mobile phones and the like, their use is not included in telematics.

Vehicle telematics

The etymology of *telematics*, as determined by Automotive Telematics author and academic Dennis Foy, is from the Greek "tele" ('far away', especially in relation to the process of producing or recording) and ~Matos (a derivative of the Greek machinari, or contrivance, usually taken in this context to mean 'of its own accord'). As combined, the term "telematics" describes the process of long-distance transmission of computer-based information. It was first introduced in French by Simon Nora and Alain Minc in *L'informatisation de la Société* (La Documentation Française, 1978)

Telematics —

1. The convergence of telecommunications and information processing, the term later evolved to refer to automation in automobiles, such as the invention of the emergency warning system for vehicles. GPS navigation, integrated hands-free cell phones, wireless safety communications and automatic driving assistance systems all are covered under the telematics umbrella.
2. The science of **Tele**communications and Infor**matics** applied in wireless technologies and computational systems. 802.11p, the IEEE standard in the 802.11 family and also referred to as Wireless Access for the Vehicular Environment (WAVE), is the primary standard that addresses and enhances Intelligent Transportation System.
3. Emad Isaac, CTO of the Morey Corporation defines Telematics as "The potential for collection, aggregation, and storage of pertinent data that can be digested locally, or post-processed remotely." While this definition suggests a more universally applicable technology as a superset of M2M (Machine to Machine) connectivity, and as part of an "intelligent network of connected things", the term is rare outside the vehicle market.

Practical applications of vehicle telematics

When used in a commercial environment vehicle telematics can potentially be a powerful and valuable tool to improve the efficiency of an organization. Some practical applications of vehicle telematics include;

Telematics education

A project entitled the European Automotive Digital Innovation Studio (EADIS) has been awarded 400,000 Euros from the European commission under its Leonardo programme. EADIS will use a virtual work environment called the Digital Innovation Studio to train and develop professional designers in the automotive industry in the impact and application of 'vehicle telematics' so that they may integrate new technologies into future products within the automotive industry.

Leonardo da Vinci is a European Community programme which aims to support national training strategies through funding a range of transnational partnership projects aimed at improving quality, fostering innovation and promoting the European dimension in vocational training. The programme promotes transnational projects based on co-operation between the various players in vocational training - training bodies, vocational schools, universities, businesses, chambers of commerce, etc. - in an effort to increase mobility, to foster innovation and to improve the quality of training. The Leonardo da Vinci programme aims at helping people improve their skills throughout their lives.

"The European automotive industry is losing competitiveness as challengers from lower-cost economies have increased their share of world automotive markets" (CLEPA, European Association of automotive supplier's White paper 2005). As a European solution to this problem, EADIS will develop training and infrastructure to enable European companies to operate more innovatively and efficiently.

This project is executed in partnership with:

- Coventry University (CEPAD), UK
- Oulu University of Applied Sciences, Finland
- Munster University of Applied Sciences, Germany
- Turin Polytechnic, Italy
- Technical University of Delft, the Netherlands

An Advisory panel made up of industry representatives including RDM automotive, Ricardo and MIRA has been set up to evaluate the project. All the partners are looking forward to developing the project and using it as a platform for building relationships and collaborating internationally with other universities and industry partners.

Vehicle tracking

Vehicle tracking is a way of monitoring the location, movements, status and behaviour of a vehicle or fleet of vehicles. This is achieved through a combination of a GPS(GNSS) receiver and an electronic device (usually comprising a GSM GPRS modem or SMS sender) installed in each vehicle, communicating with the user (dispatching, emergency or co-ordinating unit) and PC- or web-based software. The data are turned into information by management reporting tools in conjunction with a visual display on computerised mapping software. Vehicle tracking systems may also use odometry or dead reckoning as an alternative or complementary means of navigation.

Trailer tracking

Trailer tracking is the technology of tracking the movements and position of an articulated vehicle's trailer unit, through the use of a location unit fitted to the trailer and a method of returning the position data via mobile communication network or geostationary satellite communications, for use through either PC- or web-based software.

Cold store

Cold store freight trailers that are used to deliver fresh or frozen foods are increasingly incorporating telematics to gather time-series data on the temperature inside the cargo container, both to trigger alarms and record an audit trail for business purposes. An increasingly sophisticated array of sensors, many incorporating RFID technology, are being used to ensure that temperature throughout the cargo remains within food-safety parameters.

Fleet management

Fleet management is the management of a company's vehicle fleet. Fleet management includes the management of ships and or motor vehicles such as cars, vans and trucks. Fleet (vehicle) Management can include a range of Fleet Management functions, such as vehicle financing, vehicle maintenance, vehicle telematics (tracking and diagnostics), driver management, fuel management and health & safety management. Fleet Management is a function which allows companies which rely on transportation in their business to remove or minimize the risks associated with vehicle investment, improving efficiency, productivity and reducing their overall transportation costs, providing 100% compliancy with government legislation and Duty of Care obligations. These functions can either be dealt with by an in-house Fleet Management department or an outsourced Fleet Management provider.

The Association of Equipment Management Professionals (AEMP) successfully developed the industry's first Telematic Standard.

In 2008, AEMP brought together the major construction equipment manufacturers and telematics providers in the heavy equipment industry to discuss the development of the industry's first telematics standard. Following agreement from Caterpillar, Volvo CE, Komatsu, and John Deere Construction & Forestry to support such a standard, the AEMP formed a standards development subcommittee, chaired by Pat Crail CEM, to develop the standard,. This committee consisted of developers provided by the Caterpillar/Trimble joint venture known as Virtual Site Solutions, Volvo CE, and John Deere. Will McFadyen of McFadyen & Associates provided expertise derived through years of integrating telematics data from various providers into a wide variety of customer fleet management, estimating, and accounting systems. This group worked from February 2009 through September 2010 to develop the industry's first standard for the delivery of telematics data.

The result, the AEMP Telematics Data Standard V1.1, was released in 2010 and officially went live on October 1st, 2010. As of November 1, 2010, Caterpillar, Volvo CE, John Deere Construction & Forestry, OEM Data Delivery, and Navman Wireless are able to support customers with delivery of basic telematics data in a standard xml format. Komatsu, Topcon, and others are finishing beta testing and have indicated that they will be able to support customers before the end of 2010.

The AEMP's telematics data standard was developed to allow end users to integrate key telematics data (operating hours, location, fuel consumed, and odometer reading where applicable) into their existing fleet management reporting systems. As such, the standard was primarily intended to facilitate importation of these data elements into enterprise software systems such as those used by many medium to large construction contractors. Prior to the standard, end users had few options for integrating this data into their reporting systems in a mixed-fleet environment consisting of multiple brands of machines and a mix of telematics-equipped machines and legacy machines (those without telematics devices where operating data is still reported manually via pen and paper). One option available to machine owners was to visit multiple websites to manually retrieve data from each manufacturer's telematics interface and then manually enter it into their fleet management program's database. This option was cumbersome and labor-intensive.

A second option was for the end user to develop an API (Application Programming Interface), or program, to integrate the data from each telematics provider into his or her database. This option was quite costly, as each telematics provider had a different procedure for accessing and retrieving the data and the data format varied from provider to provider. This option automated the process, but because each provider required a unique, custom API to retrieve and parse the data, it was an expensive option. in addition, another API had to be developed any time another brand of machine or telematics device was added to the fleet.

A third option for mixed-fleet integration was to replace the various factory-installed telematics devices with devices from a third party telematics provider. Although this solved the problem of having multiple data providers requiring unique integration methods, this was by far the most expensive option. In addition to the expense, many of the third-party devices available for construction equipment are unable to access data directly from the machine's electronic control modules (ECMs), or computers, and as such are more limited than the device installed by the OEM (Cat, Volvo, Deere, Komatsu, etc) in the data they are able to provide. In some cases, these devices are limited to location and engine run time, although they are increasingly able to accommodate a number of add-on sensors to provide additional data.

The AEMP Telematics Data Standard provides a fourth option. By concentrating on the key data elements that drive the majority of fleet management reports (hours, miles, location, fuel consumption), making those data elements available in a standardized xml format, and standardizing the means by which the document is retrieved, the standard allows the end user to use one API to retrieve data from any participating telematics provider. Because one API can retrieve data from any participating telematics provider, as opposed to the unique API for each provider that was required previously, integration development costs are greatly reduced.

Satellite navigation

Satellite navigation in the context of vehicle telematics is the technology of using a GPS and electronic mapping tool to enable the driver of a vehicle to locate a position, then route plan and navigate a journey.

Mobile data and mobile television

Mobile data is use of wireless data communications using radio waves to send and receive real time computer data to, from and between devices used by field based personnel. These devices can be fitted solely for use while in the vehicle (Fixed Data Terminal) or for use in and out of the vehicle (Mobile Data Terminal).

Mobile data can be used to receive TV channels and programs, in a similar way to mobile phones, but using LCD TV devices.

Wireless vehicle safety communications

Wireless vehicle safety communications telematics aid in car safety and road safety. It is an electronic sub-system in a car or other vehicle for the purpose of exchanging safety information, about such things as road hazards and the locations and speeds of vehicles, over short range radio links. This may involve temporary ad hoc wireless local area networks.

Wireless units will be installed in vehicles and probably also in fixed locations such as near traffic signals and emergency call boxes along the road. Sensors in the cars and at the fixed locations, as well as possible connections to wider networks, will provide the information, which will be displayed to the drivers in some way. The range of the radio links can be extended by forwarding messages along multi-hop paths. Even without fixed units, information about fixed hazards can be maintained by moving vehicles by passing it backwards. It also seems possible for traffic lights, which one can expect to become smarter, to use this information to reduce the chance of collisions.

Further in the future, it may connect directly to the adaptive cruise control or other vehicle control aids. Cars and trucks with the wireless system connected to their brakes may move in convoys, to save fuel and space on the roads. When any column member slows down, all those behind it will automatically slow also. There are also possibilities that need less engineering effort. A radio beacon could be connected to the brake light, for example.

Network ideas are scheduled for test in fall 2008, in Europe where radio frequency bandwidth has been allocated. The 30 MHz allocated is at 5.9 GHz, and unallocated bandwidth at 5.4 GHz may also be used. The standard is IEEE 802.11p, a low latency form of the Wi-Fi local area network standard. Similar efforts are underway in Japan and the USA.

Emergency warning system for vehicles

Telematics technologies are self-orientating open network architecture structure of variable programmable intelligent beacons developed for application in the development of intelligent vehicles — with target intent to accord (blend, or mesh) warning information with surrounding vehicles in the vicinity of travel, intra-vehicle, and infrastructure. Emergency warning system for vehicles telematics particularly developed for international harmonisation and standardisation of vehicle-to-vehicle — infrastructure-to-vehicle — and vehicle-to-infrastructure real-time Dedicated Short Range Communication (DSRC) systems.

Telematics most commonly relate to computerised systems that update information at the same rate as they receive data, enabling them to direct or control a process such as an instantaneous autonomous warning notification in a remote machine or group of machines. By use of telematics as applied to intelligent vehicle technologies, instantaneous direction travel cognizance of a vehicle may be transmitted in real-time to surrounding vehicles traveling in the local area of vehicles equipped (with EWSV) to receive said warning signals of danger.

Intelligent vehicle technologies

Telematics comprise electronic, electromechanical, and electromagnetic devices — usually silicon micromachined components operating in conjunction with computer controlled devices and radio transceivers to provide precision repeatability functions (such as in robotics artificial intelligence systems) emergency warning validation performance reconstruction.

Intelligent vehicle technologies commonly apply to car safety systems and self-contained autonomous electromechanical sensors generating warnings that can be transmitted within a specified targeted area of interest, say within 100 meters of the emergency warning system for vehicles transceiver. In ground applications, intelligent vehicle technologies are utilized for safety and commercial communications between vehicles or between a vehicle and a sensor along the road.

On November 3, 2009 the most advanced Intelligent Vehicle concept car was demonstrated in New York City. A 2010 Toyota Prius became the first LTE Connected Car. The demonstration was provided by the NG Connect project, a collaboration of automotive telematic technologies designed to exploit in-car 4G wireless network connectivity.

Car clubs

Telematics technology has allowed car clubs to emerge, such as City Car Club in the UK. Telematics-enabled computers allow organisers to track members' usage and bill them on a pay-as-you-drive. Car Clubs such as Australia's Charter Drive use telematics to monitor and report on vehicle use within pre-defined geofence areas, in order to demonstrate the reach of their transit media car club fleet.

Auto insurance

The basic idea of telematic auto insurance is that a driver's behavior is monitored directly while the person drives and this information is transmitted to an insurance company. The insurance company then assesses the risk of that driver having an accident and charges insurance premiums accordingly. A driver who drives long distance at high speed, for example, will be charged a higher rate than a driver who drives short distances at slower speeds.

Telematic auto insurance was independently invented and patented by a major U.S. auto insurance company, Progressive Auto Insurance U.S. Patent 5,797,134 and a Spanish independent inventor, Salvador Minguijon Perez (European Patent EP0700009B1). The Progressive patents cover the use of a cell phone and GPS to track movements of a car. The Perez patents cover monitoring the car's engine control computer to determine distance driven, speed, time of day, braking force, etc. Ironically, Progressive is developing the Perez technology in the US and European auto insurer Norwich Union is developing the Progressive technology for Europe.

Trials conducted by Norwich Union in 2005 have found that young drivers (18 to 23 year olds) signing up for telematic auto insurance have had a 20% lower accident rate than average.

Recent theoretical economic research on the social welfare effects of Progressive's telematics technology business process patents have questioned whether the business process patents are pareto efficient for society. Preliminary results suggest that it is not, but more work is needed.