Broadcast Engineering

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Occupation

Broadcast engineer

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	Outside broadcast engineer
	Remote broadcast engineer
Type	profession

Description

Competencies	Technical knowledge, Management skills, Professionalism
Fields of employment	Radio, television, military
Related jobs	Technologist, RF engineer, engineering technician, Technical operator

Broadcast engineering is the field of electrical engineering, and now to some extent computer engineering and information technology, which deals with radio and television broadcasting. Audio engineering and RF engineering are also essential parts of broadcast engineering, being their own subsets of electrical engineering.

Broadcast engineering involves both the studio end and the transmitter end (the entire airchain), as well as remote broadcasts. Every station has a broadcast engineer, though one may now serve an entire station group in a city, or be a contract engineer who essentially freelances his services to several stations (often in small media markets) as needed.

Duties

Modern duties of a broadcast engineer include maintaining broadcast automation systems for the studio and automatic transmission systems for the transmitter plant. There are also important duties regarding radio towers, which must be maintained with proper lighting and painting. Occasionally a station's engineer must deal with complaints of RF interference, particularly after a station has made changes to its transmission facilities.

Titles

Broadcast engineers may have varying titles depending on their level of expertise and field specialty. Some widely used titles include:

- Broadcast design engineer
- Broadcast systems engineer
- Broadcast IT engineer
- Broadcast IT systems engineer
- Broadcast network engineer
- Broadcast maintenance engineer
- Video broadcast engineer
- TV studio broadcast engineer
- Outside broadcast engineer
- Remote broadcast engineer

Qualifications

Broadcast engineers may need to possess some or all of the following degrees, depending on the broadcast technical environment. If one of the formal qualifications is not present, a related degree or equivalent professional experience is desirable.

- Degree in electrical engineering
- Degree in electronic engineering
- Degree in telecommunications engineering
- Degree in computer engineering
- Degree in management information system
- Degree in broadcast technology

Knowledge

Broadcast engineers are generally required to have knowledge in the following areas, from conventional video broadcast systems to modern Information Technology:

- Conventional broadcast
    - Audio/Video instrumentation measurement
    - Baseband video – standard / high-definition
    - Broadcast studio acoustics
    - Television studios - broadcast video cameras and camera lenses
    - Production switcher (Video mixer)
    - Audio mixer

- Broadcast IT
    - Video compression - DV25, MPEG, DVB or ATSC (or ISDB)
    - Digital server playout technologies. - VDCP, Louth, Harris, control protocols
    - Broadcast automation
    - Disk storage – RAID / NAS / SAN technologies.
    - Archives – Tape archives or grid storage technologies.
    - Computer networking
    - Operating systems – Microsoft Windows / Mac OS / Linux / RTOS
    - Post production – video capture and non-linear editing systems (NLEs).

- RF
    - RF satellite uplinking – High-powered amplifiers (HPA)
    - RF communications satellite downlinking – Band detection, carrier detection and IRD tuning, etc.
    - RF transmitter maintenance - IOT UHF transmitters, solid state VHF transmitters, antennas, transmission line, high power filters, digital modulators.

- Health and safety
    - Occupational safety and health
    - Fire suppression systems like FM 200.
    - Basic structural engineering
    - RF hazard mitigation

Above mentioned requirements vary from station to station.

Digital engineering

The conversion to digital broadcasting means broadcast engineers must now be well-versed in digital television and digital radio, in addition to analogue principles. New equipment from the transmitter to the radio antenna to the receiver may be encountered by engineers new to the field. Furthermore, modern techniques place a greater demand on an engineer's expertise, such as sharing broadcast towers or radio antennas among different stations (diplexing).

Digital audio and digital video have revolutionized broadcast engineering in many respects. Broadcast studios and control rooms are now already digital in large part, using non-linear editing and digital signal processing for what used to take a great deal of time or money, if it was even possible at all. Mixing consoles for both audio and video are continuing to become more digital in the 2000s, as is the computer storage used to keep

digital media libraries. Effects processing and TV graphics can now be realized much more easily and professionally as well.

Other devices used in broadcast engineering are telephone hybrids, broadcast delays, and dead air alarms.

Engineering services

Broadcast stations often call upon outside engineering services for certain needs. For example, because structural engineering is generally not a direct part of broadcast engineering, tower companies usually design broadcast towers.

Other companies specialize in both broadcast engineering and broadcast law, which are both essential when making an application to a national broadcasting authority for a construction permit or broadcast license. This is especially critical in North America, where stations bear the entire burden of proving that their proposed facilities will not cause interference and are the best use ot the radio spectrum. Such companies now have special software that can map projected radio propagation and terrain shielding, as well as lawyers that will defend the applications before the U.S. Federal Communications Commission, Canadian Radio-television and Telecommunications Commission (CRTC), or the equivalent authorities in some other countries.

Chapter 1

Audio Engineering and RF Engineering

Audio Engineering

Audio engineering is a skilled trade that deals with the use of machinery and equipment for the recording, mixing and reproduction of sounds. The field draws on many artistic and vocational areas, including electronics, acoustics, psychoacoustics, and music. An audio engineer is proficient with different types of recording media, such as analog tape, digital multitrack recorders and workstations, and computer knowledge. With the advent of the digital age, it is becoming more and more important for the audio engineer to be versed in the understanding of software and hardware integration from synchronization to analog to digital transfers.

Audio engineering concerns the creative and practical aspects of sounds and music, in contrast with the formal engineering discipline known as acoustical engineering. Producer, engineer, mixer Phil Ek has described audio engineering as the "technical aspect of recording—the placing of microphones, the turning of pre-amp knobs, the setting of levels. The physical recording of any project is done by an engineer... the nuts and bolts." Many recording engineers also invented new technology, equipment and techniques, to enhance the process and art.

Lexical dispute

The expressions "audio engineer" and "sound engineer" are ambiguous. Such terms can refer to a person working in sound and music production, as well as to an engineer with a degree who designs professional equipment for these tasks.

Individuals who design acoustical simulations of rooms, shaping algorithms for digital signal processing and computer music problems, perform institutional research on sound, and other advanced fields of audio engineering are most often graduates of an accredited college or university, or have passed a difficult civil qualification test.

Certain jurisdictions specifically prohibit the use of the title engineer to any individual not a registered member of the local professional engineering body, responsible for regulating ethics and the safety of the public with respect to the engineering profession, which often may not include audio engineers. In such situations they are formally referred to as audio technicians.

Other languages, such as German and Italian, have different words to refer to these activities. For instance, in German, the *Tontechniker* (audio technician) is the one who operates the audio equipment and the *Tonmeister* (sound master) is a person who creates recordings or broadcasts of music who is both deeply musically trained (in 'classical' and non-classical genres) and who also has a detailed theoretical and practical knowledge of virtually all aspects of sound, whereas the *Toningenieur* (audio engineer) is the one who designs, builds and repairs it.

Practitioners

An engineer at an audio console.

An audio engineer is someone with experience and training in the production and manipulation of sound through mechanical (analog) or digital means. As a professional title, this person is sometimes designated as a sound engineer or recording engineer instead. A person with one of these titles is commonly listed in the credits of many commercial music recordings (as well as in other productions that include sound, such as movies).

Audio engineers are generally familiar with the design, installation, and/or operation of sound recording, sound reinforcement, or sound broadcasting equipment, including large and small format consoles. In the recording studio environment, the audio engineer records, edits, manipulates, mixes, and/or masters sound by technical means in order to realize an artist's or record producer's creative vision. While usually associated with music production, an audio engineer deals with sound for a wide range of applications, including post-production for video and film, live sound reinforcement, advertising, multimedia, and broadcasting. When referring to video games, an audio engineer may also be a computer programmer.

In larger productions, an audio engineer is responsible for the technical aspects of a sound recording or other audio production, and works together with a record producer or director, although the engineer's role may also be integrated with that of the producer. In smaller productions and studios the sound engineer and producer is often one and the same person.

In typical sound reinforcement applications, audio engineers often assume the role of producer, making artistic and technical decisions, and sometimes even scheduling and budget decisions.

Different professional branches

There are four distinct steps to commercial production of a recording: Recording, editing, mixing, and mastering. Typically, each is performed by a sound engineer who specializes only in that part of production.

- Studio engineer – an engineer working within a studio facility, either with a producer or independently
- Recording engineer – engineer who records sound.
- Assistant engineer – often employed in larger studios, allowing them to train to become full-time engineers. They often assist full-time engineers with microphone setups, session breakdowns and in some cases, rough mixes.
- Mixing engineer – a person who creates mixes of multi-track recordings. It is common for a commercial record to be recorded at one studio and later mixed by different engineers in other studios.
- Mastering engineer – typically the person who mixes the final stereo tracks (or sometimes just a few tracks or stems) that the mix engineer produces. The mastering engineer makes any final adjustments to the overall sound of the record in the final step before commercial duplication. Mastering engineers use principles of equalization and compression to affect the coloration of the sound.
- Game audio designer engineer – deals with sound aspects of game development.

- Live sound engineer – a person dealing with live sound reinforcement. This usually includes planning and installation of speakers, cabling and equipment and mixing sound during the show. This may or may not include running the foldback sound. A live/sound reinforcement engineer hears musical material and tries to correlate that sonic experience with system performance.
- Foldback or Monitor engineer – a person running foldback sound during a live event. The term "foldback" is outdated and refers to the practice of folding back audio signals from the FOH (Front of House) mixing console to the stage in order for musicians to hear themselves while performing. Monitor engineers usually have a separate audio system from the FOH engineer and manipulate audio signals independently from what the audience hears, in order to satisfy the requirements of each performer on stage. In-ear systems, digital and analog mixing consoles, and a variety of speaker enclosures are typically used by monitor engineers. In addition most monitor engineers must be familiar with wireless or RF (radio-frequency) equipment and must interface personally with the artist(s) during each performance.
- Systems engineer – responsible for the design setup of modern PA systems which are often very complex. A systems engineer is usually also referred to as a "crew chief" on tour and is responsible for the performance and day-to-day job requirements of the audio crew as a whole along with the FOH audio system.
- Audio post engineer – a person who edits and mixes audio for film and/or television.
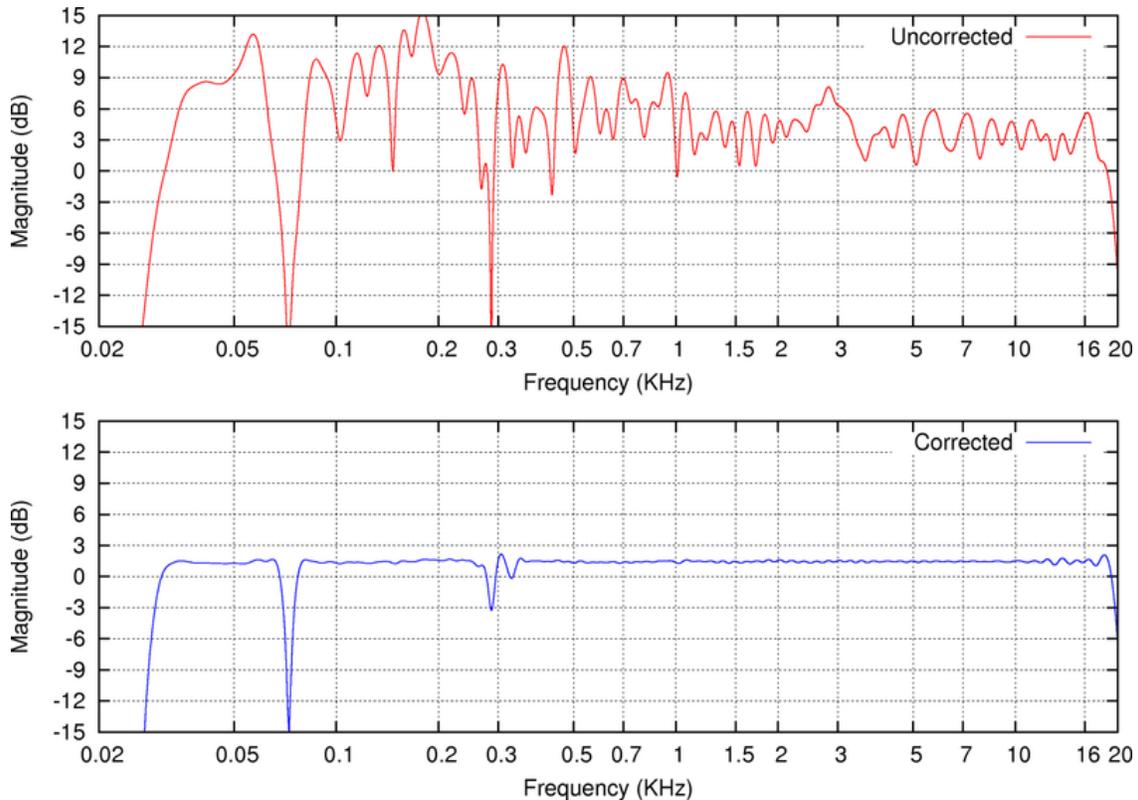
Correcting a room's frequency response.

Education

Audio engineers come from backgrounds such as fine arts, broadcasting, music or electronics. Many colleges and accredited institutions around the world offer degrees in audio engineering, such as a BS in audio production. The University of Miami's Frost School of Music was the first university in the United States to offer a four-year Bachelor of Music degree in Music Engineering Technology. In the last 25 years, some contemporary music schools have initiated audio engineering programs, usually awarding a Bachelor of Music degree to graduates. Additionally, a number of audio engineers are autodidacts with no formal training.

Equipment

Audio engineers in their daily work operate and make use of:

* Mixing consoles
* Microphones
* Signal processors
* Analog-to-digital converters

* Tape machines
* Digital audio workstations
* Music sequencers
* Digital-to-analog converters

* Loudspeakers
* Preamplifiers
* Amplifiers
* Dynamic range compression

RF Engineering

RF Engineering, also known as **R**adio **F**requency Engineering, is a subset of electrical engineering that deals with devices which are designed to operate in the Radio Frequency spectrum. These devices operate within the range of about 3 kHz up to 300 GHz.

RF Engineering is incorporated into almost everything that transmits or receives a radio wave which includes, but is not limited to, Mobile Phones, Radios, WiFi and walkie talkies.

RF Engineering is a highly specialized field. To produce quality results, an in-depth knowledge of Mathematics, Physics, general electronics theory as well as specialized training in propagation and microstrip design may be required. Even with this, the initial design of an RF Circuit usually bears very little resemblance to the final physical circuit produced, as revisions to the design are often required to achieve intended results.

Duties

RF Engineers are specialists in their respective field and can take on many different roles, such as design, installation and maintenance. RF engineers require many years of extensive experience in the area of study. This type of engineer has experience with transmission systems, device design and placement of antennas for optimum

performance. An RF Engineer at a broadcast facility is responsible for maintenance of the stations high power broadcast transmitters, and associated systems. This includes transmitter site emergency power, remote control, main transmission line and antenna adjustments, microwave radio relay STL/TSL links and more. In addition, an RF Design Engineer must be able to understand electronic hardware design, circuit board material, antenna radiation and the effect of interfering frequencies that prevent optimum performance within the piece of equipment being developed. Many notable individuals have contributed to the advancement of RF engineering theory and design including the following:

Guglielmo Marconi, who transmitted the first radio signal across the atlantic. Heinrich Hertz, who developed the unit of measure to describe frequency of a wave. Chris Pinter, who developed a method of improving radio sensitivity through the use of dynamic range software. Phillip H. Smith, who developed a graphical method of calculating impedances, admittances, reflection coefficients and scattering parameters.

Chapter 2

AM Broadcasting

AM broadcasting is the process of radio broadcasting using amplitude modulation.

History

AM was the dominant method of broadcasting during the first eighty years of the 20th century and remains widely used into the 21st.

AM radio began with the first, experimental broadcast on Christmas Eve of 1906 by Canadian experimenter Reginald Fessenden, and was used for small-scale voice and music broadcasts up until World War I. San Francisco, California radio station KCBS claims to be the direct descendant of KQW, founded by radio experimenter Charles "Doc" Herrold, who made regular weekly broadcasts in San Jose, California as early as June 1909. On that basis KCBS has claimed to be the world's oldest broadcast station and celebrated its 100th anniversary in the summer of 2009. The great increase in the use of AM radio came late in the following decade as radio experimentation increased worldwide following World War I. The first licensed commercial radio services began on AM in the 1920s. XWA of Montreal, Quebec (later CFCF, now CINW) claims status as the first commercial broadcaster in the world, with regular broadcasts commencing on May 20, 1920. The first licensed American radio station was started by Frank Conrad, KDKA in Pittsburgh, Pennsylvania. Radio programming boomed during the "Golden Age of Radio" (1920s–1950s). Dramas, comedy and all other forms of entertainment were produced, as well as broadcasts of news and music.

Operation

AM radio technology is simpler than Frequency Modulated (FM) radio, Digital Audio Broadcast (DAB), Satellite Radio or HD (digital) Radio. An AM receiver detects amplitude variations in the radio waves at a particular frequency. It then amplifies changes in the signal voltage to drive a loudspeaker or earphones. The earliest crystal radio receivers used a crystal diode detector with no amplification.

In North American broadcasting practice, transmitter power input to the antenna for commercial AM stations ranges from about 250 watts to 50,000 watts. Experimental licenses were issued for up to 500,000 watts radiated power, for stations intended for wide-area communication during disasters including Cincinnati station WLW, which used such power on occasion before World War II. WLW's superpower transmitter still exists at the station's suburban transmitter site, but it was decommissioned in the early 1940s and no current commercial broadcaster in the US or Canada is authorized for such power levels. Some other countries do authorize higher power operation (for example the Mexican station XERF formerly operated at 250,000 watts). Antenna design must consider the coverage desired and must direct the transmitted signal so as not to interfere with other stations operating on the same or adjacent frequencies.
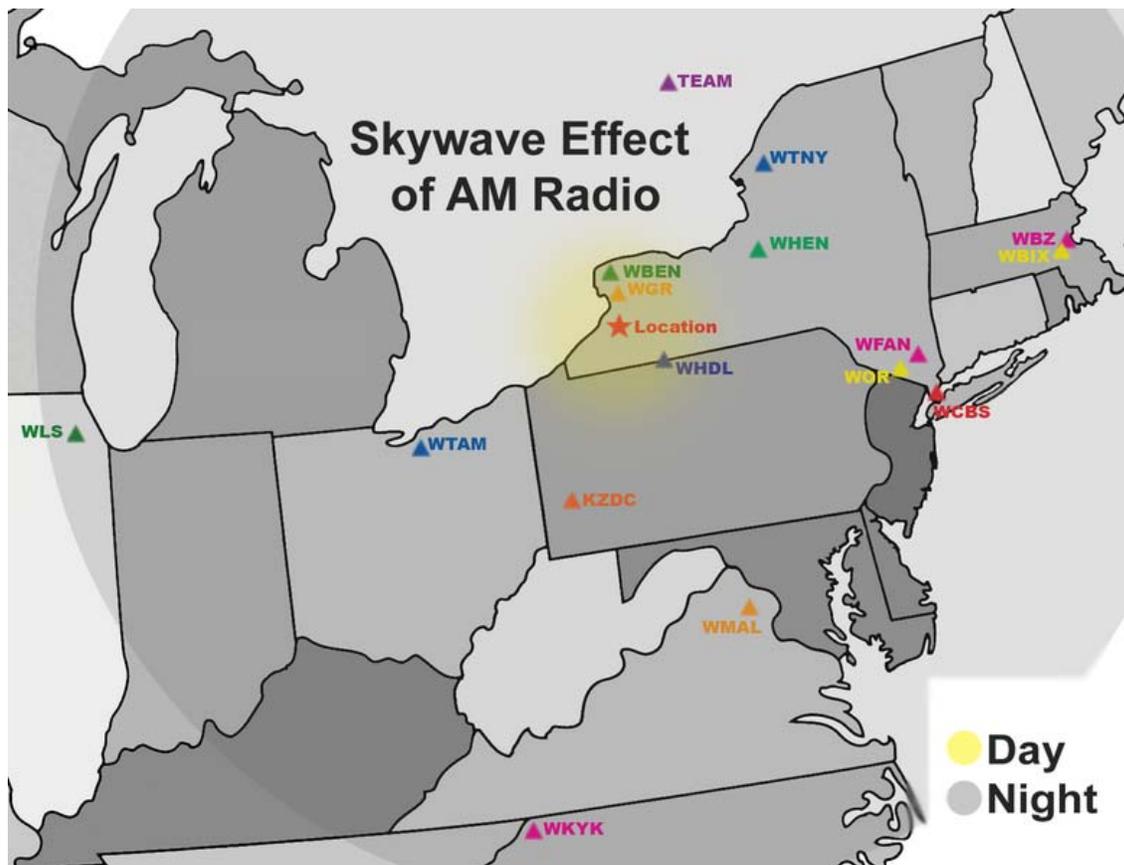
An example of the difference in range of an am radio at different times.

Medium-wave and short-wave radio signals act differently during daytime and nighttime. During the day, AM signals travel by groundwave, diffracting around the curve of the earth over a distance up to a few hundred miles (or kilometers) from the signal transmitter. However, after sunset, changes in the ionosphere cause AM signals to travel by skywave, enabling AM radio stations to be heard much farther from their point of origin than is normal during the day. This phenomenon can be easily observed by scanning an AM radio dial at night. As a result, many broadcast stations are required as a condition of license to reduce their broadcasting power significantly (or use directional antennas) after sunset, or even to suspend broadcasting entirely during nighttime hours. Such stations are commonly referred to as daytimers. In Australia AM stations are not

required to reduce their power at night and consequently stations such as the 50Kw 3LO can be heard in some parts of New Zealand at night.

In the United States and Canada, some AM radio stations are granted clear channel status, meaning that they broadcast on frequencies with few other stations allocated, allowing an extended coverage area. Relatively few stations enjoy clear-channel status. Commercial broadcasters generally rely on the ground-wave coverage only as their target market for advertising.

The hobby of listening to long distance signals is known as DX or DX'ing, from an old telegraph abbreviation for "distance". Several non-profit hobbyist clubs are devoted exclusively to DXing the AM broadcast band, including the National Radio Club and International Radio Club of America. Similarly, people listening to short wave transmissions are SWLing.

Frequency bands

AM radio is broadcast on several frequency bands. The allocation of these bands is governed by the ITU's Radio Regulations and, on the national level, by each country's telecommunications administration (the FCC in the U.S., for example) subject to international agreements.

- *Long wave* is 148.5 kHz–283.5 kHz, with 9 kHz channel spacing generally used. Long wave is used for radio broadcasting in Europe, Africa and parts of Asia (ITU region 1), and is not allocated in the Western Hemisphere. In the United States and Canada, Bermuda and U.S. territories this band is mainly reserved for aeronautics navigational aids, though a small section of the band could theoretically be used for microbroadcasting under the United States Part 15 rules. Due to the propagation characteristics of long wave signals, the frequencies are used most effectively in latitudes north of 50°.
- *Medium wave* is 520 kHz–1,610 kHz. In the Americas (ITU region 2) 10 kHz spacing is used; elsewhere it is 9 kHz. ITU region 2 also authorizes the Extended AM broadcast band between 1610 kHz and 1710 kHz. Medium wave is by far the most heavily used band for commercial broadcasting. This is the "AM radio" that most people are familiar with.
- *Short wave* is 1.711 MHz–30.0 MHz, divided into 15 broadcast bands. Shortwave broadcasts generally use a narrow 5 kHz channel spacing. Short wave is used by audio services intended to be heard at great distances from the transmitting station. The long range of short wave broadcasts comes at the expense of lower audio fidelity. The mode of propagation for short wave is different. AM is used mostly by broadcast services – other shortwave users may use a modified version of AM such as SSB or an AM-compatible version of SSB such as SSB with carrier reinserted.

Frequencies between the broadcast bands are used for other forms of radio communication, and are not broadcast services intended for reception by the general public.

Limitations

Because of its susceptibility to atmospheric and electrical interference, AM broadcasting now attracts mainly talk radio and news programming, while music radio and public radio mostly shifted to FM broadcasting in the late 1970s. However, in the late 1960s and 1970s, top 40 rock and roll stations in the US and Canada such as WABC and CHUM transmitted highly processed and extended audio to 11 kHz, successfully attracting huge audiences. In the UK during the 1980s, BBC Radio 4 (a largely speech channel) had an FM location, whereas BBC Radio 1, a music channel, was confined to AM broadcasts over much of the UK. Frequency response is typically 40 Hz–5 kHz with a 50 dB Signal to noise(S/N) ratio.

The limitation on AM fidelity comes from current receiver design. Moreover, to fit more transmitters on the AM broadcast band in the United States maximum, transmitted audio bandwidth is limited to 10.2 kHz by a National Radio Systems Committee (NRSC) standard adopted by the FCC in June 1989, resulting in a channel occupied bandwidth of 20.4 kHz. The former audio limitation was 15 kHz resulting in a channel occupied bandwidth of 30 kHz.

AM radio signals can be severely disrupted in large urban centres by metal structures, tall buildings and sources of radio frequency interference (RFI) and electrical noise, such as electrical motors, fluorescent lights, or lightning. As a result, AM radio in many countries has lost its dominance as a music broadcasting service, and in many cities is now relegated to news, sports, religious and talk radio stations. Some musical genres – particularly country, oldies, nostalgia and ethnic/world music – survive on AM, especially in areas where FM frequencies are in short supply or in thinly populated or mountainous areas where FM coverage is poor.

Other distribution methods

Stereo transmissions are possible, and hybrid digital broadcast systems are now being used around the world. In the United States, iBiquity's proprietary HD Radio has been adopted and approved by the FCC for medium wave transmissions, while Digital Radio Mondiale is a more open effort often used on the shortwave bands, and can be used alongside many AM broadcasts. Both of these standards are capable of broadcasting audio of significantly greater fidelity than that of standard AM with current bandwidth limitations, and a theoretical frequency response of 0–16 kHz, in addition to stereo sound and text data.

While FM radio can also be received by cable, AM radio generally cannot, although an AM station can be converted into an FM cable signal. In Canada, cable operators that offer FM cable services are required by the CRTC to distribute all locally available AM stations in this manner. In Switzerland a system known as "wire broadcasting" transmits AM signals over telephone lines in the longwave band.

Microbroadcasting

Some microbroadcasters and pirate radio broadcasters, especially those in the United States under the FCC's Part 15 rules, broadcast on AM to achieve greater range than is possible on the FM band. On mediumwave (AM), such radio stations are often found between 1610 kHz and 1710 kHz. Hobbyists also use low-power AM transmitters to provide local programming for antique radio equipment in areas where AM programming is not widely available or is of questionable quality; in such cases the transmitter, which is designed to cover only the immediate property and perhaps nearby areas, is connected to a computer or music player.

Chapter 3

Broadcast Automation

Broadcast automation is the use of technology to automate broadcasting operations. Used either at a station or a network, it can run a facility in the absence of a human operator. They can also run in a "live assist" mode when there are on-air personnel present at the broadcast studio or control room.

The radio transmitter end of the airchain is handled by a separate automatic transmission system (ATS).

History

Originally, many (if not most) broadcast licensing authorities required a licensed operator to run every station at all times, meaning that every DJ had to pass an exam to obtain a license to be on-air, if their duties also required them to ensure proper operation of the transmitter. This was often the case on overnight and weekend shifts when there was no broadcast engineer present, and all of the time for small stations with only a contract engineer on call.

In the U.S., it was also necessary to have an operator on duty at all times in case the Emergency Broadcast System (EBS) was used, as this had to be triggered manually. While there has not been a requirement to relay any other warnings, any mandatory messages from the U.S. president would have had to first be authenticated with a code word sealed in a pink envelope sent annually to stations by the Federal Communications Commission (FCC).

Gradually, the quality and reliability of electronic equipment improved, regulations were relaxed, and no operator had to be present (or even available) while a station was operating. In the U.S., this came about when the EAS replaced the EBS, starting the movement toward automation to assist, and sometimes take the place of, the live disc jockeys (DJs) and radio personalities.

Early analog systems

Harris automation system used at the former WWJQ (now WPNW) in 1993.

Early automation systems were electromechanical systems which used relays. Later systems were "computerized" only to the point of maintaining a schedule, and were limited to radio rather than TV. Music would be stored on reel-to-reel audio tape. Subaudible tones on the tape marked the end of each song. The computer would simply rotate among the tape players until the computer's internal clock matched that of a scheduled event. When a scheduled event would be encountered, the computer would finish the currently-playing song and then execute the scheduled block of events. These events were usually advertisements, but could also include the station's top-of-hour station identification, news, or a bumper promoting the station or its other shows. At the end of the block, the rotation among tapes resumed.

Advertisements, jingles, and the top-of-hour station identification required by law were often on "carts". Short for cartridges, these were endless tapes similar to 8-track tapes, and looked nearly identical as well. A primary difference between carts and 8 track deals with the pinch roller and capstan. The roller was self-contained in an 8-track; carts had a slot for a pinch roller on a spindle which was activated by solenoid upon pressing the start button on the cart machine. This allowed for nearly instantaneous playback start without artifacts. Mechanical carousels would rotate the carts in and out of multiple tape

players as dictated by the computer. Time announcements were provided by a pair of dedicated cart players, with the even minutes stored on one and the odd minutes on the other. This meant an announcement would always be ready to play, even if the minute was changing when the announcement was triggered. The system did require attention throughout the day to change reels as they ran out and reload carts. It became obsolete when a method was developed to automatically rewind and re-cue the reel tapes when they ran out, extending 'walk-away' time indefinitely.

Radio station WIRX may have been one of the world's first completely automated radio stations, built and designed by Brian Brown in 1963 when Brown was only 10 years old. The station broadcast in a classical format, called "More Good Music (MGM)" and featured five minute bottom of the hour news feeds from the Mutual Broadcasting System. The heart of the automation was a 8 x 24 telephone stepping relay which controlled two reel-to-reel tape decks, one twelve inch Ampex machine providing the main program audio and a second RCA seven inch machine providing "fill" music. The tapes played by these machines were originally produced in the MWF's Madison, Wisconsin production facility by WSJM Chief Engineer Richard E. McLemore (and later in-house at WSJM) with sub-audible tones used to signal the end of a song. The stepping relay was programmed by slide switches in the front of the two relay racks which housed the equipment. The news feeds were triggered by a microswitch which was attached to a Western Union clock and tripped by the minute hand of the clock. and then reset the stepping relay. Originally, 30-minute station identification was accomplished by a simulcast switch in the control booth for sister station WSJM-AM, whereupon the disc jockey in the booth would announce "This is WSJM-AM and... (then pressing the momentary contact button) ...WSJM-FM, St. Joseph, Michigan." This only lasted about six months, however, and a standard tape cartridge player was wired in to announce the station identification and triggered by the Western Union clock.

Solidyne GMS200 tape recorder with computer self-adjustment. Argentina 1980-1990

A different technology appeared in 1980 with the analog recorders made by Solidyne, which used a computer-controlled tape positioning system. Four GMS 204 units were controlled from a 6809 microprocessor, with the program stored in a solid-state plug-in memory module. This system has a limited programming time of about eight hours.

Satellite programming often used audible dual-tone multi-frequency signals to trigger events at affiliate stations. This allowed the automatic local insertion of ads and station IDs. Because there are 12 (or 16) tone pairs, and typically four tones were sent in rapid succession (less than one second), more events could be triggered than by sub-audible tones (usually 25 Hz and 35 Hz).

Modern digital systems

Modern systems run on hard disk, where all of the music, jingles, advertisements, voice tracks, and other announcements are stored. These audio files may be either compressed or uncompressed, or often with only minimal compression as a compromise between file size and quality. For radio, these disks are usually in computers, sometimes running their own custom operating systems, but more often running as an application on a stable OS like GNU/Linux, Windows NT or others.

Scheduling was an important advance of these systems, allowing for exact timing. Some systems use GPS satellite receivers to obtain exact atomic time, for perfect synchronization with satellite-delivered programming. Reasonably-accurate timekeeping can also be obtained with the use of Internet protocols like Network Time Protocol.

Automation systems are also more interactive than ever before with digital audio mixing consoles, and can even record from a telephone hybrid to play back an edited conversation with a telephone caller. This is part of a system's live-assist mode.

The use of automation software and voice tracks to replace live DJs is a current trend in radio broadcasting, done by many Internet radio and adult hits stations. Stations can even be voice-tracked from another city far away, now often delivering sound files over the Internet. In the U.S., this is a common practice under controversy for making radio more generic and artificial. Having local content is also touted as a way for traditional stations to compete with satellite radio, where there may be no radio personality on the air at all.
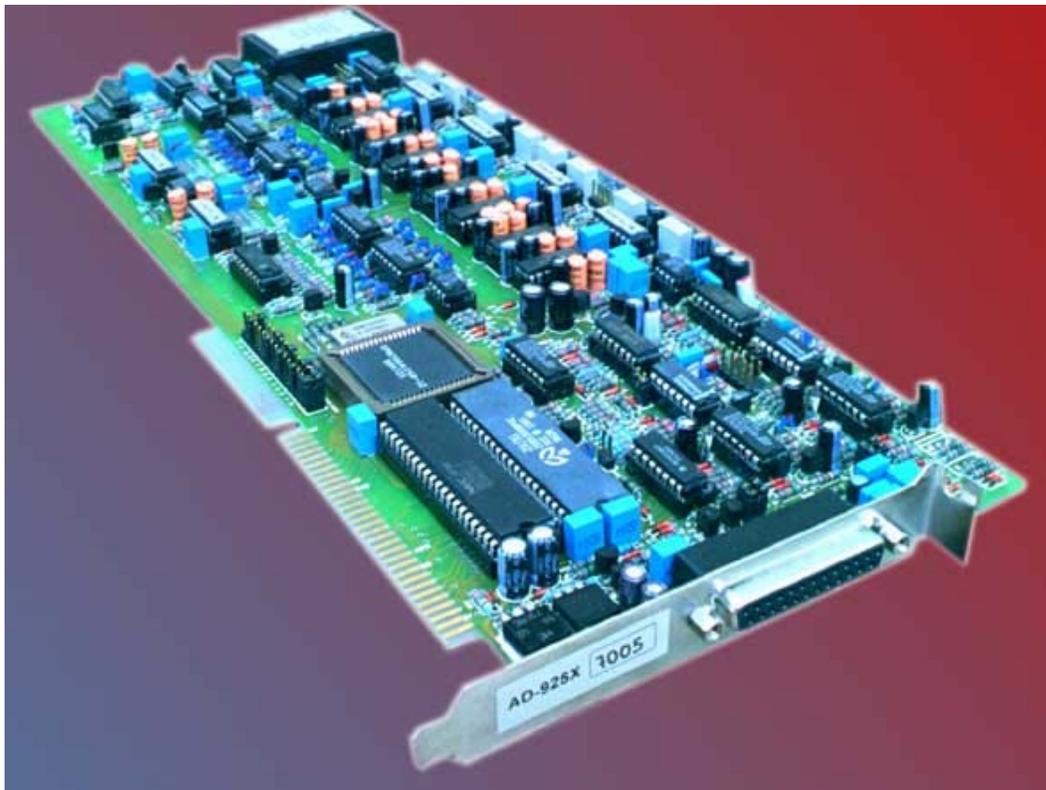
Solidyne 922: The first bit compression card for PC, 1990

A commercially-available, for-sale product named Audicom was introduced by Oscar Bonello in 1989. It is based on psychoacoustic lossy compression, the same principle being used in most modern lossy audio encoders (e.g. MP3, AAC), and it allowed both broadcast automation and recording to hard drives.

Television

In television, automated playout is also becoming more practical as the storage space of hard drives increases. TV shows and commercials, as well as digital on-screen graphics, can all be controlled by computer. These systems can be very extensive, tied-in with parts that allow the "ingest" (as it is called in the industry) of video from satellite networks and electronic news gathering operations and management of the video library, including archival of footage for later use. In ATSC, Programming Metadata Communication Protocol (PMCP) is then used to pass information about the video through the airchain to Program and System Information Protocol (PSIP), which transmits the current electronic program guide information over digital television to the viewer.

Chapter 4

Broadcast Range and Outside Broadcasting

Broadcast Range

A **broadcast range** (also **listening range** or **listening area** for radio, or **viewing range** or **viewing area** for television) is the service area that a broadcast station or other transmission covers via radio waves (or possibly infrared light, which is closely related). It is generally the area in which a station's signal strength is sufficient for most receivers to decode it, however this also depends on interference from other stations.

Legal definitions

The "primary service area" is the area served by a station's strongest signal. The "city-grade contour" is 70 dBμ (decibels relative to one microvolt per meter of signal strength) or 3.16mV/m (millivolts per meter) for FM stations in the United States, according to Federal Communications Commission (FCC) regulations. This is also significant in broadcast law, in that a station must cover its city of license within this area, except for non-commercial educational and low-power stations.

The legally-protected range of a station extends beyond this range, out to the point where signal strength is expected to be 1mV/m for most stations in North America, though for class B1 stations it is 0.7mV/m, and as low as 0.5mV/m for full class B stations (the maximum allowed in densely-populated areas of both Canada and the U.S.).

Practical application

In reality, radio propagation changes along with the weather and tropospheric ducting, and occasionally along with other upper-atmospheric phenomena like sunspots and even meteor showers. Thus, while a broadcasting authority might fix the range to an area with exact boundaries (defined as a series of vectors), this is rarely if ever true. When a

broadcast reaches well outside of its intended range due to unusual conditions, DXing is possible.

The local terrain can also play a major role in limiting broadcast range. Mountain ranges block FM broadcasts, AM broadcasts, and TV broadcasts, and other signals in the VHF and especially UHF ranges, respectively. This terrain shielding occurs when the line of sight is blocked by something through which the radio waves cannot pass, particularly stone. At times this may be moot due to weather, such as when the tall cumulonimbus clouds of a squall line of thunderstorms reflect the signal over the top, like an extremely tall radio tower. Conversely, heavy rain may attenuate the range of even local stations. ATSC digital television is affected by wind and trees (even if not surrounding the transmitter or receiver locations), apparently related to its use of 8VSB modulation instead of COFDM.

AM broadcasting stations have different issues, due to using the mediumwave band. Broadcast range in these stations is determined by ground conductivity, and the proper use and maintenance of grounding radials which act as a ground plane for the mast radiators used. skywave reflects off the ionosphere at a much greater distance above Earth's surface at night. This in turn causes mediumwave, most shortwave, and even longwave stations to travel much further at night, which is the side of the Earth where the solar wind pulls the ionosphere (and magnetosphere) away from the planet, instead of pushing toward it as on the day side. Because of this, many AM stations must cut power or go off-air at night, except for the very earliest stations still grandfathered on clear channels. Border blaster stations in northern Mexico also used this effect, along with very high-power transmitters, to extend their nighttine broadcast ranges well over the US/Mexico border and across most of the United States.

Various broadcast relay stations can help to extend a station's area by retransmitting them on the same or another channel. What is usually called a repeater in amateur radio is called a broadcast translator (different channel) or booster (same channel) in American broadcasting, or the much broader category or rebroadcasters in Canadian broadcasting (which includes more than just the low-power broadcasting used in the U.S.) Boosters are used only within the broadcast range of the parent station, and serve the same function locally as regional and national single-frequency networks do in Europe. Distributed transmission has also undergone tests in the U.S., but to preserve stations' market share in their home media markets, these will be limited to the broadcast area of a single large station. Satellite radio, which is designed for use without a dish, also uses ground repeaters in large cities due to the many obstructions their high-rise buildings cause to the many current and potential customers that are concentrated there.

Edge-of-range issues

Those at the edge of a station's broadcast range will typically notice static in an analog broadcast, while error correction will keep a digital signal clear until it hits the cliff effect and suddenly disappears completely. FM stations may flip back and forth (sometimes annoyingly rapidly when moving) due to the capture effect, while AM stations (including TV video) may overlay or fade with each other.

FM stereo will tend to get static more quickly than the monophonic sound due to its use of subcarriers, so stations may choose to extend the usable part of their range by disabling the stereo generator. Listeners can also choose to disable stereo decoding on the receiver, though loss of the stereo pilot tone causes this to happen automatically. Because this tends to turn on and off when at the threshold of reception, and the threshold is often set too low by the manufacturer's product design, manually disabling this when at the edge of the broadcast range prevents the annoying noisy-stereo/quiet-mono switching.

The same is true of analog TV stereo and second audio programs, and even for color TV, all of which use subcarriers. Radio reading services and other subcarrier services will also tend to suffer from dropouts sooner than the main station.

Technologies are available that allow for switching to a different signal carrying the same radio program when leaving the broadcast range of a station. Radio Data System allows for switching to a different FM or station with the same identifier, or even to (but not necessarily from) an AM station. Satellite radio also is designed to switch seamlessly between repeaters and/or satellite when moving outside the range of one or the other. HD Radio switches back to the analog signal as a fallback when the edge of the digital range is encountered, but the success of this from the listener's perspective depends on how well the station's broadcast engineer has synchronized the two.

Digital versus analog

Digital transmissions require less power to be received clearly than analog ones. The exact figure for various modes depends on how robust the signal is made to begin with, such as modulation, guard interval, and forward error correction. In each of these three factors, the caveat is that a higher data rate means a tradeoff with reduced broadcast range. The hierarchical modulation used on DVB is a unique case, which reduces the range of the full-definition signal, in exchange for an increase in the usable range of the lower-definition part of the video.

Digital stations in North America usually are operated by the same groups as the analog side, and thus operate their own independent facilities. Because of this, the FCC requires U.S. TV stations to replicate their analog coverage with their digital signal as well. However, ATSC digital TV only requires about one-fifth the amount of power to reach the same area on the same channel as analog does. For HD Radio, the figure is only one percent of the station's analog wattage, in part because it is an in-band on-channel method, which uses sidebands that must prevent interference to adjacent channels, especially for older or cheaper receivers which have insufficient sensitivity and/or selectivity.

Outside Broadcasting

Outside broadcasting is the production of television or radio programmes (typically to cover news and sports events) from a mobile television studio. This mobile control room is known as an "Outside Broadcasting Van", "OB Van", "Scanner" (a BBC term), "mobile unit", "remote truck", "live truck", "live eye", or "production truck". Signals from cameras and microphones come into the OB Van for processing and transmission. The term "OB" is almost unheard of in the United States.

Interior

A typical OB Van is usually divided into 5 parts.

- The first and largest part is the production area where the director, technical director, assistant director, character generator operator and producers usually sit in front of a wall of monitors. This area is very similar to a Production control room. The technical director sits in front of the video switcher. The monitors show all the video feeds from various sources, including computer graphics, cameras, video tapes, video servers and slow motion replay machines. The wall of monitors also contains a preview monitor showing what could be the next source on air (does not have to be depending on how the video switcher is set up) and a program monitor that shows the feed currently going to air or being recorded. The dirty feed (feed with graphics) is what is actually transmitted back to the central studio that is controlling the outside broadcast. A clean feed (without the graphics) could be being sent to other trucks for use in their production. The video switcher is usually operated by 1 person called the Technical Director or Vision Mixer in Europe. That person is responsible for putting all the video sources to air as directed to. Behind the directors there is usually a desk with monitors for the editors to operate. It is essential that the directors and editor are in connection with each other during events, so that replays and slow-motion shots can be selected and aired.

- The second part of a van is for the audio engineer; it has a sound mixer (being fed with all the various audio feeds: reporters. commentary, on-field microphones, etc. The audio engineer can control which channels are added to the output and will follow instructions from the director. The audio engineer normally also has a dirty feed monitor to help with the synchronization of sound and video.

- The 3rd part of the van is video tape. The tape area has a collection of video tape machines (VTRs) and may also house additional power supplies or computer equipment.

- The 4th part is the video control area where the cameras are controlled by 1 or 2 people to make sure that the iris is at the correct exposure and that all the cameras look the same.

- The 5th part is transmission where the signal is monitored by and engineered for quality control purposes and is transmitted or sent to other trucks.

Chapter 5

Automatic Picture Transmission

A colorized APT satellite image, received from NOAA-18.

The **Automatic Picture Transmission** (APT) system is an analog image transmission system developed for use on weather satellites. It was introduced in the 1960s and over four decades has provided image data to relatively low-cost user stations at locations in most countries of the world. A user station anywhere in the world can receive local data at least twice a day from each satellite as it passes nearly overhead.

Transmission

Figure 4.2.2-1. APT Frame Format.
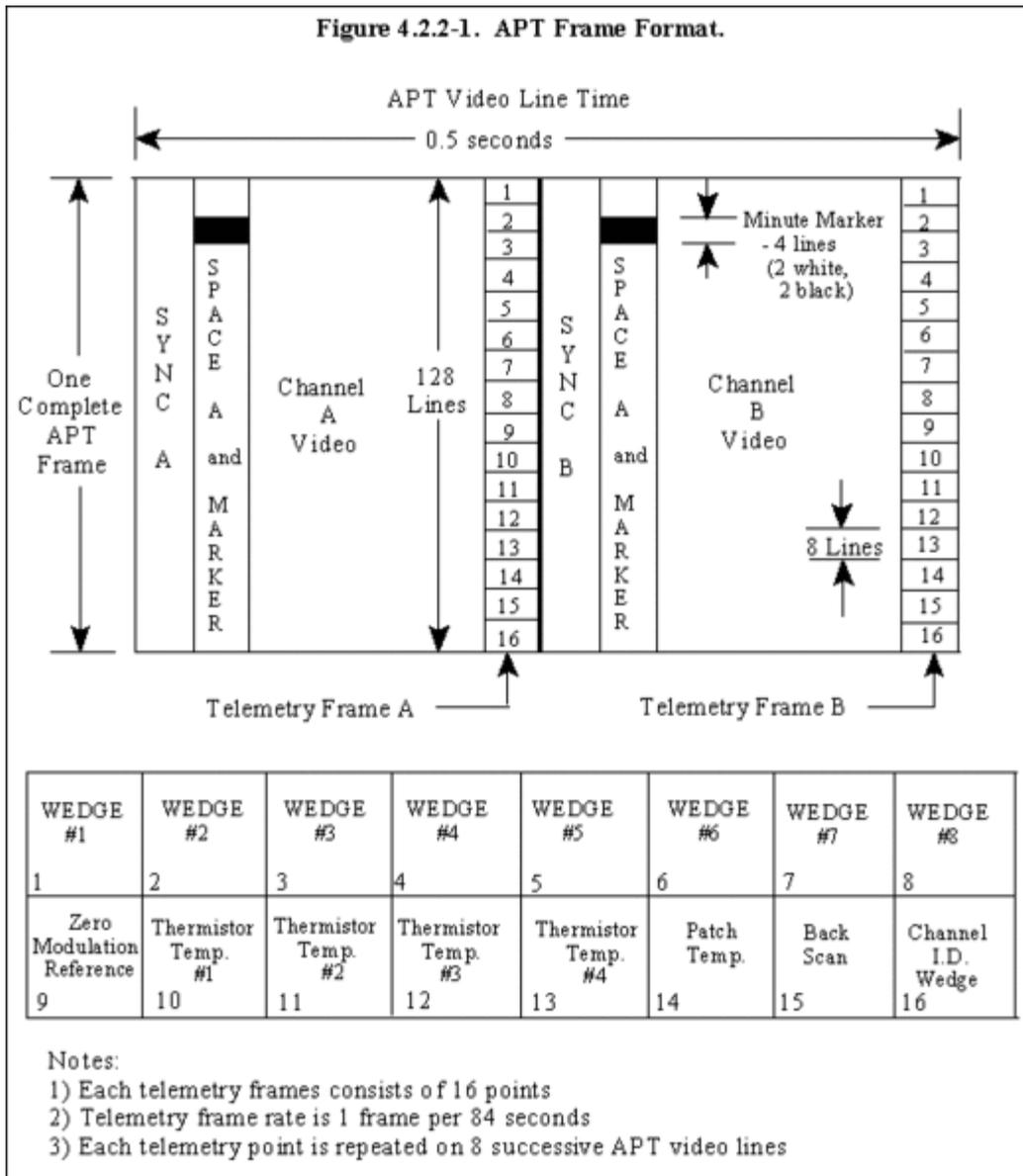
The APT transmission format

Structure

The broadcast transmission is composed of two image channels, telemetry information, and synchronization data, with the image channels typically referred to as Video A and Video B. All this data is transmitted as a horizontal scan line. A complete line is 2080 pixels long, with each image using 909 pixels and the remainder going to the telemetry

and synchronization. Lines are transmitted at 2 per second, which equates to a 4160 words per second, or 4160 baud.

Images

On NOAA POES system satellites, the two images are 4 km / pixel smoothed 8-bit images derived from two channels of the Advanced Very High Resolution Radiometer (AVHRR) sensor. The images are corrected for nearly constant geometric resolution prior to being broadcast, as such the images are free of distortion caused by the curve of the Earth.

Of the two images, one is typically long-wave infrared (10.8 micrometers) with the second switching between near-visible (0.86 micrometers) and mid-wave infrared (3.75 micrometers) depending on whether the ground is illuminated by sunlight. However, NOAA can configure the satellite to transmit any two of the AVHRR's image channels.

Synchronization and telemetry

Included in the transmission are a series of synchronization pulses, minute markers, and telemetry information.

The synchronization information, transmitted at the start of each video channel, allows the receiving software to align its sampling with the baud rate of the signal, which can vary slightly over time. The minute markers are four lines of alternating black then white lines which repeat every 60 seconds (120 lines).

The telemetry section is composed of sixteen blocks, each 8 lines long, which are used as reference values to decode the image channels. The first eight blocks, called "wedges," begin at 1/8th max intensity and successively increase by 1/8th to full intensity in the eighth wedge, with the ninth being zero intensity. Blocks ten through fifteen each encode a calibration value for the sensor. The sixteenth block identifies which sensor channel was used for the preceding image channel by matching the intensity of one of the wedges one through six. Video channel A typically matches either wedge two or three, channel B matches wedge four.

The first fourteen blocks should be identical for both channels. The sixteen telemetry blocks repeat every 128 lines, and these 128 lines are referred to as a frame.

Broadcast signal

The signal itself is a 256-level amplitude modulated 2400Hz subcarrier, which is then frequency modulated onto the 137 MHz-band RF carrier. Maximum subcarrier modulation is 87% (±5%), and overall RF bandwidth is 34 kHz. On NOAA POES vehicles, the signal is broadcast at approximately 40dBm (10 watts) effective radiated power.

Receiving images

An APT signal is continuously broadcast, with reception beginning at the start of the next line when the receiver is within radio range. Images can be received in real-time by relatively unsophisticated, inexpensive receivers during the time the satellite is within radio range, which typically lasts 8 to 15 minutes.

As of 2004 there were almost 5,000 APT receiving stations registered with the World Meteorological Organization (WMO). It is unclear what percent of the total user-base this represents, since registration is not a requirement, and was only available after 1996.

Radio receiver

The bandwidth required to receive APT transmissions is approximately 34 kHz. Most older scanners (police and fire type receivers)are the standard 15 kHz bandwidth which were designed to support voice transmissions. Newer VHF general coverage receivers are equipped with multiple IF bandpasses; some are, but not limited to: 6 kHz, 15 kHz 50 kHz & 230 kHz(broadcast FM). Use of a receiver with too narrow a bandwidth will produce pictures that are saturated in the blacks and whites, as well as possible inversion. Too wide, and the noise floor of the receiver will be too high to acquire a good picture. For the amateur enthusiast, a computer controller receiver is the best option to allow the software to automatically tune and set the required modes for proper reception. There are also dedicated APT receivers made specifically for computer control and APT reception. Specifically, ICOM PCR1000, PCR1500 & PCR2500 will produce excellent results. Searching on the web for "NOAA APT (RECEPTION or RECEIVER)" will produce a wealth of information on receivers, software, and antennas.

Antenna

APT images from weather satellites can be received with a right-hand circular polarized, 137 MHz antenna. Normally, there is no need to have the antenna follow the satellite and a fixed position antenna will provide good results.

The two most frequently recommended antennas are the crossed dipole and the quadrifilar helix antenna (QHA).

Displaying the images

Years ago, to receive APT images, a specialized decoder was required in addition to the receiver to display or print images, much like HF WEFAX (serving the maritime community). Often both receiver and decoder were combined into one unit.

Today, with the advent of personal computers, all that is required is dedicated software (many of which offer "free" versions) and a sound card. The sound card acquires and digitizes the slow scan video (in the audible range) coming from the speaker, phones, or line-out of the receiver, and then the software will process the various visible and infrared channels of the AVHRR sensor. Most software will automatically save every image and publish your processed image onto the website of your choice, putting up a new image on every pass of an APT satellite.

Enhanced images

Since each channel of the AVHRR sensor is sensitive to only one wavelength of light, each of the two images is luminance only, also known as grayscale. However, different materials tend to emit or reflect with a consistent relative intensity. This has enabled the development of software that can apply a color palette to the images which simulates visible light coloring. If the decoding software knows exactly where the satellite was, it can also overlay outlines and boundaries to help in utilizing the resulting images.

History

- Developed by the National Earth Satellite Service
- Tested on TIROS-8, launched December 21, 1963
- Nimbus 1, launched August 28, 1964, was the first application satellite
- First NOAA polar-orbiting vehicle to use it was TIROS-N, launched on October 13, 1978, and it has flown on all NOAA polar-orbiting vehicles since then.
- Also flown on the Soviet METEOR weather satellites.

Current status

NOAA satellites transmitting APT

- NOAA-18
- NOAA-17
- NOAA-15
- NOAA-19

Soviet / Russian satellites transmitting APT

- Meteor 2-21
- Meteor 3-5

Future

With the improvement in electronics, analog transmission systems are giving way to digital transmissions systems. The MetOp program, a collaboration between NOAA and EUMETSAT, has switched to Low Rate Picture Transmission (LRPT) for its new polar-orbit satellites and NOAA has stated they will not fly APT transmitters on POES vehicles after NOAA-N'.

Chapter 6

Radio Broadcasting

Long wave radio broadcasting station, Motala, Sweden

Broadcasting tower in Trondheim, Norway

Radio broadcasting is a one-way transmission over radio waves intended to reach a wide audience. Stations can be linked in radio networks to broadcast common programming, either in syndication or simulcast or both. Audio broadcasting also can be done via cable FM, local wire networks, satellite and the Internet.

History

The earliest radio stations were simply radiotelegraphy systems and did not carry audio. The first claimed audio transmission that could be termed a *broadcast* occurred on Christmas Eve in 1906, and was made by Reginald Fessenden. Whether this broadcast actually took place is disputed. While many early experimenters attempted to create systems similar to radiotelephone devices where only two parties were meant to communicate, there were others who intended to transmit to larger audiences. Charles

Herrold started broadcasting in California in 1909 and was carrying audio by the next year. (Herrold's station eventually became KCBS).

For the next decade, radio tinkerers had to build their own radio receivers. In The Hague, the Netherlands, PCGG started broadcasting on November 6, 1919. In 1916, Frank Conrad, an employee for the Westinghouse Electric Corporation, began broadcasting from his Wilkinsburg, Pennsylvania garage with the call letters 8XK. Later, the station was moved to the top of the Westinghouse factory building in East Pittsburgh, Pennsylvania and, as claiming to be "the world's first commercially licensed radio station", Westinghouse relaunched the station as KDKA on November 2, 1920. The commercial designation came from the type of license; advertisements did not air until years later. The first licensed broadcast in the United States came from KDKA itself: the results of the Harding/Cox Presidential Election. The Montreal station that became CFCF began program broadcasts on May 20, 1920, and the Detroit station that became WWJ began program broadcasts beginning on August 20, 1920, although neither held a license at the time.

Radio Argentina began regularly scheduled transmissions from the Teatro Coliseo in Buenos Aires on August 27, 1920, making its own priority claim. The station got its license on November 19, 1923. The delay was due to the lack of official Argentine licensing procedures before that date. This station continued regular broadcasting of entertainment and cultural fare for several decades.

Radio in education soon followed and colleges across the U.S. began adding radio broadcasting courses to their curricula. Curry College in Milton, Massachusetts introduced one of the first broadcasting majors in 1932 when the college teamed up with WLOE in Boston to have students broadcast programs.

Types
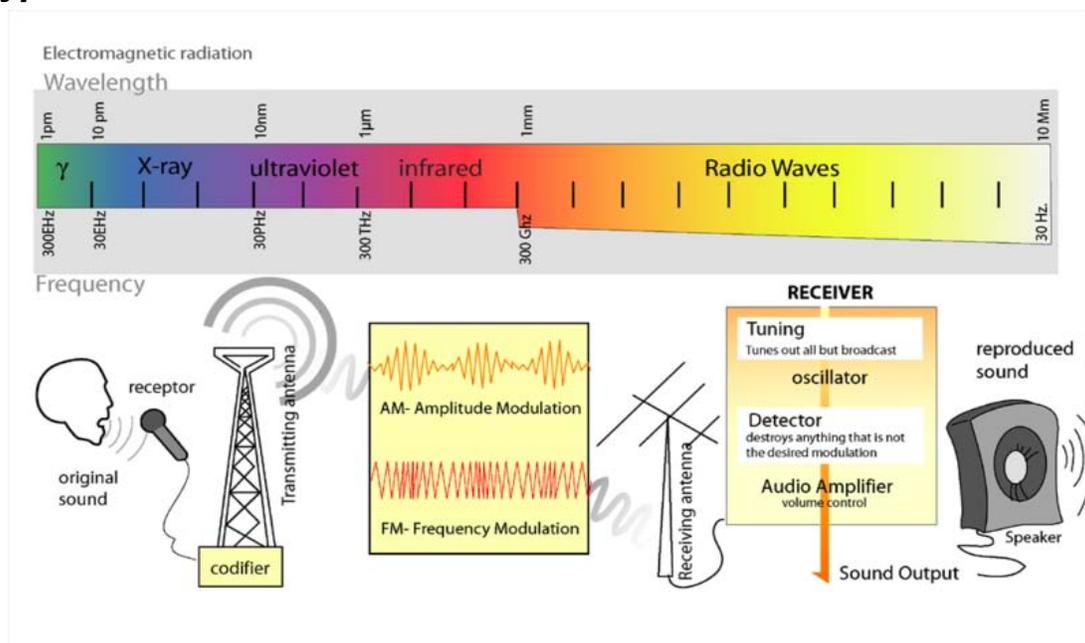
Transmission and reception schematic

Broadcasting by radio takes several forms. These include AM and FM stations. There are several subtypes, namely commercial, public and nonprofit varieties as well as student-run campus radio stations and hospital radio stations can be found throughout the world.

Many stations that broadcast on shortwave bands using AM technology that can be received over thousands of miles (especially at night). For example, the BBC has a full schedule transmitted via shortwave to Africa and Asia. These broadcasts are very sensitive to atmospheric conditions and solar activity.

Arbitron, the United States based company that reports on radio audiences, defines a "radio station" as a government-licensed AM or FM station; an HD Radio (primary or multicast) station; an internet stream of an existing government-licensed station; one of the satellite radio channels from XM Satellite Radio or Sirius Satellite Radio; or, potentially, a station that is not government licensed.

Shortwave

Shortwave for the differences between shortwave, medium wave and long wave spectra. Used largely for national broadcasters, international propaganda, or religious organizations.

AM
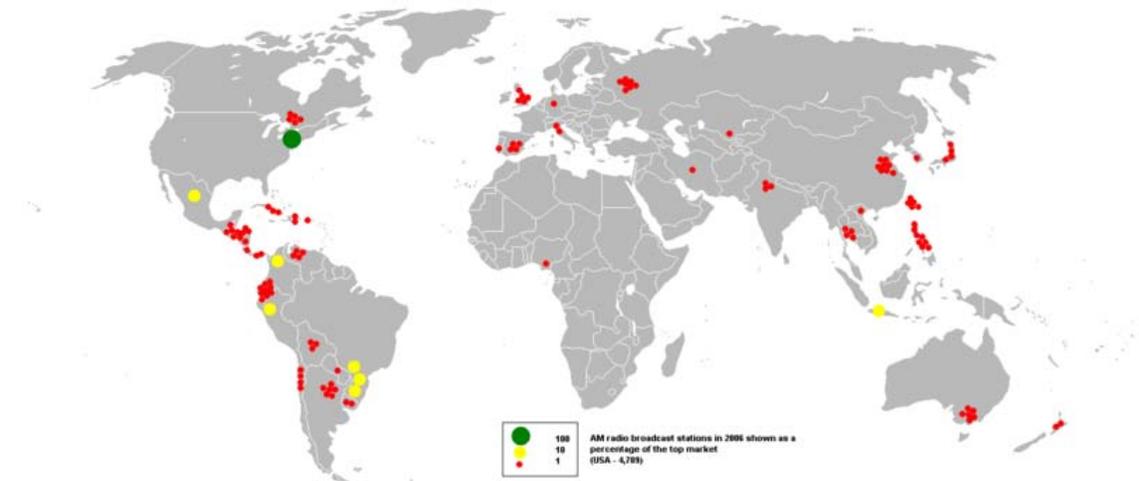
AM radio broadcast stations in 2006

AM stations were the earliest broadcasting stations to be developed. AM refers to amplitude modulation, a mode of broadcasting radio waves by varying the amplitude of the carrier signal in response to the amplitude of the signal to be transmitted.

The medium-wave band is used worldwide for AM broadcasting. Europe also uses the long wave band. In response to the growing popularity of FM radio stereo radio stations in the late 1980s and early 1990s, some North American stations began broadcasting in AM stereo, though this never gained popularity, and very few receivers were ever sold.

One of the advantages of AM is that its signal can be detected (turned into sound) with simple equipment. If a signal is strong enough, not even a power source is needed; building an unpowered crystal radio receiver is a common childhood project.

AM broadcasts occur on North American airwaves in the medium wave frequency range of 530 to 1700 kHz (known as the "standard broadcast band"). The band was expanded in the 1990s by adding nine channels from 1620 to 1700 kHz. Channels are spaced every 10 kHz in the Americas, and generally every 9 kHz everywhere else.

The signal is subject to interference from electrical storms (lightning) and other EMI.

AM transmissions cannot be ionospherically propagated during the day due to strong absorption in the D-layer of the ionosphere. In a crowded channel environment this means that the power of regional channels which share a frequency must be reduced at night or directionally beamed in order to avoid interference, which reduces the potential nighttime audience. Some stations have frequencies unshared with other stations in North America; these are called clear-channel stations. Many of them can be heard across much of the country at night. This is not to be confused with Clear Channel Communications, merely a brand name, which currently owns many U.S. radio stations on both the AM and FM bands. During the night, this absorption largely disappears and permits signals to travel to much more distant locations via ionospheric reflections. However, fading of the signal can be severe at night.

AM radio transmitters can transmit audio frequencies up to 15 kHz (now limited to 10 kHz in the US due to FCC rules designed to reduce interference), but most receivers are only capable of reproducing frequencies up to 5 kHz or less. At the time that AM broadcasting began in the 1920s, this provided adequate fidelity for existing microphones, 78 rpm recordings, and loudspeakers. The fidelity of sound equipment subsequently improved considerably, but the receivers did not. Reducing the bandwidth of the receivers reduces the cost of manufacturing and makes them less prone to interference. AM stations are never assigned adjacent channels in the same service area. This prevents the sideband power generated by two stations from interfering with each other. Bob Carver created an AM stereo tuner employing notch filtering that demonstrated that an AM broadcast can meet or exceed the 15 kHz baseband bandwidth alloted to FM stations without objectionable interference. After several years, the tuner was discontinued. Bob Carver had left the company and the Carver Corporation later cut the number of models produced before discontinuing production completely. AM stereo broadcasts declined with the advent of HD Radio.

FM
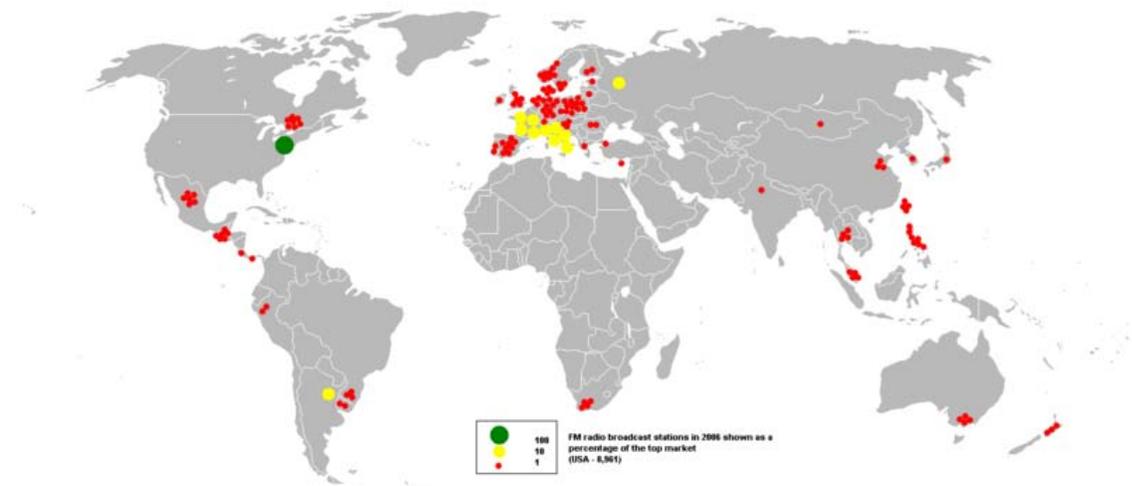
FM radio broadcast stations in 2006

FM refers to frequency modulation, and occurs on VHF airwaves in the frequency range of 88 to 108 MHz everywhere (except Japan and Russia). Japan uses the 76 to 90 MHz band. Russia has two bands widely used by the Soviet Union, 65.9 to 74 MHz and 87.5 to 108 MHz worldwide standard. FM stations are much more popular since higher sound fidelity and stereo broadcasting became common in this format.

FM radio was invented by Edwin H. Armstrong in the 1930s for the specific purpose of overcoming the interference problem of AM radio, to which it is relatively immune. At the same time, greater fidelity was made possible by spacing stations further apart. Instead of 10 kHz apart, as on the AM band in the US, FM channels are 200 kHz (0.2 MHz) apart. In other countries greater spacing is sometimes mandatory, such as in New Zealand, which uses 700 kHz spacing (previously 800 kHz). The improved fidelity made available was far in advance of the audio equipment of the 1940s, but wide interchannel spacing was chosen to take advantage of the noise-suppressing feature of wideband FM.

Bandwidth of 200 kHz is not needed to accommodate an audio signal — 20 kHz to 30 kHz is all that is necessary for a narrowband FM signal. The 200 kHz bandwidth allowed room for ±75 kHz signal deviation from the assigned frequency, plus guard bands to reduce or eliminate adjacent channel interference. The larger bandwidth allows for broadcasting a 15 kHz bandwidth audio signal plus a 38 kHz stereo "subcarrier"—a piggyback signal that rides on the main signal. Additional unused capacity is used by some broadcasters to transmit utility functions such as background music for public areas, GPS auxiliary signals, or financial market data.

The AM radio problem of interference at night was addressed in a different way. At the time FM was set up, the available frequencies were far higher in the spectrum than those used for AM radio - by a factor of approximately 100. Using these frequencies meant that even at far higher power, the range of a given FM signal was much shorter; thus its

market was more local than for AM radio. The reception range at night is the same as in the daytime.

The original FM radio service in the U.S. was the Yankee Network, located in New England. Regular FM broadcasting began in 1939, but did not pose a significant threat to the AM broadcasting industry. It required purchase of a special receiver. The frequencies used, 42 to 50 MHz, were not those used today. The change to the current frequencies, 88 to 108 MHz, began after the end of World War II, and was to some extent imposed by AM broadcasters as an attempt to cripple what was by now realized to be a potentially serious threat.

FM radio on the new band had to begin from the ground floor. As a commercial venture it remained a little-used audio enthusiasts' medium until the 1960s. The more prosperous AM stations, or their owners, acquired FM licenses and often broadcast the same programming on the FM station as on the AM station ("simulcasting"). The FCC limited this practice in the 1970s. By the 1980s, since almost all new radios included both AM and FM tuners, FM became the dominant medium, especially in cities. Because of its greater range, AM remained more common in rural environments.

Pirate radio

Pirate radio is radio broadcasting not sanctioned by the regulations of the originating country. Pirate radio may be a commercial enterprise supported by advertising targeted to listeners in the reception area, or may be privately run for entertainment, or political reasons, sometimes on a very small scale covering only a few city blocks.

Terrestrial digital radio

Digital radio broadcasting has emerged, first in Europe (the UK in 1995 and Germany in 1999), and later in the United States, France, the Netherlands, South Africa and many other countries worldwide. The most simple system is named DAB Digital Radio, for Digital Audio Broadcasting, and uses the public domain EUREKA 147 (Band III) system. DAB is used mainly in the UK and South Africa. Germany and Holland use the DAB and DAB+ systems, and France use the L-Band system of DAB Digital Radio.

In the United States digital radio isn't used in the same way as Europe and South Africa. Instead, the IBOC system is named HD Radio and owned by a consortium of private companies that is called iBiquity. An international non-profit consortium Digital Radio Mondiale (DRM), has introduced the public domain DRM system.

Satellite

Satellite radio broadcasters are slowly emerging, but the enormous entry costs of space-based satellite transmitters, and restrictions on available radio spectrum licenses has restricted growth of this market. In the USA and Canada, just two services, XM Satellite Radio and Sirius Satellite Radio exist. Both XM and Sirius are owned by Sirius XM Radio, which was formed by the merger of XM and Sirius on July 29, 2008, whereas in Canada, XM Radio Canada and Sirius Canada remain separate companies.

Program formats

Radio program formats differ by country, regulation and markets. For instance, the U.S. Federal Communications Commission designates the 88–92 megahertz band in the U.S. for non-profit or educational programming, with advertising prohibited.

In addition, formats change in popularity as time passes and technology improves. Early radio equipment only allowed program material to be broadcast in real time, known as *live* broadcasting. As technology for sound recording improved, an increasing proportion

of radio stations. Some stations now operate without direct human intervention by using entirely pre-recorded material sequenced by computer control.

Chapter 7

Conditional Access

Conditional Access (abbreviated **CA**) is the protection of content by requiring certain criteria to be met before granting access to this content. The term is commonly used in relation to digital television systems, most notably satellite television.

Conditional access in DVB

Under the DVB, conditional access system standards are defined in the specification documents for DVB-CA (Conditional Access), DVB-CSA (the Common Scrambling Algorithm) and DVB-CI (the Common Interface). These standards define a method by which a digital television stream can be obfuscated, with access provided only to those with valid decryption smart cards. The DVB specifications for Conditional Access are available from the standards page on the DVB website.

This is achieved by a combination of scrambling and encryption. The data stream is scrambled with an 8-byte secret key, called the *control word*. Knowing the value of the control word at a given moment is of relatively little value, as under normal conditions, content providers will change the control word several times per minute. The control word is generated automatically in such a way that successive values are not usually predictable; the DVB specification recommends using a physical process for that.

In order for the receiver to unscramble the data stream, it must be permanently informed about the current value of the control word. In practise, it must be informed slightly in advance, so that no viewing interruption occurs. Encryption is used to protect the control word during transmission to the receiver: the control word is encrypted as an *entitlement control message* (ECM). The CA subsystem in the receiver will decrypt the control word only when authorised to do so; that authority is sent to the receiver in the form of an *entitlement management message* (EMM). The EMMs are specific to each subscriber, as identified by the smart card in his receiver, or to groups of subscribers, and are issued

much less frequently than ECMs, usually at monthly intervals. This being apparently not sufficient to prevent unauthorized viewing, TPS has lowered this interval down to about 12 minutes. This can be different for every provider, BSkyB uses a term of 6 weeks. When Nagravision 2 was hacked, Digital+ started sending a new EMM every three days to make unauthorized viewing more cumbersome.

The contents of ECMs and EMMs are not standardized and as such they depend on the conditional access system being used.

The control word can be transmitted through different ECMs at once. This allows the use of several conditional access systems at the same time, a DVB feature called *simulcrypt,* which saves bandwidth and encourages multiplex operators to cooperate. DVB Simulcrypt is widespread in Europe; some channels, like the CNN International Europe from the Hot Bird satellites, can use 7 different CA systems in parallel.

The decryption cards are read, and sometimes updated with specific access rights, either through a Conditional Access Module (CAM), a PC card-format card reader meeting DVB-CI standards, or through a built-in ISO/IEC 7816 card reader, such as that in the Sky Digibox.

Several companies provide competing CA systems; VideoGuard, Irdeto Access, Nagravision, CoreTrust, Conax, Viaccess, Latens, Verimatrix, and Mediaguard (a.k.a. SECA) are among the most commonly used CA systems.

Due to the common usage of CA in DVB systems, many tools to aid in or even directly circumvent encryption exist. CAM emulators and multiple-format CAMs exist which can either read several card formats or even directly decrypt a compromised encryption scheme. Most multiple format CAMs and all CAMs that directly decrypt a signal are based on reverse engineering of the CA systems. A large proportion of the systems currently in use for DVB encryption have been opened to full decryption at some point, including Nagravision, Conax, Viaccess and Mediaguard (v1).

Conditional access in the USA

In the United States cable systems, the standard for conditional access is provided with CableCARDs whose specification was developed by the cable company consortium CableLabs. Cable companies in the US are required by the Federal Communications Commission to support CableCARDs; standards now exist for two way communication (M-card) but satellite television has its own standards . Next generation approaches in the United States eschew such physical cards and employ schemes using downloadable software for conditional access such as DCAS. The main appeal of such approaches is that the access control may be upgraded dynamically in response to security breaches without requiring expensive exchanges of physical conditional access modules. Another appeal is that it may be inexpensively incorporated into non-traditional media display devices such as Portable media players.

Conditional Access Systems

Conditional access systems include:

Analog Systems

- EuroCrypt
- Nagravision
- Videocipher
- VideoCrypt

Digital Systems

CA id.	Name	Developed by	Introduced (year)	Security	Notes
0x4800	Accessgate	Telemann			
0x4A20	AlphaCrypt	AlphaCrypt			
?	B-CAS				Used in Japan only
0x1702, 0x1722, 0x1762	BetaCrypt 1	BetaTechnik/Beta Research (subsidiary of KirchMedia)		Partly compromised (older smartcards)	Irdeto modification
0x1710	BetaCrypt 2	BetaTechnik/Beta Research (subsidiary of KirchMedia)		Partly compromised (older smartcards)	Irdeto modification
0x2600	BISS	European Broadcasting Union		Compromised	
0x4900	China Crypt	CrytoWorks (China) (Irdeto)			
0x22F0	Codicrypt	Scopus Network Technologies		Secure	
0x0B00	Conax CAS 5	Norwegian Telekom			
0x0B00	Conax CAS 7	Norwegian Telekom			Chip pairing (married card)
0x0B00	Conax CAS 7	Cyfrowy Dom - Telewizja na Karte - TNK	2009	Secure	
?	CoreCrypt	CoreTrust	2000	S/W & H/W Security	CA for IPTV, Satellite, Cable TV and Mobile TV
4347	CryptOn	CryptOn			
0x0D00, 0x0D02, 0x0D03, 0x0D05, 0x0D07, 0x0D20	Cryptoworks	Philips CryptoTec		Partly compromised (older smartcards)	
0x4ABF	CTI-CAS	Beijing Compunicate			

		Technology Inc.			
0x0700	DigiCipher 2	Jerrold/GI/Motorola 4DTV		Secure	DVB-S2 compatible , used for retail BUD dish service and for commercial operations as source programming for cable operators
0x4A70	DreamCrypt	Dream Multimedia			
0x4A10	EasyCas	Easycas			
0464	EuroDec	Eurodec			
5501	Griffin	Nucleus Systems, Ltd.			
0x5581	Bulcrypt	Bulcrypt	200?		Used in Bulgaria and Serbia
0x0606	Irdeto 1	Irdeto	199?	Compromised	
0x0602, 0x0604, 0x0606, 0x0608, 0x0622, 0x0626, 0x0664	Irdeto 2	Irdeto	2000	Partly compromised	
0x4AA1	KeyFly	SIDSA		Partly compromised (v. 1.0)	
0x0100	Seca Mediaguard 1	SECA			
0x0100	Seca Mediaguard 2 (v1+)	SECA		Partly compromised	
0x0100	Seca Mediaguard 3	SECA	2008		
0x1800, 0x1801, 0x1810, 0x1830	Nagravision	Nagravision	2003	Compromised	
0x1801	Nagravision Carmageddon	Nagravision			Combination of Nagravision with BetaCrypt
0x1702, 0x1722, 0x1762, 0x1801	Nagravision Aladin	Nagravision			
0x1801	Nagravision 3 - Merlin	Nagravision	2007	Secure	
0x1801	Nagravision - ELK	Nagravision	2008?	Secure	IPTV
0x4A02	Novel-SuperTV	Novel-SuperTV	1998	Secure	China and Other Countries
0x4AD4	OmniCrypt	Widevine Technologies	2004		Used only for adult

					television channels
0x0E00	PowerVu	Scientific Atlanta		Secure	Professional system widely used by cable operators for source programming
0x0E00	PowerVu+	Scientific Atlanta		Secure	Professional system used by cable operators for source programming
0x1000	RAS (Remote Authorisation System)	Tandberg Television			Professional system, not intended for consumers.
0xA101	RosCrypt-M	NIIR	2006		
4A60, 4A61, 4A63	SkyCrypt/Neotioncrypt/Neotion SHL	AtSky/Neotion	2003		
?	T-crypt				
0x4A80	ThalesCrypt	TPS			Viaccess modification. Was developed after TPS-Crypt was compromised.
0x0500	TPS-Crypt	France Telecom		Compromised	Viaccess modification used with Viaccess 2.3
0x0500	Viaccess PC2.3, or Viaccess 1	France Telecom		Compromised	
0x0500	Viaccess PC2.4, or Viaccess 2	France Telecom	2002	Compromised	
0x0500	Viaccess PC2.5, or Viaccess 2	France Telecom		Secure	
0x0500	Viaccess PC2.6, or Viaccess 3	France Telecom	2005	Secure	
0x0500	Viaccess PC3.0	France Telecom		Secure	
	VideoCrypt I	News Datacom			
	VideoCrypt II	News Datacom			
	VideoCrypt-S	News Datacom			
0x0911, 0x0919, 0x0960, 0x0961	NDS Videoguard 1	NDS		Compromised	
0x0911, 0x0919, 0x0960, 0x0961	NDS Videoguard 2	NDS			

0x0911, 0x0919, 0x0960, 0x0961, 0x093b, 0x0963	NDS Videoguard 3	NDS	2008	
4AD0, 4AD1	X-Crypt	XCrypt Inc.		Used only for adult television channels
0x5500, 0x4AE0, 0x4AE1	Z-Crypt/DRE-Crypt	Digi Raum Electronics		Secure
0x4AE5	PRO-Crypt	IK SATPROF	2008	Secure
0x4B00	Safeview	Safeview	2006	Secure

Chapter 8

Television Channel

A **television channel** is a physical or virtual channel over which a television station or television network is distributed. For example, in North America, "channel 2" refers to the broadcast or cable band of 54 to 60 MHz, with carrier frequencies of 55.25 MHz for NTSC analog video (VSB) and 59.75 MHz for analog audio (FM), or 55.31 MHz for digital ATSC (8VSB). Channels may be shared by many different television stations or cable-distributed channels depending on the location and service provider.

Depending on the multinational bandplan for a given region, analog television channels are typically 6, 7, or 8 MHz in bandwidth, and therefore television channel frequencies vary as well. Channel numbering is also different. Digital television channels are the same for legacy reasons, however through multiplexing, each physical radio frequency (RF) channel can carry several digital subchannels. On satellites, each transponder normally carries one channel, however small, independent channels can be used on each transponder, with some loss of bandwidth due to the need for guard bands between unrelated transmissions. ISDB, used in Japan and Brazil, has a similar segmented mode.

Channel separation on over-the-air channels is accomplished by skipping at least one channel between two analog stations' frequency allocations. (There can be gaps between channels, where numbers are sequential, but frequencies are not contiguous, such as the skip from VHF low to high, and the jump to UHF.) On cable TV, it is possible to use adjacent channels only because they are all at the same power, something which could only be done over the air if the two stations were transmitted at the same power and height from the same location. For digital TV, selectivity is inherently better, therefore channels adjacent (either to analog or digital stations) can be used even in the same area.

Digital Television This basically means that before broadcasting the analogue pictures, these are transferred or coded into a very long series of zeroes and ones (or rather on/off signals) and after receiving this digital data it's decoded back to analogue pictures via a so called digital box that either is built into a TV-set, or via an external unit between the antenna and the TV.

Many European countries have during the last five years began digital broadcasting through the common ground net. This is done by the DVB-T technique. This means that the UHF-band no longer broadcasts single channels, but so called MUXes which contains several channels at one frequency. How many channels that can be broadcast in one MUX depends on two things. Normal channel uses only a fraction of a MUX while High Definition TV uses a lot more. The second factor is how the digital signals are coded, in the older MPEG2 or the newer and more efficient MPEG4 code. To receive digital TV a digital box for decoding the digital signals back to analogue pictures is needed. If the broadcasting source is a MPEG2 MUX-signal, an MPEG2 decoding digital box is needed. To receive modern MPEG4 MUX-signal an MPEG4 decoder is needed, but MPEG4 decoding digital boxes also can handle the older MPEG2-signal. But *not* the other way around.

Apart from a correct decoding digital box, also the antenna needs to be adjusted to digital broadcasting. But only a common UHF-antenna is required. A new one straight away. Old ones sometimes may need removal of the filter (which only is used to improve old analogue signals). VHF-antennas do not work with the digital television of today. If the UHF-antenna gives week receiving an active antenna, which uses a low voltage to amplify the digital signals, can make wonders. Otherwise old fashion rules apply to digital receiving, like bigger och higher antenna and correct direction.

You do not need anything else if you only are interested in *free channels* (including national license channels in Europe) and new televisions usually have an MPEG4 digital box inside already. The box automatically separates all channels inside the broadcast MUX, and "translates" the digital signals back to analogue pictures. But not all digital boxes manage the newer kind of digital code, the MPEG4. For payment channels there are no basic differences - they can even be broadcast inside a MUX which also contains free/license channels, and they may be either of MPEG2 or MPEG4 technique. (However every MUX is either MPEG2 or MPEG4, never both together.) But you will also need a box that has place for a so called CA-module, and in this you put a "smartcard" that "unlocks" the channels you have paid for. The payment channels needs *a second decoding* which only can be done via the smartcard. However even with a CA-module and (an activated) smartcard with a MPEG2 box you cannot receive channels from MPEG4-MUXes.

With digital television is it possible to broadcast several more channels then with the old analogue technique, especially with MPEG4-MUXes. The old problem with a certain amount of frequencies, and the "frequency distances" between channels is solved by the MUX-technique.

The digital technique "revolution" will most probably be "the start of the end" of cable-TV, although cable-TV also is made digital through the DVB-C technique, but who will have any use for the cables in the long run? UHF-antenna technique with hundreds of airborne channels ("bunched together" in a few MUX:es), many of them free/licenced will became very hard for cable distributors to compete with.

Other meanings

Commonly, the term "television channel" is used to refer to either a terrestrial television station or its cable/satellite counterpart (both outlined below). Sometimes, especially outside the U.S. and in the context of cable/satellite television, it is used instead of the term television network, which otherwise (in its technical use above) describes a group of geographically-distributed television stations that share affiliation/ownership and some or all of their programming with one another.

This terminology may be muddled somewhat in other jurisdictions, for instance Europe, where terrestrial channels are commonly mapped from physical channels to common numerical positions (i.e. BBC One does not broadcast on any particular "channel 1" but is nonetheless mapped to the "1" input on most British television sets). On digital platforms, such (location) channels are usually arbitrary and changeable, due to virtual channels.

Television station

A television station is a type of broadcast station that broadcasts both audio *and* video to television receivers in a particular area. Traditionally, TV stations made their broadcasts by sending specially-encoded radio signals over the air, called terrestrial television. Individual television stations are usually granted licenses by a government agency to use a particular section of the radio spectrum (a channel) through which they send their signals. Some stations use LPTV broadcast translators to retransmit to further areas.

Many television stations are now in the process of converting from analogue (NTSC, PAL or SECAM) to digital TV (ATSC, DVB or ISDB).

Non-broadcast television channels

Because some regions have had difficulty picking up over-the-air signals (particularly in mountainous areas), alternative means of distribution such as direct-to-home satellite and cable television have been introduced. Television channels specifically built to run on cable or satellite blur the line between TV station and TV network. That fact led some early cable channels to call themselves superstations.

Satellite and cable have created changes. Local broadcast TV stations in an area can sign-up or even be required to be carried on cable, but content providers like TLC cannot. They are not licensed to run broadcast equipment like a station, and they do not regularly provide content to licensed broadcasters either. Furthermore, a distributor like TNT may begin producing its own programming, and shows presented exclusively on cable/satellite by one distributor may be syndicated to broadcast stations. The cost of creating a nationwide channel has been reduced and there has been a huge increase in the number of such channels, with most catering to a small group.

From the definitions above, use of the terms "network" or "station" in reference to nationwide cable/satellite channels is technically inaccurate. However, this is an arbitrary, inconsequential distinction, and varies from company to company. Indeed, the term "cable network" has entered into common usage in the United States in reference to such channels. There is even some geographical separation among "national"

cable/satellite channels in the U.S., be it programming (e.g., the Fox Sports Net group of regional sports channels, which share several programs), or simply regionalized advertising inserted by the local cable company.

Should a legal distinction be necessary between a (location) channel as defined above and a television channel in this sense, the terms "programming service" (e.g.) or "programming undertaking" (for instance,) may be used instead for the latter definition.

A person viewing by cable or satellite might not know what kind of organization is responsible for a given program, especially if it is syndicated, so what seems to be a station or a network may be neither.

Chapter 9

Traffic Message Channel

Traffic Message Channel (TMC) is a technology for delivering traffic and travel information to drivers. It is typically digitally coded using the FM-RDS system on conventional FM radio broadcasts. It can also be transmitted on DAB or satellite radio. It allows silent delivery of dynamic information suitable for reproduction or display in the language chosen by the user and without interrupting normal audio broadcast services. Services, both public and commercial, are now operational in many countries worldwide. When data is integrated directly into a navigation system, this gives the driver the option to take alternative routes to avoid traffic incidents.

How it works

Each traffic incident is binary-encoded and sent as a TMC message. Each message consists of an event code and a location code in addition to expected incident duration, affected extent and other details.

The message is coded according to the *Alert C* standard. It contains a list of up to 2048 event phrases (1402 pr 01.02.2007) which can be translated by a TMC receiver into the language of the user. Some phrases describe individual situations such as a crash, while others cover combinations of events such as a crash causing long delays.

In Europe, location code tables are maintained on a national level, assigning numerical codes to locations (typically major junctions) on the road network. Those location tables are integrated in the maps provided by in-vehicle navigation system companies such as NAVTEQ and Tele Atlas, and by vehicle manufacturers such as Volvo. In other countries such as the U.S. and Canada, private companies maintain the location tables and market TMC services commercially.

Sources of traffic information typically include police, traffic control centres, camera systems, traffic speed detectors, floating car data, winter driving reports, roadwork reports and others.

TMC-Forum

TMC-Forum is a non-profit organization. The members are service providers, receiver manufactures, car manufactures, map vendors, broadcasters (public and private), automobile clubs, public authorities and others. It is a forum to discuss traffic information related aspects. Furthermore it maintains the TMC-Standard (ISO 14819). On 11 November 2007 the TMC-Forum and the TPEG-Forum has merged into TISA (Traveller Information Services Association). TISA has taken over all TMC-Forum activities

Discussion

RDS-TMC is an extremely low-bandwidth system, with each RDS-TMC message comprising only 37 data bits sent at most 1-3 times per second, using a very basic data channel primarily designed for FM radio tuning and station name identification. Compressing entire traffic incident descriptions in multiple languages into a mere 16 bits for a location, 11 bits for an event code, plus 5 bits for an extent and a few more bits for the duration and system management might be regarded a miracle of ingenuity, whose need was dictated by constraints already set in the pre-existing RDS standard. Almost all the broadcast data bits were already taken.

Given so few bits to work with, one major design challenge of RDS-TMC was to find a way of using 16 bits (about 65000 locations) to describe an entire state or country. Such a system could not convey latitude-longitude data so easily available 25 years later with great precision using GPS. Instead RDS-TMC has to rely on the use of relatively lean location tables, pointing only to significant road junctions along defined national and regional highways. The precision of each traffic events' location when compared to modern GPS devices can seem to be low. The user's navigation system locates a driver to about 3 metres, but only knows that the crash is between Exit 3 and Exit 4, northbound on the motorway. This is because traffic events (accidents, congestion, burst water mains, faulty traffic lights, etc.) have to be superimposed onto the maps in users' GPS devices by matching the reported location into the location table.

Navigation system makers may maintain that if the nearest location table point (nearest significant junction) is located some distance from the point of the crash, then the traffic event might be shown on the device as being out of place. (In reality, it is shown as being on a section of main road between two junctions.) Even if the lack of accuracy causes an error of only a short distance this could make a significant difference as to how the program in the GPS device will interpret the event in relation to the user's planned route. For example, if there is roadwork close to a junction the position of the roadwork may be interpreted as being a short distance away. This could place the apparent roadwork on the other side of the junction. The consequence would be that the GPS device might not divert the user from the roadwork because it was assumed to not affect the route.

In fact, though, operationally, this level of detail may be exactly what is required. From the police and road authorities' viewpoints, it may be as just much as they wish to give out. The police may not want sightseers homing in on exact crash sites - additionally, emergency calls are often to somewhat vague locations, or may describe an incident (such as a multi-vehicle accident or an accident requiring multiple emergency vehicles for extrication, etc.) whose actual extent of disruption is more a segment of road than a

specific point. Also, road authorities and local communities do not want drivers taking shortcuts through the minor residential streets now opened up by in-vehicle navigation systems. On motorways and other limited-access roads, knowing where the crash is located to 3 meters is no help to casual drivers when road junctions are kilometers apart. On city streets, the commercial needs of navigation system users may be to cut through minor residential roads and play areas, but this is not necessarily the optimum solution from a community perspective.

In the U.S. and elsewhere, systems such as CARS already exist that could track and pinpoint event locations with accuracies of a meter, and these real-time data are already being published in XML for access by companies such as Google and TomTom. These incident reports are also being received from Google on mobile phones and handheld devices that are in vehicles already. Laws on the use of mobile devices may determine that this is potentially dangerous, but it exists and is working today. In conclusion, though, what this discussion has missed so far is that live incident reports themselves are almost always highly uncertain in terms of precise locations. But if it is assumed that these will get better, we now have technology required to provide the data. It is now up to society to regulate how much detail shall be given, and how safe it is for users to use these data in real time while they drive.

Security

In April 2007 research about RDS-TMC was presented at the CanSecWest security conference by two Italian security researchers.

The presentation, titled **Unusual Car Navigation Tricks**, raised the point that RDS-TMC is a wireless cleartext protocol and showed how to build a receiver and transmitter with cheap electronics, capable of injecting false and potentially dangerous messages.

The TMC Forum responded to this claim by stating that the effects of any 'pirate' TMC broadcasts would be minimal or even non existent, due to the fact that TMC equipped receivers filter out information that does not lie on the planned route. Also, it was stated that such broadcasts would directly interfere with that country's TMC carrier station, which would contravene the respective laws of that county, leading to criminal or civil liability. It was therefore concluded that such a motive is unlikely, given the legal risks and minimal disruptions that could occur if the perpetrator were successful in broadcasting a TMC signal.

Detailed instructions and schematics have also been posted on Issue #64 of Phrack hacking magazine.

Devices and Navigation Programs

An RDS-TMC receiver is in effect a special FM radio tuner that can decode TMC data. Satellite TMC receivers utilize a dedicated data channel that is broadcast as part of the much larger broadcast digital audio channels. TMC decoding is carried out by matching event and location codes against look-up tables of phrases and locations that can be translated into audio or displayed on a Sat nav device. The look-up tables must be implemented in a service-specific database mapped to geographic routes and

intersections. As with the navigation systems themselves, periodic upgrades are needed as the road system changes. These steps provide opportunities for vendors to generate revenue from users who cannot use the system unless they have the latest lookup tables.

The technical concepts of RDS-TMC started to be developed about 30 years ago, initially by Blaupunkt and Philips. With European Commission funding, the BBC, Transport Research Laboratory and CCETT came together in a team led by Castle Rock Consultants to develop the standard. More recently, dedicated navigation device (PND) has emerged as an alternative way of delivering traffic information via mobile phones and hand-held PDAs with GPS. Nevertheless, automobile companies continue to roll out RDS-TMC launches in various countries across the world. One reason is that the use of cellular phones and PDAs by drivers is attracting a great deal of legislative attention concerned about driver distraction. Like car radios, in-vehicle navigation systems have not so far attracted the same concerns, and may continue to outsell handheld solutions, just as luxury car radios eventually outsold pocket transistor radios in the 20th century.

The reality is that both types of services have their place, with no single solution having all the answers. Higher-end models of Personal Navigation Assistant come with a TMC receiver built-in and depending on the country, the service is available in Eclipse, Garmin, iPhone (Navigon), Navman, Navway, Mio, Pioneer, TomTom and Uniden navigation systems, and in Volvo, BMW and Ford Falcon navigation systems, among many others.

There are also TMC adapters, which extends mobile navigation systems with integrated GPS receiver (as mobile phones/PDAs with GPS) with TMC functionality. They can include a bluetooth or non-bluetooth (mainly, USB) connection. With help of the adapter, the received traffic messages are through-handed to the navigation software, these can again compute an alternative route with consideration of the new traffic conditions and avoid the traffic jam. The adaptors generally includes connector for FM/TMC Antenna (2,5mm phone jack). Some examples of compatible navigation programs are Navigon MN5, Falk Navigator TMC Edition (special version for MyGuide Navigator 6500XL TMC Bundle) and Destinator PN.

Simple RDS-TMC Decoder is a simple RDS (Radio Data System) decoder written for TMC analysis.

Coverage

In some places, TMC coverage is smaller than that of the radio programme carrying the TMC service, therefore white spots exist. For example, in the USA, one of the two TMC commercial services is run by Clear Channel Communications, whose 95 FM station urban markets will probably all have some level of traffic information services. However, the other is Sirius Satellite Radio, which covers all of North America, including deeply rural areas and almost empty deserts. Although vendors are beginning to make arrangements with statewide and multi-state information source systems such as CARS, operated by state police and state departments of transportation, it can be expected that coverage will remain sketchy in some states during the next few years.

TMC services in operation

The following countries provide a TMC service:

Australia

Intelematics Australia broadcasts a national RDS-TMC service focused initially on urban Australia, under the consumer brand 'SUNA Traffic Channel'. The service, which reaches around 85% of urban Australia is transmitted by commercial FM broadcasters in seven cities, as well as via XML for online and smartphone applications. The service is available on GPS systems including TomTom, Navman, Garmin, Uniden, iPhone (Navigon), Mio, Eclipse and Pioneer navigation systems, and in Ford Falcon navigation. SUNA is currently the only source of comprehensive, metropolitan congestion monitoring content in Australia - this is achieved using proprietary technology interfacing to traffic light control systems. The Suna broadcast service is fully compliant with both the RDS and TMC standard.

Austria

In Austria, ORF is broadcasting the service, free of charge, on the radio channels Ö1, *Ö2* (9 regional channels), *Ö3*, *Radio Salzburg* and FM4 and is supported by the *Federal Ministry for Traffic, Innovation and Technology (BMVIT)*. *ASFINAG* is responsible for the location table, currently in version 2.1, which has undergone a number of updates in order to handle increased use during Euro 2008. In total, around 8.000 location codes are present in this table.

Baltic region

Destia Traffic has expressed plans to start broadcasting traffic information in the Baltic region soon.

Belgium

In Belgium there are 4 TMC services: *TMOBILIS* in Belgium, *TIC-VL* and *4FMTMC* in Flanders and RTBF in Wallonia. All of them (except for *TMOBILIS*) are currently open services.

The first service is *TMOBILIS* provided by *Be-Mobile* and *Touring Mobilis*. It is the only fully Belgian service: On the one hand it combines all Belgian sources from the Flemish, Walloon and Brussels government, the police stations, a national Floating Car Datasystem based on Proximus and GPS vehicles, and the *Touring Mobilis* call center. On the other hand it is also nationally broadcast by both VRT on Studio Brussel for Flanders and RTBF on *Classic21* in Wallonia.

The service *TIC-VL* is broadcast by VRT on *Radio 2* and is using content from the *Vlaams Verkeerscentrum*. Coverage of content and transmissions is limited to the Flanders region.

In the southern part of Belgium, Wallonia, the service *CLASS.21* is broadcast by RTBF on *Classic 21*. The service is from the *Centre PEREX* of the *Ministère de l'Équipement et des Transports (MET)* in collaboration with *TMC4U*. Both coverage of transmissions and content is limited to Wallonia.

A last TMC service is *4FMTMC* provided by *Vialis*, which is also operating TMC services in the Netherlands. It is broadcast by 4FM in Flanders, containing both the content from the *Vlaams Verkeerscentrum* and *PEREX* and so covers Belgium in total. In future they plan to add information on speed cameras.

Tritel creates the location tables by order of the regional communities. Since December 2004 the broadcast messages are according to location table version 1.4b, in which N-roads are added. The latest, currently used, version is 2.3 (from July 2008).

Czech Republic

In the Czech Republic, 3 services are available. 2 of them (DIC PRAGUE, TELEASIST) are in operation from January 2006 and one (JSDI) from 2008. All services are free to air.

A first service, called *DIC PRAHA*, is available in Prague. It is broadcast on Český Rozhlas – Regina (92.6 MHz). The service provider is *TSK-Praha* (Communication Technical Administration). The content comes from the traffic centre in Prague (*TIC Prague*) and consists of closures and restrictions and levels of service in Prague.

A second service, *TELEASIST* provided by Teleasist together with *Global Assistance* is available countrywide, however is not as detailed as *TIC Prague* in specific areas. It is being broadcasted by CRo1 Radiožurnál.

Last service, called JSDI, is provided by Czech Road Motorway Directorate (*ŘSD ČR*) and is broadcasted countrywide on ČRo3 Vltava. The content consists of closures and road restrictions and winter maintenance from all over the country, accident information from rescue services and detailed content from TIC Prague.

TMC developments are coordinated by CEDA. They are responsible for the location table (current version is 3.0, containing more than 16 000 records).

Denmark

The free TMC service *DK-TMC* in Denmark is operated by *Vejdirektoratet* or *DRD* (Danish Road Directorate). It is broadcast on DR *P1*, *P2*, *P3* and *P4*.

DRD is also responsible for the location tables. The current version used is 9.0. It contains around 2.450 location codes.

Finland

The commercial service in Finland is provided by Destia. The service covers biggest cities and roads 1-999. These areas cover the whole country. TMC messages are broadcast nationally on YLE Radio Suomi channel. Destia uses several information

sources to validate traffic data including induction loops, traffic cameras, radio stations, road users and several other partnership companies. The service is encrypted, based on the encryption specifications made by the TMC Forum.

The location table is provided by FINNRA, the Finnish Road Administration. The newest location table is version number 1.42 and it is used by Destia's TMC service. This version of the table contains around 8.100 problem locations.

France

Both a free public service and a commercial service are available in France.

The free service is provided by the motorway operators and provides information on their toll-roads. The toll-road operators are *AREA*, *ASF*, *ATMB*, *Cofiroute*, *ESCOTA*, *SANEF*, *SAPN*, *SAPRR*, *SFTRF* and *SMTPC*. The TMC data is on the 107.7 traffic channel so it can only be received along the motorways.

The commercial service *V-Trafic* is provided by *Mediamobile*. It is a partnership between TDF, Renault, *Trafficmaster* and *Cofiroute*. The service, which replaces the previous *Visionaute* service, is transmitted on the frequencies of *France Inter* and can be received nationally. It includes the information from the motorways but also on Paris congestion. The service was first open but it is now a pay-service, but it is not encrypted: by using a different location table number they can restrict the use. This method is *TMC Forum* 's Interim encryption method. They have about 60000 customers.

Next to that a service from *ViaMichelin* and *Carte Blanche* is provided, transmitted by the *Towercast* network (*NRJ* group). In September 2005 PSA Peugeot Citroën signed a partnership with *ViaMichelin* for the use of this info in their navigation systems.

Location tables are released by the government agency *SETRA* and includes about 20000 locations. Since version 0.4 it includes both inside Paris and outside Paris. The latest certified version is 8.0 for France (the last release contained around 13.500 problem locations) and 0.0 for Andorra (containing 62 problem locations).

Germany

In Germany both a public and a commercial service are available. The public service is an open, free service that can be received by the public radio stations.

The other service *TMCpro* is a pay service provided by *Navteq Services GmbH* owned by Navteq. The service was developed and formerly provided by T-Systems Traffic GmbH a subsidiary of T-Systems which was bought by Navteq in January 2009. The service went live at the beginning of 2005 across Germany. The content is provided by *ddg Gesellschaft für Verkehrsdaten mbh*, a wholly owned subsidiary of *T-Systems Traffic GmbH*. It is an encrypted service, based on the conditional access specifications made by the *TMC Forum*.

BASt, the German Federal Highway Research Institute, is releasing location tables. In version 5.1 all major access roads leading to the football arenas which were used in the

World Championship in 2006 were added. The current version is 8.0, which contains around 40.100 location codes.

Location tables for Germany have been updated, the new version (version 9) will be implemented on the 13 Apr 2010 11 am.

Hungary

A public TMC-service is available from 1 August 2008 in Budapest and from 20 August 2008 in the rest of the country. The current version of the location table is 2.0. The service is provided by TrafficNav on Radio MR2 and NEO FM (also on Radio Cafe 98.6 in Budapest)

Indonesia

In Oct 2009, GEWI Europe GmbH & Co. KG released the TISA certified Location Table version 1.0 for Indonesia.

Iran

The service is currently unavalable, although the infrastructure is already in place; originally for use by the Iranian National Broadcasting Company (IRIB). The service is expected to become publicly available in 2010.

Ireland

TMC for Dublin, Ireland went live as of November 2010. It is expected to be rolled out to cover the entire country soon.

Israel

A commercial RDS-TMC service is offered by Decell Technologies since February 2011. Decell provides national coverage broadcasted by several leading regional radio stations. The content distribution relies on Decell's TISA certified TMC location table number 36. Decell provides real-time flow and incident traffic data on RDS-TMC to all leading navigation companies.

Italy

A public RDS-TMC service free of charge is available in Italy from 1 July 1998 by RAI. *CCISS* (National Traffic Information Centre) is providing the service. It is broadcasted on *Rai Radio 1* FM; this service covers Italy.

Another TMC service is provided by the commercial radio station RTL 102.5 in cooperation with *InfoBlu*. This service is available as Premium Service so you have to use a software enabled receiver and covers 90% of the population of Italy, and is still increasing.

The Italian location table, provided by RAI-CCISS, is in its version 2.1 with around 12.500 codes.

The current version (as of September 2010) is version 3.1 with around 41.000 location codes. It has all highways, state roads, county roads and urban roads for main towns. It is available here.

Netherlands

The service provider *TMC4U* is delivering a TMC service in the Netherlands. Currently it is free, but they plan a pay-service including local information. *TMC4U* is a collaboration between *Siemens* and *ANWB*. The transmissions are on the radio channels of *SkyRadio*, *Radio Veronica*, *Radio 1* and *Radio 3*.

A second TMC service *ViaTMC* is provided by *Vialis*. They are transmitting on the FM channels of *Q-music* (previously *Radio Noordzee*), *BNR Nieuwsradio* and *Radio 538*. Information of traffic jams, road works and so on is the same on both channels, but they add information on speed traps to it independent of each other.

Radio 2 is also sending out TMC-messages, working with data from Vialis.

Location tables come from *AVV Transport Research Centre* and are supplied by *TIC Nederland*. The current version is 6.1 which has additions for parking areas / parking lots compared to the 'old' 2003.a version.

Norway

As of 2009, NRK has an open TMC service in a testing phase. The open service is transmitted using the P1-frequency, and information on coverage and nearest transmitter can be found on. NRK broadcasts information on roadworks, planned closures and winter-closed mountain passes. Updates on accidents and other unforeseen information are currently done Mon-Fri 05.30-22.00, Sat 09.30-17.00 and Sun 13.00-22.00.

The private radio station P4 is working with Destia Traffic to provide TMC info in Norway. This service is encrypted but free (according to Destia Traffic) for all private users, and some GPS manufacturers, such as TomTom, Garmin, mio and Navigon provide Destia Traffic' service for free.

In 2003 there was an experiment with distributing TMC-messages in a limited area (Østfold, Akershus and Oslo). A private operator might start a commercial service during 2008. In June Destia starts to broadcast the TMC service in Norway.

Statens vegvesen, the *Norwegian Public Roads Administration (NPRA)*, is releasing location tables. The current version is V3.1

Poland

From 1 May 2010, commercial TMC service is available in Poland, on private radio station RMF FM. The service is provided by Destia Traffic and it's currently available for Garmin and Navigon users.

Singapore

In Jun 2006, GEWI Europe GmbH & Co. KG released the first TISA certified TMC Location Table for Singapore and started a broadcast service which is operated by its branch company, GEWI Asia Pacific Pte. Ltd. GEWI's traffic services are available on several models of Nokia smartphones, PAPAGO! and Garmin GPS navigation devices.

In Nov 2010, the Land Transport Authority announced the release of the Location Table for Singapore. Quantum Inventions offers a traffic data service based on this location table and includes traffic incidents information, traffic speeds, parking availability, weather, road closures, etc. Various brands of GPS systems using the Galactio software provide these dynamic data in the navigation system.

Slovenia

In June 2009 Slovenian national radio has started to broadcast traffic data every 15 minutes. Available for Monolit and Garmin users. Plans are in place to also affer the service to Navteq users.

Spain

A TMC service is available in Spain on *RNE 3*. It is provided by

- SCT as the operator of traffic management in Catalonia Autonomous Community
- DT in the Basque Country Autonomous Community
- DGT (Traffic General Directorate) as the operator for the rest of the country's traffic management.

The road network coverage is the motorways, national roads and first level roads that belong to the Autonomous Communities. Next to that, RACC is working on urban TMC services, starting with Seville and Barcelona. This will broadcast on *RNE 2*.

Location tables are coming from *DGT*, *Dirección General de Tráfico*. The current version is 2.1 and contains about 7.750 problem locations.

Sweden

A free service is available in Sweden. Swedish Transport Administration, or Trafikverket, is responsible for the free service and for making the location tables. Nowadays version 2.2.2009 is in use for broadcasting RDS-TMC messages, which contains about 22587 location Codes and 923 Area, 4191 road/ segment/ street and 17473 points. New versions are always backward compatible.

Regarding the transmission, Sweden is divided into 8 broadcasting zones in order not to transmit traffic information that is not useful at that location. They cover the European, national and major county highways and contain information about traffic accidents, road works and road weather. The service is broadcast on Sveriges Radio P3 radio station and covers 98 percent of Sweden. 98 percent is multi-messages in the air in Sweden.

Swedish Transport Administration (Trafikverket) has an information page for Trafikverket RDS-TMC in Swedish.

Switzerland

A TMC service is available in Switzerland. The broadcaster is SRG SSR idée suisse or *Swiss Broadcasting Corporation* who transmits TMC on *FM chain 1* (general, services) and *FM chain 3* (pop/rock) all over Switzerland.

- In German speaking areas: DRS 1 (G) / DRS 3 (G) / La 1ère (F) / Rete Uno (I) partly
- In French speaking areas: La 1ère (F) / Couleur 3 (F) / DRS 1 (G) / Rete Uno (I) partly
- In Italian speaking areas: Rete Uno (I) / Rete Tre (I) / DRS 1 (G) / La 1ère (F)

It is *Viasuisse*, a daughter company of it, that operates the service.

Location codes are the responsibility of the *Swiss Federal Roads Authority FEDRO* but *B+S Ingenieur (Bundesamt fuer Strassen)* makes the location tables. Version 5.5 is the latest version, containing around 10.000 codes, and is backwards compatible.

Taiwan

The Taiwanese police radio station and Ministry of Transportation and Communication (MOTC) both broadcast RDS-TMC traffic data. It is currently available for TomTom, Garmin, Panasonic, PaPaGo and Mio devices.

United Kingdom

The private company *iTIS Holdings* provides a commercial TMC service *iTMC* in the United Kingdom. It is broadcast nationally on Classic FM and broadcast is supplemented by use of other commercial radio stations. ITIS provides traffic data on RDS-TMC to all the major automotive companies (BMW, Mercedes, Toyota, Ford , Jaguar/Landrover and others). The price of the service is included in the price of the car or of the navigation system.

This system uses Floating Vehicle Data, positional information from over 160,000 vehicles fitted with fleet management systems, this data provides the information about traffic speed and congestion throughout the UK road network. The data is complemented by journalistic or "Incident" data provided by Trafficlink. Trafficlink is owned by ITIS and provides live traffic and travel bulletins to BBC National and Local Radio and also to over 95% of the UK commercial radio stations. The incident data included in to the TMC data includes road works, accidents and closures.

RAC Live operated by *RAC Trafficmaster Telematics* (RTT) a 50-50 joint venture between RAC Motoring Services and *Trafficmaster* also operates a national service. It uses the local and regional radio broadcaster Global Radio to ensure reception across mainland Britain. This system uses road-side infrastructure to measures a vehicle's travel time between sensors placed a few miles apart, and uses number plate recognition technology.

Both providers are responsible for their own location tables. The current location table version of *ITIS* is 5.1. The current location table version of *Trafficmaster* is 3.1.

Within the United Kingdom TMC services are only offered as pay services. As such they are currently always carried by commercial radio stations rather than by the BBC, a public service broadcaster. The BBC is required by its charter to be free from both political and commercial influence and is therefore unable to carry a pay service unavailable to all.

United States and Canada

In the United States of America, XM Satellite Radio started transmitting TMC messages all over the US, as has Sirius Satellite Radio. NAVTEQ provides traffic data to both XM and Sirius Satellite Radio. NAVTEQ Traffic delivers traffic information and related advertising via RDS and HD signals to navigation devices nationwide. NAVTEQ also provides high quality traffic sourced from sensors, probes and other technologies in 10+ countries as of Dec 2009. INRIX, Inc. fuses TMC data with real-time flow information from its crowd-sourced network of floating cars and mobile devices with information from other public and private sources to deliver real-time and predictive traffic information.

Clear Channel Communications and Tele Atlas have a TMC service called **Total Traffic Network (TTN)**, using FM RDS in 77 US cities and three Canadian metropolitan areas. These services are both subscription, and were initially available to many in-car navigation units via an expansion module purchased separately.

The TomTom RDS-TMC Traffic Receiver acquires information through an FM radio signal broadcast by Clear Channel's regional providers. By connecting a TomTom GO device to the RDS-TMC Traffic Receiver, users automatically receive traffic information via the TMC connection. Once a trip is planned, traffic alerts are displayed in the traffic bar on the right hand side of the screen. When users tap the traffic bar, they receive further information, such as accident or traffic delays. The RDS-TMC Traffic Receiver is compatible with the TomTom GO 920, TomTom GO 720, TomTom ONE XL and TomTom ONE 3rd EDITION. It provides integration of RDS-TMC Traffic information with the user interface of the TomTom GO and ONE products.

By now, in addition these after-market services, about six major motor manufacturers are offering RDS-TMC as standard in their U.S. vehicles, including Volvo and BMW.

Ibiquity HD Radio is advertising a TMC service based on the existing RDS-TMC standard. Utilizing the established standard for RDS/TMC, the Traffic Message Channel (TMC) is a data application for broadcasting real-time traffic information. Data messages

will be received and decoded by a TMC-based receiver in conjunction with HD Radio devices and navigation systems. Traffic services are delivered to the driver in a vehicle in a variety of ways: the most common of these being a TMC-enabled navigation system.

Other planned services

It is also planned to start in Portugal, however no further information is available on this at present. From 2011 in Bulgaria the service will be operational in the town of Sofia.

In Romania and Luxembourg no service is currently planned. In Dubai the location table version 1.2 has been certified. In Turkey it is planned but not in usage yet.

In China they are currently investigating on which technology their traffic information system will be based. The main choice is between the Japanese system VICS and the European *TMC*. A TMC Location table version 1.0 has been certified already.

Transmitter

Antenna tower of Crystal Palace transmitter, London

In electronics and telecommunications a **transmitter** or **radio transmitter** is an electronic device which, with the aid of an antenna, produces radio waves. The transmitter itself generates a radio frequency alternating current, which is applied to the antenna. When excited by this alternating current, the antenna radiates radio waves. In addition to their use in broadcasting, transmitters are necessary component parts of many electronic devices that communicate by radio, such as cell phones, Wifi and Bluetooth enabled devices, garage door openers, two-way radios in aircraft, ships, and spacecraft, radar sets, and navigational beacons. The term *transmitter* is usually limited to equipment that generates radio waves for communication purposes; or radiolocation, such as radar and navigational transmitters. Generators of radio waves for heating or industrial purposes, such as microwave ovens or diathermy equipment, are not usually called transmitters even though they often have similar circuits.

The term is popularly used more specifically to refer to transmitting equipment used for broadcasting, as in radio transmitter or television transmitter. This usage usually includes both the transmitter proper as described above, and the antenna, and often the building it is housed in.

An unrelated use of the term is in industrial process control, where a "transmitter" is a device which converts measurements from a sensor into a signal, and sends it, usually via wires, to be received by some display or control device located a distance away.

Description

A transmitter can be a separate piece of electronic equipment, or an electrical circuit within another electronic device. A transmitter and receiver combined in one unit is called a transceiver. The term transmitter is often abbreviated "XMTR" or "TX" in technical documents. The purpose of most transmitters is radio communication of information over a distance. The information is provided to the transmitter in the form of an electronic signal, such as an audio (sound) signal from a microphone, a video (TV) signal from a TV camera, or in wireless networking devices a digital signal from a computer. The transmitter combines the information signal to be carried with the radio frequency signal which generates the radio waves, which is often called the carrier. This process is called *modulation*. The information can be added to the carrier in several different ways, in different types of transmitter. In an amplitude modulation (AM) transmitter, the information is added to the radio signal by varying its amplitude (strength). In a frequency modulation (FM) transmitter, it is added by varying the radio signal's frequency slightly. Many other types of modulation are used.

Legal restrictions

In most parts of the world, use of transmitters is strictly controlled by laws because of the potential for dangerous interference with other radio transmissions (for example to emergency communications). Transmitters must be licensed by governments, under a variety of license classes depending on use: (broadcast, marine radio, etc.), and are restricted to certain frequencies and power levels. In some classes each transmitter is given a unique call sign consisting of a string of letters and numbers which must be used as an identifier in transmissions. The operator of the transmitter must hold a government

license, such as a general radiotelephone operator license, which is obtained by passing a test demonstrating adequate technical and legal knowledge of safe radio operation.

An exception is made allowing the unlicensed use of low-power short-range transmitters in devices such as wireless microphones, cordless telephones, walkie-talkies, Wifi and Bluetooth, garage door openers, and baby monitors. In the US, these fall under Part 15 of the Federal Communications Commission (FCC) regulations.

How it works

A radio transmitter is an electronic circuit which transforms electric power from a battery or electrical mains into a radio frequency alternating current, which reverses direction millions to billions of times per second. The energy in such a rapidly-reversing current can radiate off a conductor (the antenna) as electromagnetic waves (radio waves). The transmitter also "piggybacks" information, such as an audio or video signal, onto the radio frequency current to be carried by the radio waves. When they strike the antenna of a radio receiver, the waves excite similar (but less powerful) radio frequency currents in it. The radio receiver extracts the information from the received waves. A practical radio transmitter usually consists of these parts:

- A power supply circuit to transform the input electrical power to the higher voltages needed to produce the required power output.
- An electronic oscillator circuit to generate the radio frequency signal. This usually generates a sine wave of constant amplitude often called the carrier wave. In most modern transmitters this is a crystal oscillator in which the frequency is precisely controlled by the vibrations of a quartz crystal.
- A modulator circuit to add the information to be transmitted to the carrier wave produced by the oscillator. This is done by varying some aspect of the carrier wave. The information is provided to the transmitter either in the form of an audio signal, which represents sound, or for data in the form of a binary digital signal.
  - In an AM (amplitude modulation) transmitter the amplitude (strength) of the carrier wave is varied in proportion to the audio signal.
  - In an FM (frequency modulation) transmitter the frequency of the carrier is varied by the audio signal.
  - In an FSK (frequency-shift keying) transmitter, which transmits digital data, the frequency of the carrier is shifted between two frequencies which represent the two binary digits, 0 and 1.

  Many other types of modulation are also used. In large transmitters the oscillator and modulator together are often referred to as the *exciter*.

- An RF power amplifier to increase the power of the signal, to increase the range of the radio waves.
- An impedance matching (antenna tuner) circuit to match the impedance of the transmitter to the impedance of the antenna (or the transmission line to the antenna), to transfer power efficiently to the antenna. If these impedances are not equal, it causes a condition called standing waves, in which the power is reflected back from the antenna toward the transmitter, wasting power and sometimes overheating the transmitter.

In higher frequency transmitters, in the UHF and microwave range, oscillators that operate stably at the output frequency cannot be built. In these transmitters the oscillator usually operates at a lower frequency, usually a submultiple of the output frequency, and this intermediate frequency (IF) is multiplied to get a signal at the output frequency by frequency multipliers.

History

The first primitive radio transmitters (called Hertzian oscillators) were built by German physicist Heinrich Hertz in 1887 during his pioneering investigations of radio waves. These generated radio waves by a high voltage spark between two conductors. These spark-gap transmitters were used during the first three decades of radio (1887-1917), called the wireless telegraphy era. Short-lived competing techniques came into use after the turn of the century, such as the Alexanderson alternator and Poulsen Arc transmitters. But all these early technologies were replaced by vacuum tube transmitters in the 1920s, because they were inexpensive and produced continuous waves, which could be modulated to transmit audio (sound) using amplitude modulation (AM) and frequency modulation (FM). This made possible commercial radio broadcasting, which began about 1920. The development of radar before and during World War 2 was a great stimulus to the evolution of high frequency transmitters in the UHF and microwave ranges, using new devices such as the magnetron and traveling wave tube. In recent years, the need to conserve crowded radio spectrum bandwidth has driven the development of new types of transmitters such as spread spectrum.

Broadcast transmitters

Commercial FM broadcasting transmitter at radio station WDET-FM, Wayne State University, Detroit, USA. It broadcasts at 101.9 MHz with a radiated power of 48 kW.

Power output

In broadcasting and telecommunication, the part which contains the oscillator, modulator, and sometimes audio processor, is called the "exciter". Most transmitters use heterodyne principle, so they also have a frequency conversion units. Confusingly, the high-power amplifier which the exciter then feeds into is often called the "transmitter" by broadcast engineers. The final output is given as transmitter power output (TPO), although this is not what most stations are rated by.

Effective radiated power (ERP) is used when calculating station coverage, even for most non-broadcast stations. It is the TPO, minus any attenuation or radiated loss in the line to the antenna, multiplied by the gain (magnification) which the antenna provides toward the horizon. This antenna gain is important, because achieving a desired signal strength without it would result in an enormous electric utility bill for the transmitter, and a

prohibitively expensive transmitter. For most large stations in the VHF- and UHF-range, the transmitter power is no more than 20% of the ERP.

For VLF, LF, MF and HF the ERP is typically not determined separately. In most cases the transmission power found in lists of transmitters is the value for the output of the transmitter. This is only correct for omnidirectional aerials with a length of a quarter wavelength or shorter. For other aerial types there are gain factors, which can reach values until 50 for shortwave directional beams in the direction of maximum beam intensity.

Since some authors take account of gain factors of aerials of transmitters for frequencies below 30 MHz and others not, there are often discrepancies of the values of transmitted powers.

Power supply

Transmitters are sometimes fed from a higher voltage level of the power supply grid than necessary in order to improve security of supply. For example, the Allouis, Konstantynow and Roumoules transmitters are fed from the high-voltage network (110 kV in Alouis and Konstantynow, 150 kV in Roumoules) even though a power supply from the medium-voltage level of the power grid (about 20 kV) would be able to deliver enough power.

Cooling of final stages

Low-power transmitters do not require special cooling equipment. Modern transmitters can be incredibly efficient, with efficiencies exceeding 98 percent. However, a broadcast transmitter with a megawatt power stage transferring 98% of that into the antenna can also be viewed as a 20 kilowatt electric heater.

For medium-power transmitters, up to a few hundred watts, air cooling with fans is used. At power levels over a few kilowatts, the output stage is cooled by a forced liquid cooling system analogous to an automobile cooling system. Since the coolant directly touches the high-voltage anodes of the tubes, only distilled, deionised water or a special dielectric coolant can be used in the cooling circuit. This high-purity coolant is in turn cooled by a heat exchanger, where the second cooling circuit can use water of ordinary quality because it is not in contact with energized parts. Very-high-power tubes of small physical size may use evaporative cooling by water in contact with the anode. The production of steam allows a high heat flow in a small space.

Protection equipment

The high voltages used in high power transmitters (up to 40 kV) require extensive protection equipment. Also, transmitters are exposed to damage from lightning. Transmitters may be damaged if operated without an antenna, so protection circuits must detect the loss of the antenna and switch off the transmitter immediately. Tube-based transmitters must have power applied in the proper sequence, with the filament voltage applied before the anode voltage, otherwise the tubes can be damaged. The output stage

must be monitored for standing waves, which indicate that generated power is not being radiated but instead is being reflected back into the transmitter.

Lightning protection is required between the transmitter and antenna. This consists of spark gaps and gas-filled surge arresters to limit the voltage that appears on the transmitter terminals. The control instrument that measures the voltage standing-wave ratio switches the transmitter off briefly if a higher voltage standing-wave ratio is detected after a lightning strike, as the reflections are probably due to lightning damage. If this does not succeed after several attempts, the antenna may be damaged and the transmitter should remain switched off. In some transmitting plants UV detectors are fitted in critical places, to switch off the transmitter if an arc is detected. The operating voltages, modulation factor, frequency and other transmitter parameters are monitored for protection and diagnostic purposes, and may be displayed locally and/or at a remote control room.

Building

A commercial transmitter site will usually have a control building to shelter the transmitter components and control devices. This is usually a purely functional building, which may contain apparatus for both radio and television transmitters. To reduce transmission line loss the transmitter building is usually immediately adjacent to the antenna for VHF and UHF sites, but for lower frequencies it may be desirable to have a distance of a few score or several hundred metres between the building and the antenna. Some transmitting towers have enclosures built into the tower to house radio relay link transmitters or other, relatively low-power transmitters. A few transmitter buildings may include limited broadcasting facilities to allow a station to use the building as a backup studio in case of incapacitation of the main facility.

Legal and regulatory aspects

Since radio waves go over borders, international agreements control radio transmissions. In European countries like Germany often the national Post Office is the regulating authority. In the United States broadcast and industrial transmitters are regulated by the Federal Communications Commission (FCC). In Canada technical aspects of broadcast and radio transmitters are controlled by Industry Canada, but broadcast content is regulated separately by the Canadian Radio-television and Telecommunications Commission (CRTC). In Australia transmitters, spectrum, and content are controlled by the Australian Communications and Media Authority (ACMA). The International Telecommunication Union (ITU) helps managing the radio-frequency spectrum internationally.

Planning

As in any costly project, the planning of a high power transmitter site requires great care. This begins with the location. A minimum distance, which depends on the transmitter frequency, transmitter power, and the design of the transmitting antennas, is required to protect people from the radio frequency energy. Antenna towers are often very tall and therefore flight paths must be evaluated. Sufficient electric power must be available for high power transmitters. Transmitters for long and medium wave require good grounding

and soil of high electrical conductivity. Locations at the sea or in river valleys are ideal, but the flood danger must be considered. Transmitters for UHF are best on high mountains to improve the range. The antenna pattern must be considered because it is costly to change the pattern of a long-wave or medium-wave antenna.
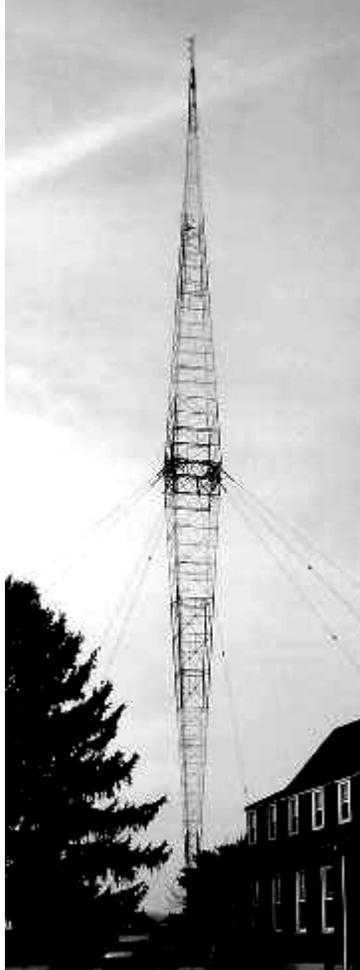
Antenna guyed tower

Transmitting antennas for long and medium wave are usually implemented as a mast radiator. Similar antennas with smaller dimensions are used also for short wave transmitters, if these send in the round spray enterprise. For arranging radiation at free standing steel towers fastened planar arrays are used. Radio towers for UHF and TV transmitters can be implemented in principle as grounded constructions. Towers may be steel lattice masts or reinforced concrete towers with antennas mounted at the top. Some transmitting towers for UHF have high-altitude operating rooms and/or facilities such as restaurants and observation platforms, which are accessible by elevator. Such towers are usually called TV tower. For microwaves one frequently uses parabolic antennas. These can be set up for applications of radio relay links on transmitting towers for FM to special platforms. For example, large parabolic antennas ranging from 3 to 100 meters in diameter are necessary to pass on signals to television satellites and space vehicles. These plants, which can be used if necessary also as radio telescope, are established on free standing constructions, whereby there are also numerous special designs, like the radio telescope in Arecibo.

Just as important as the planning of the construction and location of the transmitter is how its output fits in with existing transmissions. Two transmitters cannot broadcast on the same frequency in the same area as this would cause co-channel interference. For a good example of how the channel planners have dovetailed different transmitters' outputs see Crystal Palace UHF TV channel allocations. This reference also provides a good example of a grouped transmitter, in this case an A group. That is, all of its output is within the bottom third of the UK UHF television broadcast band. The other two groups (B and C/D) utilise the middle and top third of the band. By replicating this grouping across the country (using different groups for adjacent transmitters), co-channel interference can be minimised, and in addition, those in marginal reception areas can use more efficient grouped receiving antennas. Unfortunately, in the UK, this carefully planned system has had to be compromised with the advent of digital broadcasting which (during the changeover period at least) requires yet more channel space, and consequently the additional digital broadcast channels cannot always be fitted within the transmitter's existing group. Thus many UK transmitters have become "wideband" with the consequent need for replacement of receiving antennas. Once the Digital Switch Over (DSO) occurs the plan is that most transmitters will revert to their original groups, source Ofcom July 2007.

Further complication arises when adjacent transmitters have to transmit on the same frequency and under these circumstances the broadcast radiation patterns are attenuated in the relevant direction(s). A good example of this is in the United Kingdom, where the Waltham transmitting station broadcasts at high power on the same frequencies as the Sandy Heath transmitting station's high power transmissions, with the two being only 50 miles apart. Thus Waltham's antenna array does not broadcast these two channels in the direction of Sandy Heath and vice versa.

Where a particular service needs to have wide coverage, this is usually achieved by using multiple transmitters at different locations. Usually, these transmitters will operate at different frequencies to avoid interference where coverage overlaps. Examples include national broadcasting networks and cellular networks. In the latter, frequency switching is automatically done by the receiver as necessary, in the former, manual retuning is more common (though the Radio Data System is an example of automatic frequency switching in broadcast networks). Another system for extending coverage using multiple transmitters is quasi-synchronous transmission, but this is rarely used nowadays.

Main and relay (repeater) transmitters

Transmitting stations are usually either classified as main stations or relay stations (also known as repeaters, translators or sometimes "transposers".)

Main stations are defined as those that generate their own modulated output signal from a baseband (unmodulated) input. Usually main stations operate at high power and cover large areas.

Relay stations (translators) take an already modulated input signal, usually by direct reception of a parent station off the air, and simply rebroadcast it on another frequency. Usually relay stations operate at medium or low power, and are used to fill in pockets of poor reception within, or at the fringe of, the service area of a parent main station.

Note that a main station may also take its input signal directly off-air from another station, however this signal would be fully demodulated to baseband first, processed, and then remodulated for transmission.

Transmitters in culture

Some cities in Europe, like Mühlacker, Ismaning, Langenberg, Kalundborg, Hörby and Allouis became famous as sites of powerful transmitters. For example, Goliath transmitter was a VLF transmitter of the German Navy during World War II located near Kalbe an der Milde in Saxony-Anhalt, Germany. Some transmitting towers like the radio tower Berlin or the TV tower Stuttgart have become landmarks of cities. Many transmitting plants have very high radio towers that are masterpieces of engineering.

Having the tallest building in the world, the nation, the state/province/prefecture, city, etc., has often been considered something to brag about. Often, builders of high-rise buildings have used transmitter antennas to lay claim to having the tallest building. A historic example was the "tallest building" feud between the Chrysler Building and the Empire State Building in New York, New York.

Some towers have an observation deck accessible to tourists. An example is the Ostankino Tower in Moscow, which was completed in 1967 on the 50th anniversary of the October Revolution to demonstrate the technical abilities of the Soviet Union. As very tall radio towers of any construction type are prominent landmarks, requiring careful planning and construction, and high-power transmitters especially in the long- and medium-wave ranges can be received over long distances, such facilities were often mentioned in propaganda. Other examples were the Deutschlandsender Herzberg/Elster and the Warsaw Radio Mast.

KVLY-TV's tower located near Blanchard, North Dakota was the tallest artificial structure in the world when it was completed in 1963. It was surpassed in 1974 by the Warszawa radio mast, but regained its title when the latter collapsed in 1991. It was surpassed by the Burj Khalifa skyscraper in early 2009, but the KVLY-TV mast is still the tallest transmitter.

Records

- Tallest radio/television mast:
  - 1974–1991: Konstantynow for 2000 kW longwave transmitter, 646.38 m (2120 ft 8 in)
  - 1963–1974 and since 1991: KVLY Tower, 2,063 ft (628.8 m)

- Highest power:
  - Longwave, Taldom transmitter, 2500 kW
  - Medium wave, Bolshakovo transmitter, 2500 kW

- Highest transmission sites (Europe):
  - FM Pic du Aigu in Chamonix
  - MW Pic Blanc in Andorra

Chapter 11

Radar
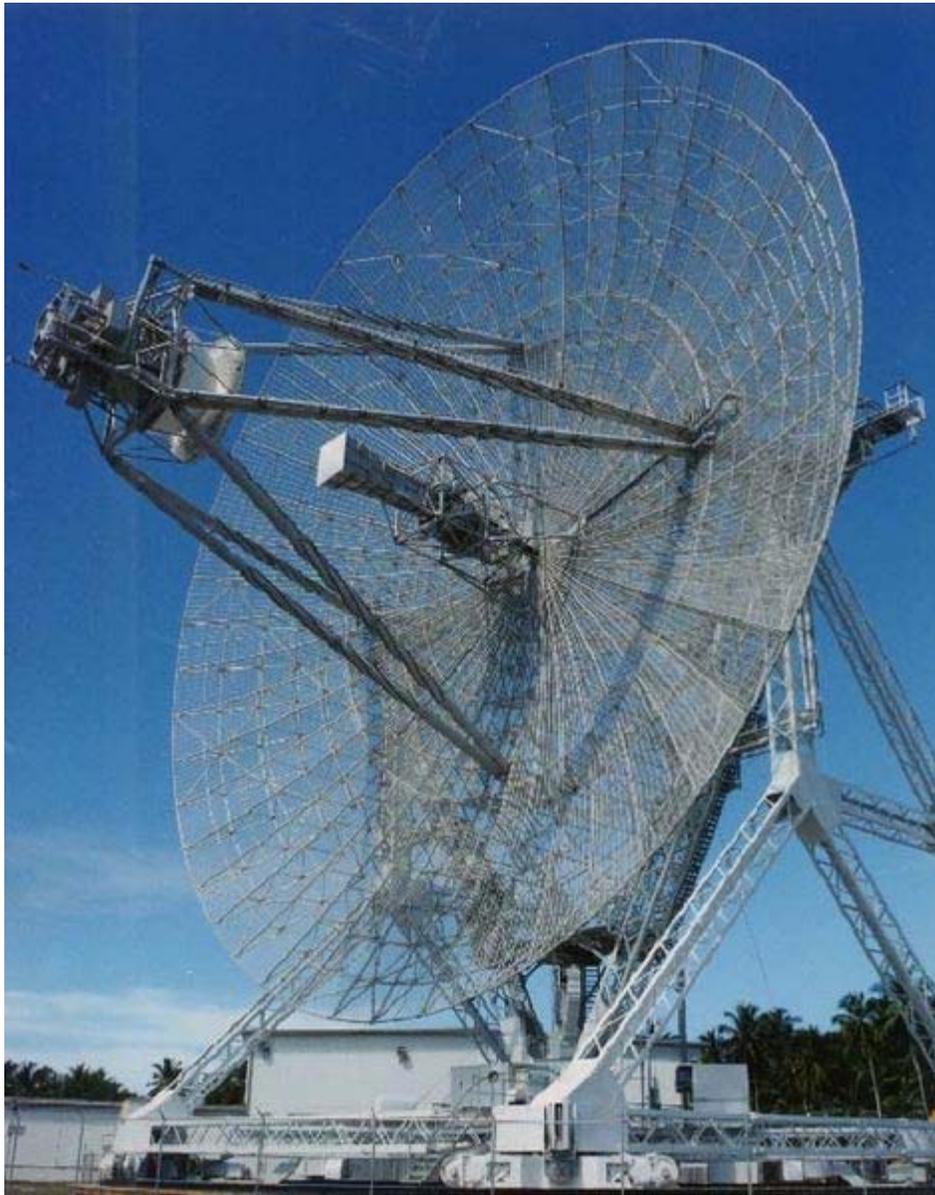
A long-range radar antenna, known as *ALTAIR*, used to detect and track space objects in conjunction with ABM testing at the Ronald Reagan Test Site on Kwajalein Atoll.

Israeli military radar is typical of the type of radar used for air traffic control. The antenna rotates at a steady rate, sweeping the local airspace with a narrow vertical fan-shaped beam, to detect aircraft at all altitudes.

Radar is an object-detection system which uses electromagnetic waves — specifically radio waves — to determine the range, altitude, direction, or speed of both moving and fixed objects such as aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain. The radar dish, or antenna, transmits pulses of radio waves or microwaves which bounce off any object in their path. The object returns a tiny part of the wave's energy to a dish or antenna which is usually located at the same site as the transmitter.

Practical radar was developed in secrecy during World War II by Britain and other nations. The term *RADAR* was coined in 1940 by the U.S. Navy as an acronym for *radio detection and ranging*. The term *radar* has since entered the English and other languages as the common noun *radar*, losing all capitalization. In the United Kingdom, this technology was initially called RDF (*range and direction finding*), using the same acronym as the one for radio direction finding to conceal its ranging capability.

The modern uses of radar are highly diverse, including air traffic control, radar astronomy, air-defense systems, antimissile systems; nautical radars to locate landmarks and other ships; aircraft anticollision systems; ocean-surveillance systems, outer-space surveillance and rendezvous systems; meteorological precipitation monitoring; altimetry and flight-control systems; guided-missile target-locating systems; and ground-penetrating radar geological observations.

Other systems similar to radar have been used in other parts of the electromagnetic spectrum. One example is "lidar", which uses visible light from lasers rather than radio waves.

History

Several inventors, scientists, and engineers contributed to the development of radar.

As early as 1886, Heinrich Hertz showed that radio waves could be reflected from solid objects. In 1895 Alexander Popov, a physics instructor at the Imperial Russian Navy school in Kronstadt, developed an apparatus using a coherer tube for detecting distant lightning strikes. The next year, he added a spark-gap transmitter. During 1897, while testing this in communicating between two ships in the Baltic Sea, he took note of an interference beat caused by the passage of a third vessel. In his report, Popov wrote that this phenomenon might be used for detecting objects, but he did nothing more with this observation.

The German Christian Hülsmeyer was the first to use radio waves to detect "the presence of distant metallic objects". In 1904 he demonstrated the feasibility of detecting a ship in dense fog, but not its distance. He received Reichspatent Nr. 165546 for his detection device in April 1904, and later patent 169154 for a related amendment for also determining the distance to the ship. He also received a British patent on September 23, 1904 for the first full Radar application, which he called *telemobiloscope*.

A Chain Home tower in Great Baddow, United Kingdom.

In August 1917 Nikola Tesla outlined a concept for primitive radar units. He stated, "[...] *by their* [standing electromagnetic waves] *use we may produce at will, from a sending station, an electrical effect in any particular region of the globe;* [with which] *we may determine the relative position or course of a moving object, such as a vessel at sea, the distance traversed by the same, or its speed*."

In 1922 A. Hoyt Taylor and Leo C. Young, researchers working with the U.S. Navy, discovered that when radio waves were broadcast at 60 MHz it was possible to determine the range and bearing of nearby ships in the Potomac River. Despite Taylor's suggestion that this method could be used in darkness and low visibility, the Navy did not immediately continue the work. Serious investigation began eight years later after the discovery that radar could be used to track airplanes.

Before the Second World War, researchers in France, Germany, Italy, Japan, the Netherlands, the Soviet Union, the United Kingdom, and the United Staes, independently and in great secrecy, developed technologies that led to the modern version of radar. Australia, Canada, New Zealand, and South Africa followed prewar Great Britain, and Hungary had similar developments during the war.

In 1934 the Frenchman Émile Girardeau stated he was building an obstacle-locating radio apparatus "conceived according to the principles stated by Tesla" and obtained a patent

(French Patent n° 788795 in 1934) for a working system, a part of which was installed on the Normandie liner in 1935. During the same year, the Soviet military engineer P.K.Oschepkov, in collaboration with Leningrad Electrophysical Institute, produced an experimental apparatus, RAPID, capable of detecting an aircraft within 3 km of a receiver. The French and Soviet systems, however, had continuous-wave operation and could not give the full performance that was ultimately at the center of modern radar.

Full radar evolved as a pulsed system, and the first such elementary apparatus was demonstrated in December 1934 by the American Robert M. Page, working at the Naval Research Laboratory. The year after the US Army successfully tested a primitive surface to surface radar to aim coastal battery search lights at night. This was followed by a pulsed system demonstrated in May 1935 by Rudolf Kühnhold and the firm GEMA in Germany and then one in June 1935 by an Air Ministry team led by Robert A. Watson Watt in Great Britain. Later, in 1943, Page greatly improved radar with the monopulse technique that was then used for many years in most radar applications.

The British were the first to fully exploit radar as a defence against aircraft attack. This was spurred on by fears that the Germans were developing death rays. The Air Ministry asked British scientists in 1934 to investigate the possibility of propagating electromagnetic energy and the likely effect. Following a study, they concluded that a death ray was impractical but that detection of aircraft appeared feasible. Robert Watson Watt's team demonstrated to his superiors the capabilities of a working prototype and then patented the device (British Patent GB593017). It served as the basis for the Chain Home network of radars to defend Great Britain. In April 1940, *Popular Science* showed an example of a radar unit using the Watson-Watt patent in an article on air defence, but not knowing that the U.S. Army and U.S. Navy were working on radars with the same principle, stated under the illustration, "This is not U.S. Army equipment."

The war precipitated research to find better resolution, more portability, and more features for radar, including complementary navigation systems like Oboe used by the RAF's Pathfinder. The postwar years have seen the use of radar in fields as diverse as air traffic control, weather monitoring, astrometry, and road speed control.

Applications of radar

Commercial marine radar antenna. The rotating antenna radiates a vertical fan-shaped beam.

The information provided by radar includes the bearing and range (and therefore position) of the object from the radar scanner. It is thus used in many different fields where the need for such positioning is crucial. The first use of radar was for military purposes: to locate air, ground and sea targets. This evolved in the civilian field into applications for aircraft, ships, and roads.

In aviation, aircraft are equipped with radar devices that warn of obstacles in or approaching their path and give accurate altitude readings. They can land in fog at airports equipped with radar-assisted ground-controlled approach (GCA) systems, in which the plane's flight is observed on radar screens while operators radio landing directions to the pilot.

Marine radars are used to measure the bearing and distance of ships to prevent collision with other ships, to navigate and to fix their position at sea when within range of shore or other fixed references such as islands, buoys, and lightships. In port or in harbour, vessel traffic service radar systems are used to monitor and regulate ship movements in busy waters. Police forces use radar guns to monitor vehicle speeds on the roads.

Radar has invaded many other fields. Meteorologists use radar to monitor precipitation. It has become the primary tool for short-term weather forecasting and to watch for severe weather such as thunderstorms, tornadoes, winter storms, precipitation types, etc. Geologists use specialised ground-penetrating radars to map the composition of the Earth's crust.

Principles

A radar system has a transmitter that emits radio waves called *radar signals* in predetermined directions. When these come into contact with an object they are usually reflected and/or scattered in many directions. Radar signals are reflected especially well by materials of considerable electrical conductivity—especially by most metals, by seawater, by wet land, and by wetlands. Some of these make the use of radar altimeters possible. The radar signals that are reflected back towards the transmitter are the desirable ones that make radar work. If the object is *moving* either closer or farther away, there is a slight change in the frequency of the radio waves, due to the Doppler effect.

Radar receivers are usually, but not always, in the same location as the transmitter. Although the reflected radar signals captured by the receiving antenna are usually very weak, these signals can be strengthened by the electronic amplifiers that all radar sets contain. More sophisticated methods of signal processing are also nearly always used in order to recover useful radar signals.

The weak absorption of radio waves by the medium through which it passes is what enables radar sets to detect objects at relatively-long ranges—ranges at which other electromagnetic wavelengths, such as visible light, infrared light, and ultraviolet light, are too strongly attenuated. In particular, there are weather conditions under which radar works well regardless of the weather. Such things as fog, clouds, rain, falling snow, and sleet that block visible light are usually transparent to radio waves. Certain, specific radio frequencies that are absorbed or scattered by water vapor, raindrops, or atmospheric gases (especially oxygen) are avoided in designing radars except when detection of these is intended.

Finally, radar relies on its own transmissions, rather than light from the Sun or the Moon, or from electromagnetic waves emitted by the objects themselves, such as infrared wavelengths (heat). This process of directing artificial radio waves towards objects is called *illumination*, regardless of the fact that radio waves are completely invisible to the human eye or cameras.

Reflection
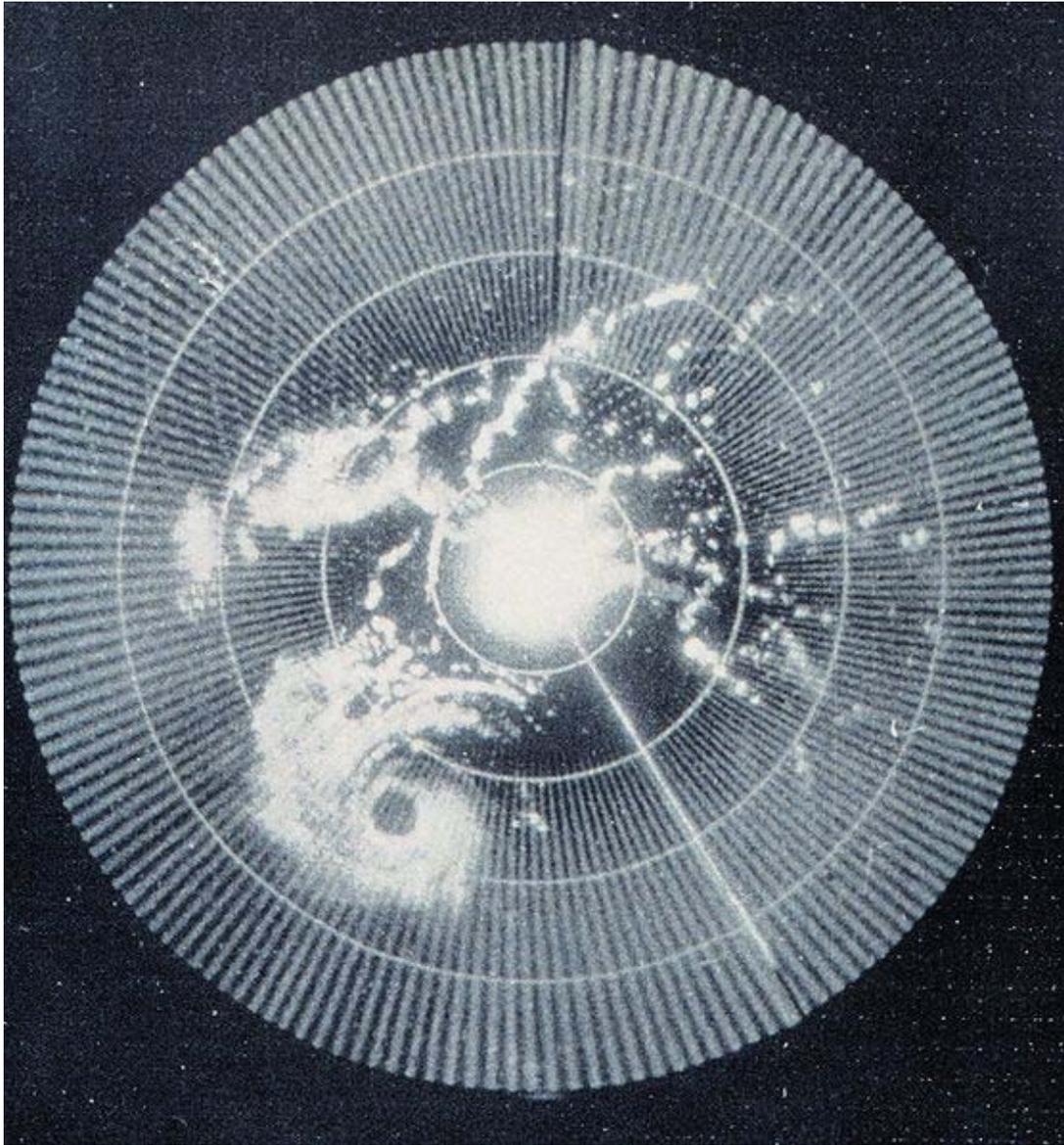
Brightness can indicate reflectivity as in this 1960 weather radar image (of Hurricane Abby). The radar's frequency, pulse form, polarization, signal processing, and antenna determine what it can observe.

Electromagnetic waves reflect (scatter) from any large change in the dielectric constant or diamagnetic constants. This means that a solid object in air or a vacuum, or other significant change in atomic density between the object and what is surrounding it, will usually scatter radar (radio) waves. This is particularly true for electrically conductive materials, such as metal and carbon fiber, making radar particularly well suited to the detection of aircraft and ships. Radar absorbing material, containing resistive and sometimes magnetic substances, is used on military vehicles to reduce radar reflection. This is the radio equivalent of painting something a dark color so that it cannot be seen through normal means.

Radar waves scatter in a variety of ways depending on the size (wavelength) of the radio wave and the shape of the target. If the wavelength is much shorter than the target's size, the wave will bounce off in a way similar to the way light is reflected by a mirror. If the wavelength is much longer than the size of the target, the target may not be visible due to poor reflection. Low Frequency radar technology is dependent on resonances for detection, but not identification, of targets. This is described by Rayleigh scattering, an effect that creates the Earth's blue sky and red sunsets. When the two length scales are comparable, there may be resonances. Early radars used very long wavelengths that were larger than the targets and received a vague signal, whereas some modern systems use shorter wavelengths (a few centimeters or shorter) that can image objects as small as a loaf of bread.

Short radio waves reflect from curves and corners, in a way similar to glint from a rounded piece of glass. The most reflective targets for short wavelengths have 90° angles between the reflective surfaces. A structure consisting of three flat surfaces meeting at a single corner, like the corner on a box, will always reflect waves entering its opening directly back at the source. These so-called corner reflectors are commonly used as radar reflectors to make otherwise difficult-to-detect objects easier to detect, and are often found on boats in order to improve their detection in a rescue situation and to reduce collisions.

For similar reasons, objects attempting to avoid detection will angle their surfaces in a way to eliminate inside corners and avoid surfaces and edges perpendicular to likely detection directions, which leads to "odd" looking stealth aircraft. These precautions do not completely eliminate reflection because of diffraction, especially at longer wavelengths. Half wavelength long wires or strips of conducting material, such as chaff, are very reflective but do not direct the scattered energy back toward the source. The extent to which an object reflects or scatters radio waves is called its radar cross section.

Radar equation

The power P_r returning to the receiving antenna is given by the radar equation:

$$P_r = \frac{P_t G_t A_r \sigma F^4}{(4\pi)^2 R_t^2 R_r^2}$$

where

- P_t = transmitter power
- G_t = gain of the transmitting antenna
- A_r = effective aperture (area) of the receiving antenna
- σ = radar cross section, or scattering coefficient, of the target
- F = pattern propagation factor
- R_t = distance from the transmitter to the target
- R_r = distance from the target to the receiver.

In the common case where the transmitter and the receiver are at the same location, $R_t = R_r$ and the term $R_t^2 R_r^2$ can be replaced by R^4, where R is the range. This yields:

$$P_r = \frac{P_t G_t A_r \sigma F^4}{(4\pi)^2 R^4}.$$

This shows that the received power declines as the fourth power of the range, which means that the reflected power from distant targets is very, very small.

The equation above with $F = 1$ is a simplification for vacuum without interference. The propagation factor accounts for the effects of multipath and shadowing and depends on the details of the environment. In a real-world situation, pathloss effects should also be considered.

Doppler effect

Ground-based radar systems used for detecting speeds rely on the Doppler effect. The apparent frequency (f) of the wave changes with the relative position of the target. The doppler equation is stated as follows for v_{obs} (the radial speed of the observer) and v_s (the radial speed of the target) and f_0 frequency of wave :

$$f = \frac{v + v_{obs}}{v - v_s} f_0$$

However, the change in phase of the return signal is often used instead of the change in frequency. It is to be noted that only the radial component of the speed is available. Hence when a target is moving at right angle to the radar beam, it has no velocity while one parallel to it has maximum recorded speed even if both might have the same real absolute motion.

Polarization

In the transmitted radar signal, the electric field is perpendicular to the direction of propagation, and this direction of the electric field is the polarization of the wave. Radars use horizontal, vertical, linear and circular polarization to detect different types of reflections. For example, circular polarization is used to minimize the interference caused by rain. Linear polarization returns usually indicate metal surfaces. Random polarization returns usually indicate a fractal surface, such as rocks or soil, and are used by navigation radars.
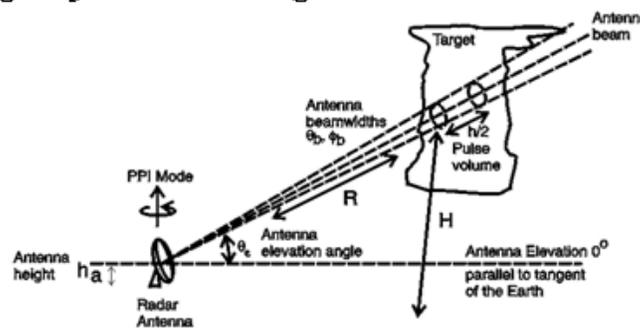
Limiting factors

Beam path and range

BEAM HEIGHT WITH DISTANCE (AGL)

$$H=\left(\sqrt{r^2+(k_e a_e)^2+2r k_e a_e \sin(\theta_e)}\right)-k_e a_e+h_a$$

$r :$ *distance* $k_e :$ *4/3 (Standard refraction coefficient)*

$a_e :$ *Earth radius* $\theta_e :$ *Elevation angle*

$h_a :$ *Height of radar above ground*

Echo heights above ground

The radar beam would follow a linear path in vacuum but it really follows a somewhat curved path in the atmosphere due to the variation of the refractive index of air. Even when the beam is emitted parallel to the ground, it will raise above it as the Earth curvature sink below the horizon. Furthermore, the signal is attenuated by the medium it crosses and the beam disperse as its not a perfect pencil shape.

The maximum range of a conventional radar can either be limited by a number of factors:

1. Line of sight, which depends on height above ground.
2. The maximum non-ambiguous range (MUR) which is determined by the Pulse repetition frequency (PRF). Simply put, MUR is the distance the pulse could travel and return before the next pulse is emitted.
3. Radar sensitivity and power of the return signal as computed in the radar equation. This includes factors such as environmentals and the size (or radar cross section) of the target.

Noise

Signal noise is an internal source of random variations in the signal, which is generated by all electronic components. Noise typically appears as random variations superimposed

on the desired echo signal received in the radar receiver. The lower the power of the desired signal, the more difficult it is to discern it from the noise (similar to trying to hear a whisper while standing near a busy road). Noise figure is a measure of the noise produced by a receiver compared to an ideal receiver, and this needs to be minimized.

Noise is also generated by external sources, most importantly the natural thermal radiation of the background scene surrounding the target of interest. In modern radar systems, due to the high performance of their receivers, the internal noise is typically about equal to or lower than the external scene noise. An exception is if the radar is aimed upwards at clear sky, where the scene is so "cold" that it generates very little thermal noise.

There will be also flicker noise due to electrons transit, but depending on 1/f, will be much lower than thermal noise when the frequency is high. Hence, in pulse radar, the system will be always heterodyne.

Interference

Radar systems must overcome unwanted signals in order to focus only on the actual targets of interest. These unwanted signals may originate from internal and external sources, both passive and active. The ability of the radar system to overcome these unwanted signals defines its signal-to-noise ratio (SNR). SNR is defined as the ratio of a signal power to the noise power within the desired signal.

In less technical terms, SNR compares the level of a desired signal (such as targets) to the level of background noise. The higher a system's SNR, the better it is in isolating actual targets from the surrounding noise signals.

Clutter

Clutter refers to radio frequency (RF) echoes returned from targets which are uninteresting to the radar operators. Such targets include natural objects such as ground, sea, precipitation (such as rain, snow or hail), sand storms, animals (especially birds), atmospheric turbulence, and other atmospheric effects, such as ionosphere reflections, meteor trails, and three body scatter spike. Clutter may also be returned from man-made objects such as buildings and, intentionally, by radar countermeasures such as chaff.

Some clutter may also be caused by a long radar waveguide between the radar transceiver and the antenna. In a typical plan position indicator (PPI) radar with a rotating antenna, this will usually be seen as a "sun" or "sunburst" in the centre of the display as the receiver responds to echoes from dust particles and misguided RF in the waveguide. Adjusting the timing between when the transmitter sends a pulse and when the receiver stage is enabled will generally reduce the sunburst without affecting the accuracy of the range, since most sunburst is caused by a diffused transmit pulse reflected before it leaves the antenna.

While some clutter sources may be undesirable for some radar applications (such as storm clouds for air-defence radars), they may be desirable for others (meteorological

radars in this example). Clutter is considered a passive interference source, since it only appears in response to radar signals sent by the radar.

There are several methods of detecting and neutralizing clutter. Many of these methods rely on the fact that clutter tends to appear static between radar scans. Therefore, when comparing subsequent scans echoes, desirable targets will appear to move and all stationary echoes can be eliminated. Sea clutter can be reduced by using horizontal polarization, while rain is reduced with circular polarization (note that meteorological radars wish for the opposite effect, therefore using linear polarization the better to detect precipitation). Other methods attempt to increase the signal-to-clutter ratio.

Constant False Alarm Rate (CFAR, a form of Automatic Gain Control, or AGC) is a method relying on the fact that clutter returns far outnumber echoes from targets of interest. The receiver's gain is automatically adjusted to maintain a constant level of overall visible clutter. While this does not help detect targets masked by stronger surrounding clutter, it does help to distinguish strong target sources. In the past, radar AGC was electronically controlled and affected the gain of the entire radar receiver. As radars evolved, AGC became computer-software controlled, and affected the gain with greater granularity, in specific detection cells.
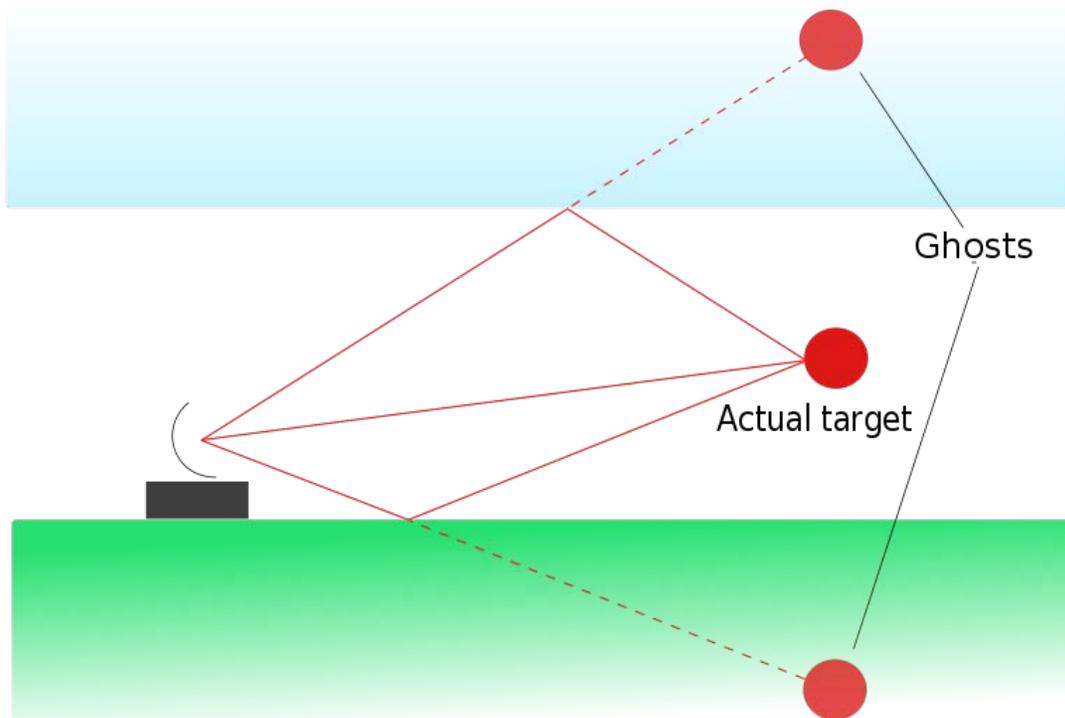
Radar multipath echoes from a target cause ghosts to appear.

Clutter may also originate from multipath echoes from valid targets due to ground reflection, atmospheric ducting or ionospheric reflection/refraction (e.g. Anomalous propagation). This clutter type is especially bothersome, since it appears to move and behave like other normal (point) targets of interest, thereby creating a ghost. In a typical

scenario, an aircraft echo is multipath-reflected from the ground below, appearing to the receiver as an identical target below the correct one. The radar may try to unify the targets, reporting the target at an incorrect height, or—worse—eliminating it on the basis of jitter or a physical impossibility. These problems can be overcome by incorporating a ground map of the radar's surroundings and eliminating all echoes which appear to originate below ground or above a certain height. In newer Air Traffic Control (ATC) radar equipment, algorithms are used to identify the false targets by comparing the current pulse returns, to those adjacent, as well as calculating return improbabilities due to calculated height, distance, and radar timing.

Jamming

Radar jamming refers to radio frequency signals originating from sources outside the radar, transmitting in the radar's frequency and thereby masking targets of interest. Jamming may be intentional, as with an electronic warfare (EW) tactic, or unintentional, as with friendly forces operating equipment that transmits using the same frequency range. Jamming is considered an active interference source, since it is initiated by elements outside the radar and in general unrelated to the radar signals.

Jamming is problematic to radar since the jamming signal only needs to travel one-way (from the jammer to the radar receiver) whereas the radar echoes travel two-ways (radar-target-radar) and are therefore significantly reduced in power by the time they return to the radar receiver. Jammers therefore can be much less powerful than their jammed radars and still effectively mask targets along the line of sight from the jammer to the radar (*Mainlobe Jamming*). Jammers have an added effect of affecting radars along other lines of sight, due to the radar receiver's sidelobes (*Sidelobe Jamming*).

Mainlobe jamming can generally only be reduced by narrowing the mainlobe solid angle, and can never fully be eliminated when directly facing a jammer which uses the same frequency and polarization as the radar. Sidelobe jamming can be overcome by reducing receiving sidelobes in the radar antenna design and by using an omnidirectional antenna to detect and disregard non-mainlobe signals. Other anti-jamming techniques are frequency hopping and polarization.

Interference has recently become a problem for C-band (5.66 GHz) meteorological radars with the proliferation of 5.4 GHz band WiFi equipment.
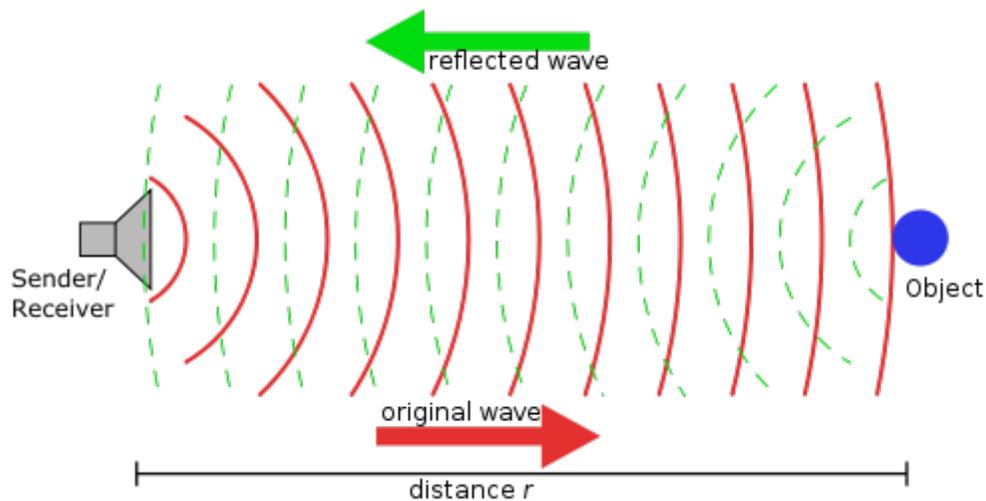
Radar signal processing

Distance measurement

Transit time
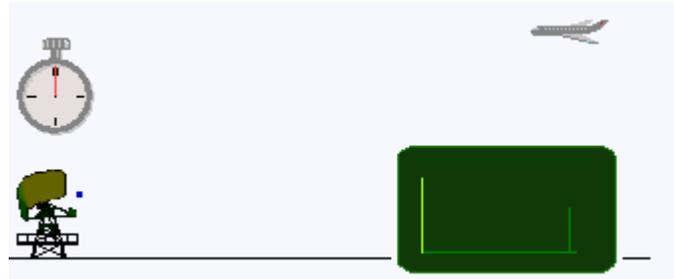
Pulse radar: The round-trip time for the radar pulse to get to the target and return is measured. The distance is proportional to this time.

Continuous wave (CW) radar

One way to measure the distance to an object is to transmit a short pulse of radio signal (electromagnetic radiation), and measure the time it takes for the reflection to return. The distance is one-half the product of the round trip time (because the signal has to travel to the target and then back to the receiver) and the speed of the signal. Since radio waves travel at the speed of light (186,000 miles per second or 300,000,000 meters per second), accurate distance measurement requires high-performance electronics.

In most cases, the receiver does not detect the return while the signal is being transmitted. Through the use of a device called a *duplexer*, the radar switches between transmitting and receiving at a predetermined rate. The minimum range is calculated by measuring the length of the pulse multiplied by the speed of light, divided by two. In order to detect closer targets one must use a shorter pulse length.

A similar effect imposes a maximum range as well. If the return from the target comes in when the next pulse is being sent out, once again the receiver cannot tell the difference.

In order to maximize range, longer times between pulses should be used, referred to as a pulse repetition time (PRT), or its reciprocal, pulse repetition frequency (PRF).

These two effects tend to be at odds with each other, and it is not easy to combine both good short range and good long range in a single radar. This is because the short pulses needed for a good minimum range broadcast have less total energy, making the returns much smaller and the target harder to detect. This could be offset by using more pulses, but this would shorten the maximum range again. So each radar uses a particular type of signal. Long-range radars tend to use long pulses with long delays between them, and short range radars use smaller pulses with less time between them. This pattern of pulses and pauses is known as the pulse repetition frequency (or PRF), and is one of the main ways to characterize a radar. As electronics have improved many radars now can change their PRF thereby changing their range. The newest radars fire 2 pulses during one cell, one for short range 10 km / 6 miles and a separate signal for longer ranges 100 km /60 miles.

The distance resolution and the characteristics of the received signal as compared to noise depends heavily on the shape of the pulse. The pulse is often modulated to achieve better performance using a technique known as pulse compression.

Distance may also be measured as a function of time. The radar mile is the amount of time it takes for a radar pulse to travel one nautical mile, reflect off a target, and return to the radar antenna. Since a nautical mile is defined as *exactly* 1,852 meters, then dividing this distance by the speed of light (*exactly* 299,792,458 meters per second), and then multiplying the result by 2 (round trip = twice the distance), yields a result of approximately 12.36 microseconds in duration.

Frequency modulation

Another form of distance measuring radar is based on frequency modulation. Frequency comparison between two signals is considerably more accurate, even with older electronics, than timing the signal. By measuring the frequency of the returned signal and comparing that with the original, the difference can be easily measured.

This technique can be used in continuous wave radar, and is often found in aircraft radar altimeters. In these systems a "carrier" radar signal is frequency modulated in a predictable way, typically varying up and down with a sine wave or sawtooth pattern at audio frequencies. The signal is then sent out from one antenna and received on another, typically located on the bottom of the aircraft, and the signal can be continuously compared using a simple *beat frequency* modulator that produces an audio frequency tone from the returned signal and a portion of the transmitted signal.

Since the signal frequency is changing, by the time the signal returns to the aircraft the broadcast has shifted to some other frequency. The amount of that shift is greater over longer times, so greater frequency differences mean a longer distance, the exact amount being the "ramp speed" selected by the electronics. The amount of shift is therefore directly related to the distance traveled, and can be displayed on an instrument. This signal processing is similar to that used in speed detecting Doppler radar. Example systems using this approach are AZUSA, MISTRAM, and UDOP.

A further advantage is that the radar can operate effectively at relatively low frequencies, comparable to that used by UHF television. This was important in the early development of this type when high frequency signal generation was difficult or expensive.

A new terrestrial radar uses low-power FM signals that cover a larger frequency range. The multiple reflections are analyzed mathematically for pattern changes with multiple passes creating a computerized synthetic image. Doppler effects are not used which allows slow moving objects to be detected as well as largely eliminating "noise" from the surfaces of bodies of water. Used primarily for detection of intruders approaching in small boats or intruders crawling on the ground toward an objective.

Speed measurement

Speed is the change in distance to an object with respect to time. Thus the existing system for measuring distance, combined with a memory capacity to see where the target last was, is enough to measure speed. At one time the memory consisted of a user making grease-pencil marks on the radar screen, and then calculating the speed using a slide rule. Modern radar systems perform the equivalent operation faster and more accurately using computers.

However, if the transmitter's output is coherent (phase synchronized), there is another effect that can be used to make almost instant speed measurements (no memory is required), known as the Doppler effect. Most modern radar systems use this principle in the pulse-doppler radar system. Return signals from targets are shifted away from this base frequency via the Doppler effect enabling the calculation of the speed of the object relative to the radar. The Doppler effect is only able to determine the relative speed of the target along the line of sight from the radar to the target. Any component of target velocity perpendicular to the line of sight cannot be determined by using the Doppler effect alone, but it can be determined by tracking the target's azimuth over time. Additional information of the nature of the Doppler returns may be found in the radar signal characteristics article.

It is also possible to make a radar without any pulsing, known as a continuous-wave radar (CW radar), by sending out a very pure signal of a known frequency. CW radar is ideal for determining the radial component of a target's velocity, but it cannot determine the target's range. CW radar is typically used by traffic enforcement to measure vehicle speed quickly and accurately where range is not important.

Other mathematical developments in radar signal processing include time-frequency analysis (Weyl Heisenberg or wavelet), as well as the chirplet transform which makes use of the fact that radar returns from moving targets typically "chirp" (change their frequency as a function of time, as does the sound of a bird or bat).

Reduction of interference effects

Signal processing is employed in radar systems to reduce the radar interference effects. Signal processing techniques include moving target indication (MTI), pulse doppler, moving target detection (MTD) processors, correlation with secondary surveillance radar (SSR) targets, space-time adaptive processing (STAP), and track-before-detect (TBD).

Constant false alarm rate (CFAR) and digital terrain model (DTM) processing are also used in clutter environments.

Plot and track extraction

Radar video returns on aircraft can be subjected to a plot extraction process whereby spurious and interfering signals are discarded. A sequence of target returns can be monitored through a device known as a plot extractor. The non relevant real time returns can be removed from the displayed information and a single plot displayed. In some radar systems, or alternatively in the command and control system to which the radar is connected, a radar tracker is used to associate the sequence of plots belonging to individual targets and estimate the targets' headings and speeds.

Radar engineering
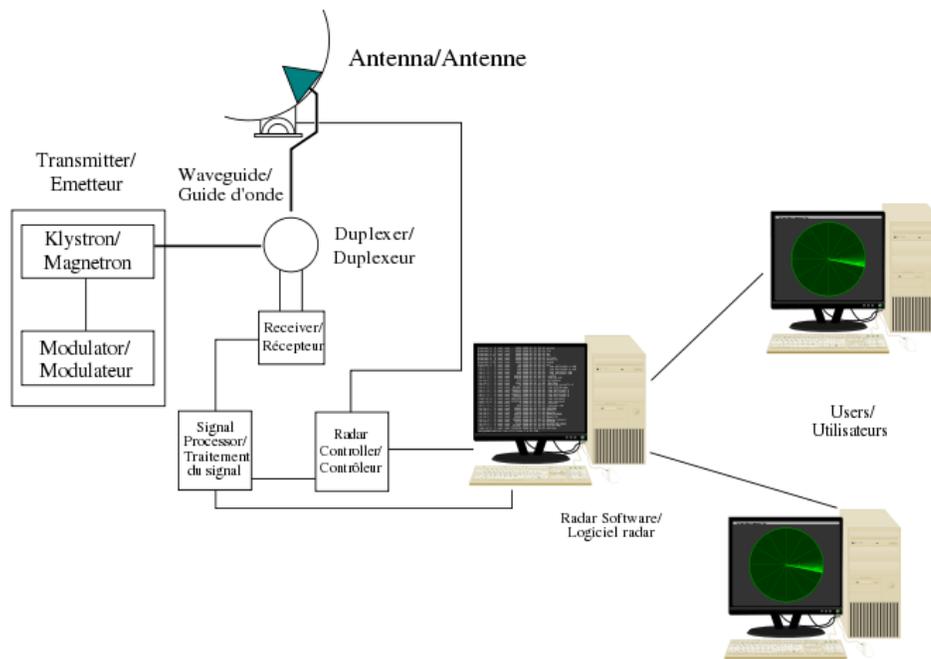
Radar components

A radars components are:

- A transmitter that generates the radio signal with an oscillator such as a klystron or a magnetron and controls its duration by a modulator.
- A waveguide that links the transmitter and the antenna.
- A duplexer that serves as a switch between the antenna and the transmitter or the receiver for the signal when the antenna is used in both situations.
- A receiver. Knowing the shape of the desired received signal (a pulse), an optimal receiver can be designed using a matched filter.

- An electronic section that controls all those devices and the antenna to perform the radar scan ordered by a software.
- A link to end users.

Antenna design

Radio signals broadcast from a single antenna will spread out in all directions, and likewise a single antenna will receive signals equally from all directions. This leaves the radar with the problem of deciding where the target object is located.

Early systems tended to use omni-directional broadcast antennas, with directional receiver antennas which were pointed in various directions. For instance the first system to be deployed, Chain Home, used two straight antennas at right angles for reception, each on a different display. The maximum return would be detected with an antenna at right angles to the target, and a minimum with the antenna pointed directly at it (end on). The operator could determine the direction to a target by rotating the antenna so one display showed a maximum while the other shows a minimum.

One serious limitation with this type of solution is that the broadcast is sent out in all directions, so the amount of energy in the direction being examined is a small part of that transmitted. To get a reasonable amount of power on the "target", the transmitting aerial should also be directional.

Parabolic reflector

More modern systems use a steerable parabolic "dish" to create a tight broadcast beam, typically using the same dish as the receiver. Such systems often combine two radar frequencies in the same antenna in order to allow automatic steering, or **radar lock**.

Parabolic reflectors can be either symmetric parabolas or spoiled parabolas:

- Symmetric parabolic antennas produce a narrow "pencil" beam in both the X and Y dimensions and consequently have a higher gain. The NEXRAD Pulse-Doppler weather radar uses a symmetric antenna to perform detailed volumetric scans of the atmosphere.

Surveillance radar antenna

- Spoiled parabolic antennas produce a narrow beam in one dimension and a relatively wide beam in the other. This feature is useful if target detection over a wide range of angles is more important than target location in three dimensions. Most 2D surveillance radars use a spoiled parabolic antenna with a narrow azimuthal beamwidth and wide vertical beamwidth. This beam configuration allows the radar operator to detect an aircraft at a specific azimuth but at an indeterminate height. Conversely, so-called "nodder" height finding radars use a dish with a narrow vertical beamwidth and wide azimuthal beamwidth to detect an aircraft at a specific height but with low azimuthal precision.

Types of scan

- Primary Scan: A scanning technique where the main antenna aerial is moved to produce a scanning beam, examples include circular scan, sector scan etc.
- Secondary Scan: A scanning technique where the antenna feed is moved to produce a scanning beam, examples include conical scan, unidirectional sector scan, lobe switching etc.
- Palmer Scan: A scanning technique that produces a scanning beam by moving the main antenna and its feed. A Palmer Scan is a combination of a Primary Scan and a Secondary Scan.

Slotted waveguide

Slotted waveguide antenna

Applied similarly to the parabolic reflector, the slotted waveguide is moved mechanically to scan and is particularly suitable for non-tracking surface scan systems, where the vertical pattern may remain constant. Owing to its lower cost and less wind exposure, shipboard, airport surface, and harbour surveillance radars now use this in preference to the parabolic antenna.

Phased array
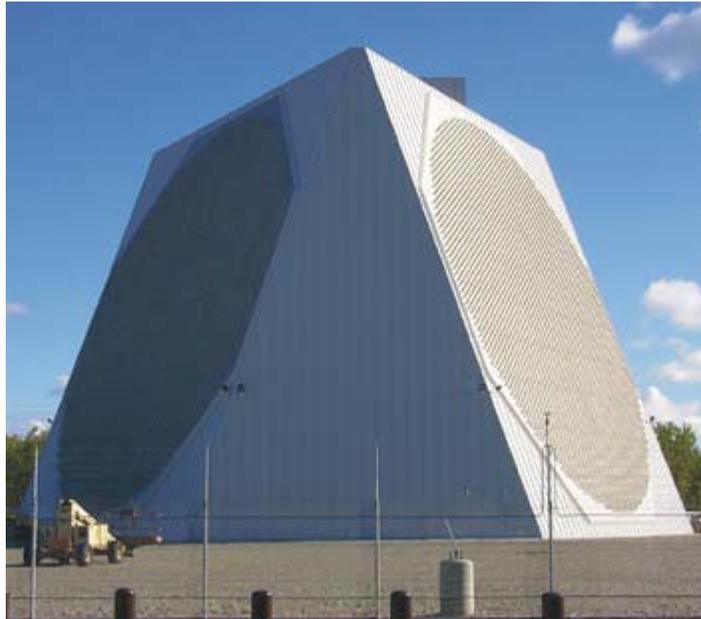
Phased array: Not all radar antennas must rotate to scan the sky.

Another method of steering is used in a phased array radar. This uses an array of similar aerials suitably spaced, the phase of the signal to each individual aerial being controlled so that the signal is reinforced in the desired direction and cancels in other directions. If the individual aerials are in one plane and the signal is fed to each aerial in phase with all others then the signal will reinforce in a direction perpendicular to that plane. By altering the relative phase of the signal fed to each aerial the direction of the beam can be moved because the direction of constructive interference will move. Because phased array radars require no physical movement the beam can scan at thousands of degrees per second, fast enough to irradiate and track many individual targets, and still run a wide-ranging search periodically. By simply turning some of the antennas on or off, the beam can be spread for searching, narrowed for tracking, or even split into two or more virtual radars. However, the beam cannot be effectively steered at small angles to the plane of the array, so for full coverage multiple arrays are required, typically disposed on the faces of a triangular pyramid.

Phased array radars have been in use since the earliest years of radar use in World War II, but limitations of the electronics led to fairly poor accuracy. Phased array radars were originally used for missile defense. They are the heart of the ship-borne Aegis combat system, and the Patriot Missile System, and are increasingly used in other areas because the lack of moving parts makes them more reliable, and sometimes permits a much larger effective antenna, useful in fighter aircraft applications that offer only confined space for mechanical scanning.

As the price of electronics has fallen, phased array radars have become more and more common. Almost all modern military radar systems are based on phased arrays, where the small additional cost is far offset by the improved reliability of a system with no moving parts. Traditional moving-antenna designs are still widely used in roles where

cost is a significant factor such as air traffic surveillance, weather radars and similar systems.

Phased array radars are also valued for use in aircraft, since they can track multiple targets. The first aircraft to use a phased array radar is the B-1B Lancer. The first aircraft fighter to use phased array radar was the Mikoyan MiG-31. The MiG-31M's SBI-16 Zaslon phased array radar is considered to be the world's most powerful fighter radar . Phased-array interferometry or, aperture synthesis techniques, using an array of separate dishes that are phased into a single effective aperture, are not typically used for radar applications, although they are widely used in radio astronomy. Because of the Thinned array curse, such arrays of multiple apertures, when used in transmitters, result in narrow beams at the expense of reducing the total power transmitted to the target. In principle, such techniques used could increase the spatial resolution, but the lower power means that this is generally not effective. Aperture synthesis by post-processing of motion data from a single moving source, on the other hand, is widely used in space and airborne radar systems.

Frequency bands

The traditional band names originated as code-names during World War II and are still in military and aviation use throughout the world in the 21st century. They have been adopted in the United States by the IEEE, and internationally by the ITU. Most countries have additional regulations to control which parts of each band are available for civilian or military use.

Other users of the radio spectrum, such as the broadcasting and electronic countermeasures (ECM) industries, have replaced the traditional military designations with their own systems.

Radar frequency bands			
Band name	Frequency range	Wavelength range	Notes
HF	3–30 MHz	10–100 m	coastal radar systems, over-the-horizon radar (OTH) radars; 'high frequency'
P	< 300 MHz	1 m+	'P' for 'previous', applied retrospectively to early radar systems
VHF	30–300 MHz	1–10 m	Very long range, ground penetrating; 'very high frequency'
UHF	300–1000 MHz	0.3–1 m	Very long range (e.g. ballistic missile early warning), ground penetrating, foliage penetrating; 'ultra high frequency'
L	1–2 GHz	15–30 cm	Long range air traffic control and surveillance; 'L' for 'long'
S	2–4 GHz	7.5–15 cm	Moderate range surveillance, Terminal air traffic control, long-range weather, marine radar; 'S' for 'short'
C	4–8 GHz	3.75–7.5 cm	Satellite transponders; a compromise (hence 'C')

			between X and S bands; weather; long range tracking
X	8–12 GHz	2.5–3.75 cm	Missile guidance, marine radar, weather, medium-resolution mapping and ground surveillance; in the USA the narrow range 10.525 GHz ±25 MHz is used for airport radar; short range tracking. Named X band because the frequency was a secret during WW2.
K_u	12–18 GHz	1.67–2.5 cm	high-resolution
K	18–24 GHz	1.11–1.67 cm	from German *kurz*, meaning 'short'; limited use due to absorption by water vapour, so K_u and K_a were used instead for surveillance. K-band is used for detecting clouds by meteorologists, and by police for detecting speeding motorists. K-band radar guns operate at 24.150 ± 0.100 GHz.
K_a	24–40 GHz	0.75–1.11 cm	mapping, short range, airport surveillance; frequency just above K band (hence 'a') Photo radar, used to trigger cameras which take pictures of license plates of cars running red lights, operates at 34.300 ± 0.100 GHz.
mm	40–300 GHz	7.5 mm – 1 mm	millimetre band, subdivided as below. The frequency ranges depend on waveguide size. Multiple letters are assigned to these bands by different groups. These are from Baytron, a now defunct company that made test equipment.
V	40–75 GHz	4.0 - 7.5 mm	Very strongly absorbed by atmospheric oxygen, which resonates at 60 GHz.
W	75–110 GHz	2.7 – 4.0 mm	used as a visual sensor for experimental autonomous vehicles, high-resolution meteorological observation, and imaging.
UWB	1.6–10.5 GHz	18.75 cm – 2.8 cm	used for through-the-wall radar and imaging systems.

Radar modulators

Modulators act to provide the waveform of the RF-pulse. There are two different radar modulator designs:

- high voltage switch for non-coherent keyed power-oscillators These modulators consist of a high voltage pulse generator formed from a high voltage supply, a pulse forming network, and a high voltage switch such as a thyratron. They generate short pulses of power to feed the e.g. magnetron, a special type of vacuum tube that converts DC (usually pulsed) into microwaves. This technology is known as Pulsed power. In this way, the transmitted pulse of RF radiation is kept to a defined, and usually, very short duration.

- hybrid mixers, fed by a waveform generator and an exciter for a complex but coherent waveform. This waveform can be generated by low power/low-voltage input signals. In this case the radar transmitter must be a power-amplifier, e.g. a

klystron tube or a solid state transmitter. In this way, the transmitted pulse is intrapulsemodulated and the radar receiver must use pulse compression technique mostly.

Radar coolant

Coolanol and PAO (poly-alpha olefin) are the two main coolants used to cool airborne radar equipment today.

Coolanol (silicate ester) was used in several military radars in the 1970s, for example the AN/APG-63 in the F-15. However, it is hygroscopic, leading to formation of highly flammable alcohol. The loss of a U.S. Navy aircraft in 1978 was attributed to a silicate ester fire. Coolanol is also expensive and toxic. The U.S. Navy has instituted a program named Pollution Prevention (P2) to reduce or eliminate the volume and toxicity of waste, air emissions, and effluent discharges. Because of this Coolanol is used less often today.

PAO is a synthetic lubricant blend of a polyol ester admixed with effective amounts of an antioxidant, yellow metal pacifier and rust inhibitors. The polyol ester blend includes a major proportion of poly (neopentyl polyol) ester blend formed by reacting poly(pentaerythritol) partial esters with at least one C7 to C12 carboxylic acid mixed with an ester formed by reacting a polyol having at least two hydroxyl groups and at least one C8-C10 carboxylic acid. Preferably, the acids are linear and avoid those which can cause odours during use. Effective additives include secondary arylamine antioxidants, triazole derivative yellow metal pacifier and an amino acid derivative and substituted primary and secondary amine and/or diamine rust inhibitor.

A synthetic coolant/lubricant composition, comprising an ester mixture of 50 to 80 weight percent of poly (neopentyl polyol) ester formed by reacting a poly (neopentyl polyol) partial ester and at least one linear monocarboxylic acid having from 6 to 12 carbon atoms, and 20 to 50 weight percent of a polyol ester formed by reacting a polyol having 5 to 8 carbon atoms and at least two hydroxyl groups with at least one linear monocarboxylic acid having from 7 to 12 carbon atoms, the weight percents based on the total weight of the composition.

Radar configurations and types

Radars configurations include Monopulse radar, Bistatic radar, Doppler radar, Continuous-wave radar, etc.. depending on the types of hardware and software used. It is used in aviation (Primary and secondary radar), sea vessels, law enforcement, weather surveillance, ground mapping, geophysical surveys, and biological research.

Chapter 12

Radio Masts and Towers

Masts of the Rugby VLF transmitter in England

A dismantled radio mast in sections

Radio masts and towers are, typically, tall structures designed to support antennas (also known as aerials) for telecommunications and broadcasting, including television. They are among the tallest man-made structures. Similar structures include electricity pylons and towers for wind turbines.

Masts are sometimes named after the broadcasting organisations that use them, or after a nearby city or town.

The Warsaw Radio Mast was the world's tallest supported structure on land, but it collapsed in 1991, leaving the KVLY/KTHI-TV mast as the tallest.

In the case of a mast radiator or radiating tower, the whole mast or tower is itself the transmitting antenna.

Mast or tower?

A radio mast base showing how virtually all support is provided by the guy-wires

The terms "mast" and "tower" are often used interchangeably. However, in structural engineering terms, a tower is a self-supporting or cantilevered structure, while a mast is held up by stays or guys. Masts tend to be cheaper to build but require an extended area surrounding them to accommodate the stay blocks. Towers are more commonly used in cities where land is in short supply.

There are a few borderline designs which are partly free-standing and partly guyed. For example:

- The Gerbrandy tower consists of a self-supporting tower with a guyed mast on top.
- The few remaining Blaw-Knox towers do the opposite: they have a guyed lower section surmounted by a freestanding part.
- Zendstation Smilde a tall tower with a guyed mast on top (guys go to ground)
- Torre de Collserola a guyed tower, with a guyed mast on top. (Tower portion is not free-standing.)

Materials

Steel lattice

Steel lattice tower

The steel lattice is the most widespread form of construction. It provides great strength, low weight and wind resistance, and economy in the use of materials. Lattices of triangular cross-section are most common, and square lattices are also widely used.

When built as a stayed mast, usually the whole mast is parallel-sided. One exception is the Blaw-Knox type.

When built as a tower, the structure may be parallel-sided or taper over part or all of its height. When constructed of several sections which taper exponentially with height, in

the manner of the Eiffel Tower, the tower is said to be an Eiffelized one. The Crystal Palace tower in London is an example.

Tubular steel

Guyed masts are sometimes also constructed out of steel tubes. This construction type has the advantage that cables and other equipment is protected from weather influence and that the structure may look nicer. They are mainly used for FM-/TV-broadcasting, but sometimes also as mast radiator, wherefore the big mast of Mühlacker transmitting station is a good example. A disadvantage of this mast type is that it is much more affected by winds than masts with open bodies. In fact several tubular guyed masts collapsed: in the UK, these were masts the Emley Moor and Waltham TV stations, which collapsed in the 1960s, in Germany that of Bielstein transmitter, which collapsed in 1985. Not in all countries such masts were built: while in Germany, France, UK, Czech, Slovakia and the former Soviet Union multiple tubular guyed masts were built, there are nearly none in Poland and North America.

At several cities in Russia and Ukraine, between 1960 and 1965 several tubular guyed masts with crossbars running from the mast structure to the guys were built. All these masts are exclusively used for FM and TV transmission and are except of the mast in Vinnytsia between 150 and 200 metres tall. The crossbars of these masts are equipped with a gangway and are equipped with smaller antennas. Their main purpose is oscillation damping.

First modern TV Tower in Stuttgart

Reinforced concrete

Reinforced concrete towers are relatively expensive to build but provide a high degree of mechanical rigidity in strong winds. This can be important when antennas with narrow beamwidths are used, such as those used for microwave point-to-point links, and when the structure is to be occupied by people.

In the 1950s, AT&T built numerous concrete towers, more resembling silos than towers, for its first transcontinental microwave route. Many are still in use today.

In Germany and the Netherlands most towers constructed for point-to-point microwave links are built of reinforced concrete, while in the UK most are lattice towers.

Concrete towers can form prestigious landmarks, such as the CN Tower in Toronto. As well as accommodating technical staff, these buildings may have public areas such as observation decks or restaurants.

The Stuttgart TV tower was the first tower in the world to be built in reinforced concrete. It was designed in 1956 by the local civil engineer Fritz Leonhardt.

Tokyo Tower

Fibreglass

Fibreglass poles are occasionally used for low-power non-directional beacons or medium-wave broadcast transmitters.

Wood

There are fewer wooden towers now than in the past. Many were built in the UK during World War II because of a shortage of steel. In Germany before World War II wooden towers were used at nearly all medium-wave transmission sites, but all of these towers have since been demolished, except for the Gliwice Radio Tower.

Ferryside Relay is an example of a TV relay transmitter using a wooden pole.

Other types of antenna supports and structures

Poles

Shorter masts may consist of a self-supporting or guyed wooden pole, similar to a telegraph pole. Sometimes self-supporting tubular galvanized steel poles are used: these may be termed monopoles.

Buildings

In some cases, it is possible to install transmitting antennas on the roofs of tall buildings. In North America, for instance, there are transmitting antennas on the Empire State Building, the Willis Tower ,and formerly on the World Trade Center towers. When the buildings collapsed, several local TV and radio stations were knocked off the air until backup transmitters could be put into service. Such facilities also exist in Europe, particularly for portable radio services and low-power FM radio stations.

Disguised cell-sites

Completed in December 2009 at Epiphany Lutheran Church in Lake Worth, Florida, this 100' tall cross conceals equipment for T-Mobile.

Many people view bare cellphone towers as ugly and an intrusion into their neighbourhoods. Even though people increasingly depend upon cellular communications, they are opposed to the bare towers spoiling otherwise scenic views. Many companies offer to 'hide' cellphone towers in, or as, trees, church towers, flag poles, water tanks and other features. There are many providers that offer these services as part of the normal tower installation and maintenance service. These are generally called "stealth towers" or "stealth installations".

The level of detail and realism achieved by disguised cellphone towers is remarkably high; for example, such towers disguised as trees are nearly indistinguishable from the

real thing, even for local wildlife (who additionally benefit from the artificial flora). Such towers can be placed unobtrusively in national parks and other such protected places, such as towers disguised as cacti in Coronado National Forest.

Even when disguised, however, such towers can create controversy; a tower doubling as a flagpole attracted controversy in 2004 in relation to the U.S. Presidential campaign of that year, and highlighted the sentiment that such disguises serve more to allow the installation of such towers in subterfuge away from public scrutiny rather than to serve towards the beautification of the landscape.

Mast radiators

A mast radiator is a radio tower or mast in which the whole structure works as an antenna. It is used frequently as a transmitting antenna for long or medium wave broadcasting.

Structurally, the only difference is that a mast radiator may be supported on an insulator at its base. In the case of a tower, there will be one insulator supporting each leg.

Telescopic, pump-up and tiltover towers

A special form of the radio tower is the *telescopic mast*. These can be erected very quickly. Telescopic masts are used predominantly in setting up temporary radio links for reporting on major news events, and for temporary communications in emergencies. They are also used in tactical military networks. They can save money by needing to withstand high winds only when raised, and as such are widely used in amateur radio.

Telescopic masts consist of two or more concentric sections and come in two principal types:

- Pump-up masts are often used on vehicles, and are raised to their full height pneumatically or hydraulically. They are usually only strong enough to support fairly small antennas.
- Telescopic lattice masts are raised by means of a winch, which may be powered by hand or an electric motor. These tend to cater for greater heights and loads than the pump-up type. When retracted, the whole assembly can sometimes be lowered to a horizontal position by means of a second tiltover winch. This enables antennas to be fitted and adjusted at ground level before winching the mast up.

Balloons and kites

A tethered balloon or a kite can serve as a temporary support. It can carry an antenna or a wire (for VLF, LW or MW) up to an appropriate height. Such an arrangement is used occasionally by military agencies or radio amateurs. The American broadcasters TV Martí broadcast a television program to Cuba by means of such a balloon.

Other special structures

For two VLF transmitters wire antennas spun across deep valleys are used. The wires are supported by small masts or towers or rock anchors. The same technique was also used for the Criggion VLF transmitter.

For ELF transmitters ground dipole antennas are used. Such structures require no tall masts. They consist of two electrodes buried deep in the ground at least a few dozen kilometres apart. From the transmitter building to the electrodes, overhead feeder lines run. These lines look like power lines of the 10 kV level, and are installed on similar pylons.

Design features

Economic and aesthetic considerations

A radio amateur's do it yourself steel-lattice tower

Felsenegg-Girstel TV-tower

Uetliberg TV-tower

Communications tower, camouflaged as a slim tree

- The cost of a mast or tower is roughly proportional to the square of its height.
- A guyed mast is cheaper to build than a self-supporting tower of equal height.
- A guyed mast needs additional land to accommodate the guys, and is thus best suited to rural locations where land is relatively cheap. An unguyed tower will fit into a much smaller plot.
- A steel lattice tower is cheaper to build than a concrete tower of equal height.
- Two small towers may be less intrusive, visually, than one big one, especially if they look identical.
- Towers look less ugly if they and the antennas mounted on them appear symmetrical.
- Concrete towers can be built with aesthetic design - and they are, especially in Continental Europe. They are sometimes built in prominent places and include observation decks or restaurants.

Masts for HF/shortwave antennas

For transmissions in the shortwave range, there is little to be gained by raising the antenna more than a few wavelengths above ground level. Shortwave transmitters rarely use masts taller than about 100 metres.

Access for riggers

Because masts, towers and the antennas mounted on them require maintenance, access to the whole of the structure is necessary. Small structures are typically accessed with a ladder. Larger structures, which tend to require more frequent maintenance, may have stairs and sometimes a lift, also called a service elevator.

Aircraft warning features

Tall structures in excess of certain legislated heights are often equipped with aircraft warning lamps, usually red, to warn pilots of the structure's existence. In the past, ruggedized and under-run filament lamps were used to maximize the bulb life. Alternatively, neon lamps were used. Nowadays such lamps tend to use LED arrays.

Height requirements vary across states and countries, and may include additional rules such as requiring a white flashing strobe in the daytime and pulsating red fixtures at night. Structures over a certain height may also be required to be painted with contrasting color schemes such as white and orange or white and red to make them more visible against the sky.

Light pollution and nuisance lighting

In some countries where light pollution is a concern, tower heights may be restricted so as to reduce or eliminate the need for aircraft warning lights. For example in the United States the 1996 Telecommunications Act allows local jurisdictions to set maximum heights for towers, such as limiting tower height to below 200 feet and therefore not requiring aircraft illumination under U.S. Federal Communications Commission (FCC) rules. The limit is more commonly set to 190 or 180 feet to allow for masts extending above the tower.

Wind-induced oscillations

One problem with radio masts is the danger of wind-induced oscillations. This is particularly a concern with steel tube construction. One can reduce this by building cylindrical shock-mounts into the construction. One finds such shock-mounts, which look like cylinders thicker than the mast, for example, at the radio masts of DHO38 in Saterland. There are also constructions, which consist of a free-standing tower (usually from reinforced concrete), onto which a guyed radio mast is installed. The best known such construction is the Gerbrandy Tower in Lopik (the Netherlands). Further towers of this building method can be found near Smilde (the Netherlands) and Fernsehturm, Waldenburg, Baden-Württemberg, Germany).

Hazard to birds

Radio, television and cell towers have been documented to pose a hazard to birds. Reports have been issued documenting known bird fatalities and calling for research to find ways to minimize the hazard that communications towers can pose to birds.

Law

Since June 2010, Telecom operators in the USA can erect new telecom masts or towers as the government has lifted the moratorium, which was earlier placed on the issuance of permits for the construction of telecommunication towers.

Chapter 13

Mixing Console

In professional audio, a **mixing console**, or **audio mixer**, also called a **sound board**, **mixing desk**, or **mixer** is an electronic device for combining (also called "mixing"), routing, and changing the level, timbre and/or dynamics of audio signals. A mixer can mix analog or digital signals, depending on the type of mixer. The modified signals (voltages or digital samples) are summed to produce the combined output signals.

Mixing consoles are used in many applications, including recording studios, public address systems, sound reinforcement systems, broadcasting, television, and film post-production. An example of a simple application would be to enable the signals that originated from two separate microphones (each being used by vocalists singing a duet, perhaps) to be heard through one set of speakers simultaneously. When used for live performances, the signal produced by the mixer will usually be sent directly to an amplifier, unless that particular mixer is "powered" or it is being connected to powered speakers.

BBC Local Radio Mark III radio mixing desk

Structure

Yamaha 2403 audio mixing console in a 'live' mixing application

A typical analog mixing board has three sections:

- Channel inputs
- Master controls
- Audio level metering

The channel inputs are replicated monaural or stereo input channels with pre-amp controls, channel fader and pan, sub-group assignment, equalization and auxiliary mixing bus level controls. The master control section has sub-group faders, master faders, master auxiliary mixing bus level controls and auxiliary return level controls. In addition it may have solo monitoring controls, a stage talk-back microphone control, muting controls and an output matrix mixer. On smaller mixers the inputs are on the left of the mixing board

and the master controls are on the right. In larger mixers, the master controls are in the center with inputs on both sides. The audio level meters may be above the input and master sections or they may be integrated into the input and master sections themselves

Channel input strip

The input strip is usually separated into these sections:

- Input jacks / microphone preamplifiers
- Basic input controls
- Channel EQ (High, Mids and low)
- Routing Section including Direct Outs, Aux-sends, Panning control and Subgroup assignments
- Input Faders

On the Yamaha Console above, these sections are color coded for quick identification by the operator. Each signal that is input into the mixer has its own *channel*. Depending on the specific mixer, each channel is stereo or monaural. On most mixers, each channel has an XLR input, and many have RCA or quarter-inch Jack plug line inputs.

Basic input controls

Below each input, there are usually several rotary controls (knobs, pots). The first is typically a *trim* or *gain* control. The inputs buffer the signal from the external device and this controls the amount of amplification or attenuation needed to bring the signal to a nominal level for processing. This stage is where most noise of interference is picked up, due to the high gains involved (around +50 dB, for a microphone). Balanced inputs and connectors, such as XLR or Tip-Ring-Sleeve (TRS) quarter-inch connectors, reduce interference problems.

There may be *insert* points after the buffer/gain stage, which send to and return from external processors which should only affect the signal of that particular channel. Insert points are most commonly used with effects that control a signal's amplitude, such as noise gates, expanders, and compressors.

Auxiliary send routing

The *Auxiliary send* routes a split of the incoming signal to an auxiliary bus which can then be used with external devices. *Auxiliary sends* can either be pre-fader or post-fader, in that the level of a pre-fade send is set by the *Auxiliary send* control, whereas post-fade sends depend on the position of the channel fader as well. *Auxiliary sends* can be used to send the signal to an external processor such as a reverb, which can then be routed back through another channel or designated auxiliary returns on the mixer. These will normally be post-fader. Pre-fade *auxiliary sends* can be used to provide a monitor mix to musicians onstage, this mix is thus independent of the main mix.

Allen & Heath Mixing desk used for live performances.

Channel equalization

Further channel controls affect the equalization (EQ) of the signal by separately attenuating or boosting a range of frequencies, e.g., bass, midrange, and treble. Most large mixing consoles (24 channels and more) usually have sweep equalization in one or more bands of its parametric equalizer on each channel, where the frequency and affected bandwidth of equalization can be selected. Smaller mixing consoles have few or no equalization controls. Care must be taken not to add too much EQ to a signal that is already close to clipping; additional energy will overdrive the channel.

Some mixers have a general equalization control (either graphic or parametric) at the output.

Subgroup and mix routing

Each channel on a mixer has an audio taper pot, or potentiometer, controlled by a sliding volume control (*fader*), that allows adjustment of the level, or amplitude, of that channel in the final *mix*. A typical mixing console has many rows of these sliding volume controls. Each control adjusts only its respective channel (or one half of a stereo channel); therefore, it only affects the level of the signal from one microphone or other audio device. The signals are summed to create the main *mix*, or combined on a *bus* as a submix, a group of channels that are then added to get the final mix (for instance, many drum mics could be grouped into a bus, and then the proportion of drums in the final mix can be controlled with one bus fader).

There may also be *insert* points for a certain bus, or even the entire mix.

Master output controls

Subgroup and main output fader controls are often found together on the right hand side of the mixer or, on larger consoles, in a center section flanked by banks of input channels. Matrix routing is often contained in this master section, as are headphone and local loudspeaker monitoring controls. Talkback controls allow conversation with the artist through their wedges, headphones or IEMs (in-ear monitor). A test tone generator might be located in the master output section. Aux returns such as those signals returning from outboard reverb devices are often in the master section.

Metering

Finally, there are usually one or more VU or peak meters to indicate the levels for each channel, or for the master outputs, and to indicate whether the console levels are overmodulating or clipping the signal. Most mixers have at least one additional output, besides the main mix. These are either individual bus outputs, or *auxiliary outputs*, used, for instance, to output a different mix to on-stage monitors. The operator can vary the mix (or levels of each channel) for each output.

As audio is heard in a logarithmic fashion (both amplitude and frequency), mixing console controls and displays are almost always in decibels, a logarithmic measurement system. This is also why special audio taper pots or circuits are needed. Since it is a relative measurement, and not a unit itself (like a percentage), the meters must be referenced to a nominal level. The "professional" nominal level is considered to be +4 dBu. The "consumer grade" level is −10 dBV.

Hardware routing and patching

For convenience, some mixing consoles include inserts or a patch bay or patch panel. Patch bays are mainly used for recording mixers.

Other features

Most, but not all, audio mixers can

- add external effects.
- use monaural signals to produce stereo sound by adjusting the position of each signal on the sound stage (pan and balance controls).
- provide phantom power (typically 48 volts) required by some microphones.
- create an audible tone via an oscillator, usually at 440 Hz, 1 kHz, or 2 kHz

Some mixers can

- add effects internally.
- read and write console automation.
- be interfaced with computers or other recording equipment (to control the mixer with computer presets, for instance).
- control or be controlled by a Digital Audio Workstation via Midi or proprietary commands.
- be powered by batteries.

Digital versus analog

Digidesign's Venue Profile mixer on location at a corporate event. This digital mixer allows plugins from third-party vendors

Digital mixing console sales have increased dramatically since their introduction in the 1990s. Yamaha sold more than 1000 PM5D mixers by July, 2005, and other manufacturers are seeing increasing sales of their digital products. Digital mixers are more versatile than analog ones and offer many new features, such as the ability to save multiple mute groups, multiple VCA groups and channel settings into a scene and reconfigure signal routing at the touch of a button. The faders can be "swapped" or

"flipped" to show aux send levels; a feature very useful in mixing artists' monitors. In addition, digital consoles often include a range of special effects such as parametric EQ, compression, gating, reverb, automatic feedback reduction, tap delay and straight delay. Some products are expandable via third-party software features (called plugins) that add further reverb, compression, delay and tone-shaping tools. Several digital mixers include spectrograph and real time analyzer functions. A few incorporate loudspeaker management tools such as crossover filtering and limiting. Digital signal processing can perform automatic mixing for some simple applications, such as courtrooms, conferences and panel discussions, but at this time no digital mixer in live audio includes automixing. Consoles with motorized faders can read and write console automation.

Digital mixers can be designed to be quieter than most analog mixers, as digital mixers often incorporate very low threshold noise gates to stop inactive mix bus background hiss from summing with active signals. Digital circuitry is more resistant to outside interference from radio transmitters such as walkie-talkies and cell phones.

Propagation delay

Digital mixers have an unavoidable amount of latency or propagation delay, ranging from 1.5 ms to as much as 10 ms, depending on the model of digital mixer and what functions are engaged. This small amount of delay isn't a problem for loudspeakers aimed at the audience or even monitor wedges aimed at the artist, but can be disorienting and unpleasant for IEMs (In ear monitors) where the artist hears their voice acoustically in their head *and* electronically amplified in their ears but delayed by a couple of milliseconds.

Every analog to digital conversion and digital to analog conversion within a digital mixer entails propagation delay. Audio inserts to favorite external analog processors make for almost double the usual delay. Further delay can be traced to format conversions such as from ADAT to AES3 and from normal digital signal processing steps.

Within a digital mixer there can be differing amounts of latency, depending on the routing and on how much DSP is in use. Assigning a signal to two parallel paths with significantly different processing on each path can result in extreme comb filtering when recombined. Some digital mixers incorporate internal methods of latency correction so that such problems are avoided.

Ease of use

16-channel mixing console with compact short-throw faders

Analog consoles remain popular due to their continuing to have one knob, fader or button per function, a reassuring feature for the user. This takes up more physical space but allows more rapid response to changing performance conditions. Most digital mixers take advantage of the technology to reduce the physical space requirements of their product, entailing compromises in user interface such as a single shared channel adjustment area that is selectable for only one channel at a time. Additionally, most digital mixers have virtual pages or layers which change the fader banks into separate controls for additional inputs or for adjusting equalization or aux send levels. This layering can be confusing for operators.

Analog consoles make for simpler understanding of hardware routing. Many digital mixers allow internal reassignment of inputs so that convenient groupings of inputs appear near each other at the fader bank, a feature that can be disorienting for persons having to make a hardware patch change.

On the other hand, many digital mixers allow for extremely easy building of a mix from saved data. USB flash drives and other storage methods are employed to bring past performance data to a new venue in highly portable manner. At the new venue, the traveling mix technician simply plugs the collected data into the venue's digital mixer and quickly makes small adjustments to the local input and output patch layout, allowing for full show readiness in very short order.

Some digital mixers allow offline editing of the mix, a feature that lets the traveling technician use a laptop to make anticipated changes to the show while *en route*, further shortening the time it takes for the sound system to be ready for the artist.

Sound quality

Both digital and analog mixers rely on analog microphone preamplifiers, a high-gain circuit that is the origin of much of the perceived character of sound quality in an audio mixer. In this respect, both formats are on par with each other. In a digital mixer, the microphone preamplifier is followed by an ADC which quantizes the audio stream. Ideally, this process is carefully engineered to deal gracefully with overloading and clipping while delivering an accurate digital stream over the linear dynamic range. Further processing and mixing of digital streams within a mixer need to avoid clipping and truncation if maximum audio quality is desired.

Analog mixers, too, must deal gracefully with overloading and clipping at the microphone preamplifier and as well as avoiding overloading of mix buses. Background hiss in an analog mixer is always present, though good gain stage management minimizes its audibility. Idle subgroups left "up" in a mix will add their background hiss to the main outputs; many digital mixers avoid this problem by low-level gating.

Many electronic design elements combine to affect perceived sound quality, making the global "analog mixer vs. digital mixer" question difficult to answer. Controlled ABX double-blind listening tests have not been published at this date; no conclusive answer can be reached. Experienced live sound professionals agree that microphones and loudspeakers (with their innate higher distortion levels) are a much greater source of coloration of sound than the choice of mixer. The mix style of the person mixing is also more important than the make and model of audio console. Analog and digital mixers both have been associated with extremely high-quality concert performances and studio recordings.

Remote control

Analog mixing in live sound has had the option since the 1990s of using wired remote controls for certain digital processes such as monitor wedge equalization and parameter changes in outboard reverb devices. That concept has expanded until wired and wireless remote controls are being seen in relation to entire digital mixing platforms. It's possible to set up a sound system and mix via wireless (or wired) laptop, touchscreen or tablet, especially if the performance requires no unpredictable fast responses to multiple changing conditions on stage. Computer networks can connect digital system elements for expanded monitoring and control, allowing the system technician to make adjustments to distant devices during the performance. The use of remote control technology can be utilized to reduce "seat-kills", allowing more paying customers into the performance space.

Virtual mixing

Increasingly, the mixing process can be performed on screen, using computer software and associated input, output and recording hardware. The traditional large control surface

of the mixing console is not utilized, saving space at the engineer's mix position. Some virtual mixing (such as the Gamble DCX) uses digital controls of analog audio circuitry, but most virtual mixers are fully digital so as to save cost and physical space. In the virtual studio, there is either no normal mixer fader bank at all or there is a compact group of motorized faders designed to fit into a small space and connected to the computer via USB or Firewire. Many project studios use such a space-efficient solution, as the mixing room at other times can serve as business office, media archival, etc. Virtual mixing is heavily integrated as part of a digital audio workstation.

Applications

A Behringer EuroRack UB1002FX in a DJ setup

Dub producers/engineers such as Lee "Scratch" Perry were perhaps the first musicians to use a mixing board as a musical instrument.

Public address systems will use a mixing console to set microphones for different speakers to the correct level, and can add in recorded sounds into the mix. A major requirement is to minimise audio feedback.

Most bands will use a mixing console to combine musical instruments and vocals to the correct level.

Radio broadcasts use a mixing desk to select audio from different sources, such as CD players, telephones, remote feeds, or prerecorded advertisements.

Noise music musicians such as Merzbow or Wolf Eyes may create feedback loops within mixers, creating an instrument known as a no-input mixer. The tones generated from a no-input mixer are created by connecting an output of the mixer into an input channel and manipulating the pitch with the mixer's dials.

Mixing console manufacturers

- Alesis
- Allen & Heath
- Audient
- Automated Processes, Inc.
- AMS Neve
- Behringer
- Cadac Electronics
- Carvin A&I
- Crest Audio
- D&R
- DiGiCo
- Digidesign
- DigiTech
- EAW
- Euphonix
- Fairlight
- Daniel Flickinger
- Harris Corporation
- Harrison Audio Consoles
- Innovason
- Klotz Digital
- Langevin
- Mackie
- MCI
- Midas Consoles
- Peavey
- Phonic Corporation
- Pioneer Corporation
- Presonus
- Rane Corporation
- Roland Corporation
- Samick

- Samson Technologies
- Shure
- Solid State Logic
- Soundcraft
- Speck Electronics
- Studer
- Studiomaster
- Tapco
- Tascam
- Ward-Beck Systems
- Yamaha Pro Audio