



# Radio Technologies

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## Chapter 1

# Cable Radio

**Cable radio** or **cable FM** is a concept similar to that of cable television, bringing radio signals into homes and businesses via coaxial cable. It is generally used as cable TV was in its early days when it was "community antenna television", to enhance the quality of terrestrial radio signals that are difficult to receive in an area. However, cable-only radio outlets also exist.

The use of cable radio varies from area to area — some cable TV systems don't include it at all, and others only have something approaching it on digital cable systems. Additionally, some stations may just transmit audio in the background while a cable access channel is operating in between periods of video programming. In the late 1970s to the mid to late 1980s, before the advent of MTS Stereo television broadcasts, cable TV subscribers would tune in specific cable FM frequencies that simulcast the television broadcasts in stereo.

A related secondary meaning of the term is any automated music stream — the usual format of cable only "stations".

### ***United States***

The first "commercial" cable radio station in the United States was Cable 108, on the Theta Cablevision system, serving West Los Angeles, California and surrounding areas. It went on the air January 1, 1972, and was run by Brad Sobel, playing what he called "progressive top 40". Cable 108 came into being after Brad's original venture, K-POT, a bootleg FM station at 88.1 MHz was busted by the FCC in November 1971. The illicit station ran for three days until it was shutdown, and the event made the front page of the Los Angeles Times and the Herald-Examiner. Because Theta Cablevision charged extra for their FM hookups, Cable 108's potential audience was between 4,700 and approximately 25,000 (based on information provided by Brad Sobel in an article in Billboard), out of Cablevision's approximately 100,000 subscriber households.

The first exclusively cablecasting community radio station was CPVR in Palos Verdes, California, a suburb of Los Angeles. CPVR 95.9 Cable FM radio was on the Times-Mirror cable system and was started by a group of teenagers who initially practiced being disc jockeys in the homes of two of the founders. Since traditional broadcasting equipment was prohibitively expensive at the time, a young engineer named Tom Hewitt built much of the electronic hardware from scratch. Mark Speer and Brad Gardner were the two who began the venture, which was run as a non-profit youth organization from a studio in the Golden Cove shopping center in Rancho Palos Verdes beginning in March 1972. Even though they were non-profit, they were not subject to the restrictions of terrestrial public radio stations, and thus were able to subsidize expenses by accepting commercial advertising. Because the air staff and audience were part of a highly desirable demographic (many of the DJ's weren't even old enough to drive), advertisers of the day, such as concert promoter Pacific Presentations and local record stores eagerly bought ad time in order to reach such a prime demographic (m-f, 13-24) as CPVR had attracted during its history, further enabling CPVR to not only continue operations, but expand into larger studios. Greg McClure, Jim Sideris, Harv Laser, Liane Benson, Lorraine Dechter and Kathy Bauer were but a few of the people who helped create the station's legendary style and sound. Unlike Cable 108, CPVR was not only on the FM dial, but was in stereo, and also appeared on the cable system's "barker" channel (Channel 3). Although the station was only on the "cable" for about two years programming free-form rock and roll, CPVR often scooped it's over-the-air competitors, breaking acts such as Bruce Springsteen and Queen and oftentimes premiering landmark albums such as Pink Floyd's "Dark Side of the Moon" and Procol Harum's "Grand Hotel" sometimes several weeks before the L.A. stations picked them up. Many of the original staff went on to careers in media (co-founder Brad Gardner has since been nominated for four (and won two) Emmys, one for a music video "The Doctor is In" and the other for the veterinary show "Horse Vet". His other two nominations are for directing and audio). For those involved and those who heard it, this tiny little community rock and roll radio station holds a special place in their hearts and minds, often discussed in the same breath as KMET, KPPC, KWST, KRLA, KROQ and KNAC, legendary southern California radio stations in their own right.

For a time, cable radio stations popped up across California and the U.S, most run by high school and/or college students. CCIA, a cable radio station on the campus of California Institute of the Arts, Valencia, California, is one example. But as the founders of these stations grew older and moved on, there was no one to take up where they left off. Eventually all these cable radio stations went dark. Today, where college or community groups might have once considered starting a "cable" radio station, they now look to creating an internet radio station.

On the East Coast the most popular commercial cable radio station was WLHE, started in 1979 in Woburn, Massachusetts. This station was the first commercial cable TV only radio station in the country and ran from 1979 to 1987. The man who started it was Larry Haber, owner and operator. Frank Palazzi and Alan Rupa were the first on air disc jockeys. Palazzi was known on the air as Frank Fitz, and Alan Rupa was known as Alan James. Mr Haber went by his own name. Other DJs were oldies expert Chuck Steven,

country music expert Glen Evans, indie rock expert Mark Sawyer, and jazz expert Scott Cavanagh (aka Scott Rogers). Larry Haber was the stations first president and general manager, Palazzi served as program director, and Rupa was music director. The station was heard only on Continental Cablevision's local Channel 6 in Woburn, Wilmington, Stoneham, North Reading, and Billerica, Massachusetts.

## **Canada**

In Canada, the Canadian Radio-television and Telecommunications Commission previously required most cable companies to provide cable FM service; those that did were required to convert all local AM broadcast radio stations to cable FM signals. The commission now requires only that campus, community, native radio stations, and one CBC Radio station in each official language, be provided by local cable companies, either via cable FM or via digital means (i.e. set-top boxes). Rogers Communications, notably, has entirely abandoned traditional cable FM distribution, instead providing a number of terrestrial radio services as part of its digital cable audio package.

## **Soviet Union**

In the former Soviet Union, cable radio was popular and one station is reported to have had as many as forty million listeners.

Initially the system had one channel that was transmitted as direct audio. The wires and plugs for the system were the same as for standard power wires and plugs which could cause receivers to burn out by attaching to mains socket. During World War II, all RF receivers were confiscated, but cable radio continued operating and, in particular, was used to transmit warnings of aerial bombing. The 1960s saw an enhancement with the addition of two additional channels, using AM on carrier frequencies of 78 and 120 kHz. The installation of this system became mandatory for all new buildings. The system, along with usual broadcasting, was created to inform people of emergencies.

Today, cable radio outlets are installed in all new homes, but many people don't use them or even uninstal the socket and wires inside their units. However, they continue to pay the mandatory fee (as of 2009, the price in Moscow is approx. 0,7 EUR per month). These payments can be avoided, but due to bureaucratic procedure it is rarely used.

## Chapter 2

# Digital Radio

**Digital radio** has several meanings.

1. Today the most common meaning is **digital radio broadcasting** technologies, such as the digital audio broadcasting (DAB) system, also known as Eureka 147. In these systems, the analog audio signal is digitized into zeros and ones, compressed using formats such as mp2, and transmitted using a digital modulation scheme. The aim is to increase the number of radio programs in a given spectrum, to improve the audio quality, to eliminate fading problems in mobile environments, to allow additional datacasting services, and to decrease the transmission power or the number of transmitters required to cover a region. However, analog radio programs and equipment, especially for the FM broadcasting system, still dominate the market.
2. An older and more wide definition, that still is used in communication engineering literature, is wireless digital transmission technologies, i.e. microwave and radio frequency communication standards where analog information signals as well as digital data is carried by a digital signal, by means of a digital modulation method. This definition includes broadcasting systems such as digital TV and digital radio broadcasting, but also two-way digital radio standards such as the second generation (2G) cell-phones and later, short-range communication such as digital cordless phones, wireless computer networks, digital micro-wave radio links, deep space communication systems such as communications to and from the two Voyager space probes, etcetera.
3. A less common definition is radio receiver and transmitter implementations that are based on digital signal processing, but may transmit or receive analog radio transmission standards, for example FM radio. This may reduce noise and distortion induced in the electronics. It also allows software radio implementations, where the transmission technology is changed just by selecting another piece of software. In most cases, this would however increase the energy consumption of the receiver equipment.

## ***One-way digital radio (digital broadcasting systems)***

### **One-way digital radio standards**

One-way standards are those used for audio and video broadcasting, and sometimes also datacasting, as opposed to those used for two-way communication. Digital radio broadcasting standards may provide terrestrial or satellite radio service. Digital radio broadcasting systems are typically designed for handheld mobile devices, just like mobile-TV systems, but as opposed to other digital TV systems which typically require a fixed directional antenna. Some digital radio systems provide in-band on-channel (IBOC) solutions that may coexist with or simulcast with analog AM or FM transmissions, while others are designed for designated radio frequency bands. The latter allows one wideband radio signal to carry a multiplex consisting of several radio-channels of variable bitrate as well as data services and other forms of media. Some digital broadcasting systems allow single-frequency network (SFN), where all terrestrial transmitters in a region sending the same multiplex of radio programs may use the same frequency channel without self-interference problems, further improving the system spectral efficiency.

While digital broadcasting offers many potential benefits, its introduction has been hindered by a lack of global agreement on standards. The Eureka 147 standard (DAB) for digital radio is the most commonly used and is coordinated by the World DMB Forum, which represents more than 30 countries. This standard of digital radio technology was defined in the late 1980s, and is now being introduced in many countries. Commercial DAB receivers began to be sold in 1999 and, by 2006, 500 million people were in the coverage area of DAB broadcasts, although by this time sales had only taken off in the UK and Denmark. In 2006 there are approximately 1,000 DAB stations in operation. There have been criticisms of the Eureka 147 standard and so a new 'DAB+' standard has been proposed.

To date the following standards have been defined for one-way digital radio:

### **Digital audio broadcasting systems**

- Eureka 147 (branded as DAB)
- DAB+
- Digital Radio Oceane
- ISDB-TSB
- Internet radio
- **FM band in-band on-channel (FM IBOC):**
  - HD Radio (OFDM modulation over FM and AM band IBOC sidebands)
  - FMExtra (FM band IBOC subcarriers)
  - Digital Radio Mondiale extension (DRM+) (OFDM modulation over AM band IBOC sidebands)
- **AM band in-band on-channel (AM IBOC):**
  - HD Radio (AM IBOC sideband)

- Digital Radio Mondiale (branded as DRM) for the short, medium and long wave-bands
- **Satellite radio:**
  - WorldSpace in Asia and Africa
  - Sirius XM Radio in North America
  - MobaHo! in Japan and the Republic of (South) Korea
- **Systems also designed for digital TV:**
  - DMB
  - DVB-H
- **Low-bandwidth digital data broadcasting over existing FM radio:**
  - Radio Data System (branded as RDS)
- **Radio pagers:**
  - FLEX
  - ReFLEX
  - POCSAG
  - NTT

## **Digital television broadcasting (DTV) systems**

- Digital Video Broadcasting (DVB)
- Integrated Services Digital Broadcasting (ISDB)
- Digital Multimedia Broadcasting (DMB)
- **Digital Terrestrial Television (DTTV or DTT) to fixed mainly roof-top antennas:**
  - DVB-T (based on OFDM modulation)
  - ISDB-T (based on OFDM modulation)
  - ATSC (based on 8VSB modulation)
  - T-DMB
- **Mobile TV reception in handheld devices:**
  - DVB-H (based on OFDM modulation)
  - MediaFLO (based on OFDM modulation)
  - DMB (based on OFDM modulation)
  - Multimedia Broadcast Multicast Service (MBMS) via the GSM EDGE and UMTS cellular networks
  - DVB-SH (based on OFDM modulation)
- **Satellite TV:**
  - DVB-S (for Satellite TV)
  - ISDB-S
  - 4DTV
  - S-DMB
  - MobaHo!

## **Status by country**

### **DAB adopters**

Digital Audio Broadcasting (DAB), also known as Eureka 147, has been under development since the early eighties, has been adopted by around 20 countries worldwide. It is based around the MPEG-1 Audio Layer II audio codec and this has been co-ordinated by the WorldDMB. DAB receivers are selling well in some markets.

WorldDMB announced in a press release in November 2006, that DAB would be adopting the HE-AACv2 audio codec, which is also known as eAAC+. Also being adopted are the MPEG Surround format, and stronger error correction coding called Reed-Solomon coding. The update has been named DAB+. Receivers that support the new DAB standard began being released during 2007 with firmware updated available for some older receivers.

DAB and DAB+ cannot be used for mobile TV because they do not include any video codecs. DAB related standards Digital Multimedia Broadcasting (DMB) and DAB-IP are suitable for mobile radio and TV both because they have MPEG 4 AVC and WMV9 respectively as video codecs. However a DMB video sub-channel can easily be added to any DAB transmission - as DMB was designed from the outset to be carried on a DAB subchannel. DMB broadcasts in Korea carry conventional MPEG 1 Layer II DAB audio services alongside their DMB video services.

### **United States**

The United States has opted for a proprietary system called HD Radio(TM) technology, a type of in-band on-channel (IBOC) technology. Transmissions use orthogonal frequency-division multiplexing, a technique which is also used for European terrestrial digital TV broadcast (DVB-T). HD Radio technology was developed and is licensed by iBiquity Digital Corporation. It is widely believed that a major reason for HD radio technology is to offer some limited digital radio services while preserving the relative "stick values" of the stations involved and to insure that new programming services will be controlled by existing licensees.

The FM digital schemes in the U.S. provide audio at rates from 96 to 128 kilobits per second (kbit/s), with auxiliary "subcarrier" transmissions at up to 64 kbit/s. The AM digital schemes have data rates of about 48 kbit/s, with auxiliary services provided at a much lower data rate. Both the FM and AM schemes use lossy compression techniques to make the best use of the limited bandwidth.

Lucent Digital Radio, USA Digital Radio (USADR), and Digital Radio Express commenced tests in 1999 of their various schemes for digital broadcast, with the expectation that they would report their results to the National Radio Systems Committee (NRSC) in December 1999. Results of these tests remain unclear, which in general describes the status of the terrestrial digital radio broadcasting effort in North America.

Some terrestrial analog broadcast stations are apprehensive about the impact of digital satellite radio on their business, while others plan to convert to digital broadcasting as soon as it is economically and technically feasible.

While traditional terrestrial radio broadcasters are trying to "go digital", most major US automobile manufacturers are promoting digital satellite radio. HD Radio technology has also made inroads in the automotive sector with factory-installed options announced by BMW, Ford, Hyundai, Jaguar, Lincoln, Mercedes, MINI, Mercury, Scion, and Volvo. Beyond the U.S., commercial implementation of HD Radio technology is gaining momentum around the world.

Satellite radio is distinguished by its freedom from FCC censorship in the United States, its relative lack of advertising, and its ability to allow people on the road to listen to the same stations at any location in the country. Listeners must currently pay an annual or monthly subscription fee in order to access the service, and must install a separate security card in each radio or receiver they use.

Ford and Daimler AG are working with Sirius Satellite Radio, previously CD Radio, of New York City, and General Motors and Honda are working with XM Satellite Radio of Washington, D.C. to build and promote satellite DAB radio systems for North America, each offering "CD quality" audio and about a hundred channels.

Sirius Satellite Radio launched a constellation of three Sirius satellites during the course of 2000. The satellites were built by Space Systems/Loral and were launched by Russian Proton boosters. As with XM Satellite Radio, Sirius implemented a series of terrestrial ground repeaters where satellite signal would otherwise be blocked by large structures including natural structures and high-rise buildings.

XM Satellite Radio has a constellation of three satellites, two of which were launched in the spring of 2001, with one following later in 2005. The satellites are Boeing (previously Hughes) 702 comsats, and were put into orbit by Sea Launch boosters. Back-up ground transmitters (repeaters) will be built in cities where satellite signals could be blocked by big buildings.

On February 19, 2007, Sirius Satellite Radio and XM Satellite Radio merged, to form Sirius XM Radio.

The FCC has auctioned bandwidth allocations for satellite broadcast in the S band range, around 2.3 GHz.

The perceived wisdom of the radio industry is that the terrestrial medium has two great strengths: it is free and it is local. Satellite radio is neither of these things; however, in recent years, it has grown to make a name for itself by providing uncensored content (most notably, the crossover of Howard Stern from terrestrial radio to satellite radio) and commercial-free, all-digital music channels that offer similar genres to local broadcast favorites.

- It must be noted that "Digital Radio" has a limited listening distance from the tower site. FCC laws currently show that 10% maximum digital signal of any US analog signal ratio. "There are still some concerns that HD Radio on FM will increase interference between different stations even though HD Radio at the 10% power level fits within the FCC spectral mask." HD Radio HD Radio#cite note-14. "HD Radio" is only 2 channels in the USA, side by side with analog stations. HD channel 1 may be on 93.2 FM, Analog station on 93.3, and HD channel 2 is on 93.4 FM. Differing stations are multicasting on different frequencies, respectively.
- Also note that "HD Radio" is digital radio, but is not "high definition" as most of the US population thinks. "HD" stands for "Hybrid Digital."

## **United Kingdom**

In the United Kingdom, 35.8% of the population owns a DAB digital radio set and 25% of listening is to digital platforms. 40.5% of all adults, or 20.9 million people, listen to digital radio each week, according to RAJAR, which equates to 45% of all radio listeners.

The UK currently has the world's biggest digital radio network, with 103 transmitters, two nation-wide DAB ensembles and 48 local and regional DAB ensembles, broadcasting over 250 commercial and 34 BBC radio stations; 51 of these stations are broadcast in London. On DAB digital radio most listeners can receive around 20 additional stations, in addition to the analogue stations available on digital.

Some areas of the country are not yet covered by DAB but the BBC has announced plans to build out national coverage to 92% by the end of 2011 with 40 new transmitters being launched in 2011 . The Government will make a decision on a radio switchover subject to listening and coverage criteria being met. A digital radio switchover would maintain FM as a platform, while moving some services to DAB-only distribution. Digital radio stations are also broadcast on digital television platforms such as Sky, Virgin Media and Freeview, as well as internet radio.

## **Australia**

Australia commenced regular digital audio broadcasting using the DAB+ standard in May 2009, after many years of trialling alternative systems. Normal radio services operate on the AM and FM bands, as well as four stations (ABC and SBS) on digital TV channels. The services are currently operating in five state capital cities (Adelaide, Brisbane, Melbourne, Perth and Sydney) and are under trial in other capitals and regional centres.

## **Japan**

Japan has started terrestrial sound broadcasting using ISDB-Tsb and MobaHO! 2.6 GHz Satellite Sound digital broadcasting

## **Korea**

On 1 December 2005 South Korea launched its T-DMB service which includes both television and radio stations. T-DMB is a derivative of DAB with specifications published by ETSI. More than 110,000 receivers had been sold in one month only in 2005.

## **Developing nations**

Digital radio is now being provided to the developing world. A satellite communications company named WorldSpace is setting up a network of three satellites, including "AfriStar", "AsiaStar", and "AmeriStar", to provide digital audio information services to Africa, Asia, and Latin America. AfriStar and AsiaStar are in orbit. AmeriStar cannot be launched from the United States as Worldspace transmits on the L-band and would interfere with USA military as mentioned above..

Each satellite provides three transmission beams that can support 50 channels each, carrying news, music, entertainment, and education, and including a computer multimedia service. Local, regional, and international broadcasters are working with WorldStar to provide services.

A consortium of broadcasters and equipment manufacturers are also working to bring the benefits of digital broadcasting to the radio spectrum currently used for terrestrial AM radio broadcasts, including international shortwave transmissions. Over seventy broadcasters are now transmitting programs using the new standard, known as Digital Radio Mondiale (DRM), and / commercial DRM receivers are available. DRM's system uses the MPEG-4 based standard aacPlus to code the music and CELP or HVXC for speech programs. At present these are priced too high to be affordable by many in the third world, however.

Low-cost DAB radio receivers are now available from various Japanese manufacturers, and WorldSpace has worked with Thomson Broadcast to introduce a village communications center known as a Telekiosk to bring communications services to rural areas. The Telekiosks are self-contained and are available as fixed or mobile units

## ***Two-way digital radio standards***

The key breakthrough or key feature in digital radio transmission systems is that they allow lower transmission power, they can provide robustness to noise and cross-talk and other forms of interference, and thus allow the same radio frequency to be reused at shorter distance. Consequently the spectral efficiency (the number of phonecalls per MHz

and base station, or the number of bit/s per Hz and transmitter, etc) may be sufficiently increased. Digital radio transmission can also carry any kind of information whatsoever - just as long as it has been expressed as a sequence of ones and zeroes. Earlier radio communication systems had to be made expressly for a given form of communications: telephone, telegraph, or television, for example. All kinds of digital communications can be multiplexed or encrypted at will.

- **Digital cellular telephony** (2G systems and later generations):
  - GSM
  - UMTS (sometimes called W-CDMA)
  - TETRA
  - IS-95 (cdmaOne)
  - IS-136 (D-AMPS, sometimes called TDMA)
  - IS-2000 (CDMA2000)
  - iDEN
- **Digital Mobile Radio:**
  - Project 25 a.k.a. "P25" or "APCO-25"
  - TETRA
  - NXDN
- **Wireless networking:**
  - Wi-Fi
  - HIPERLAN
  - Bluetooth
  - DASH7
  - ZigBee
- **Military radio systems for Network-centric warfare**
  - JTRS (Joint Tactical Radio System- a flexible software-defined radio)
  - SINCGARS (Single channel ground to air radio system)
- **Amateur packet radio:**
  - AX.25
- **Digital modems for HF:**
  - PACTOR
- **Satellite radio:**
  - Satmodems
- **Wireless local loop:**
  - Basic Exchange Telephone Radio Service
- **Broadband wireless access:**
  - IEEE 802.16

## Chapter 3

# Satellite Radio

**Satellite radio** is an analogue or digital radio signal that is relayed through one or more satellites and thus can be received in a much wider geographical area than terrestrial FM radio stations. While in Europe many primarily-FM radio stations provide an additional unencrypted satellite feed, there are also subscription based digital packages of numerous channels that do not broadcast terrestrially, notably in the US. In Europe, FM radio is used by many suppliers that use a network of several local FM repeaters to broadcast a single programme to a large area, usually a whole nation. Many of those have an additional satellite signal that can be heard in many parts of the continent. In contrast, US terrestrial stations are always local and each of them has a unique programme, albeit they are sometimes interconnected for syndicated contents; but each local station still carries its own commercial and news breaks even then. This means that a national distribution of the contents of original terrestrial stations via satellite makes no real sense in the US, wherefore satellite radio is used in a different way there. History: Began broadcasting January 5, 2001 at 11:17AM Eastern, Tim McGraw was the first artist ever played on satellite radio. He gave a special welcome introduction which segued into his song "Things Change" on Sirius! Mobile services, such as Sirius, XM, and Worldspace, allow listeners to roam across an entire continent, listening to the same audio programming anywhere they go. Other services, such as Music Choice or Muzak's satellite-delivered content, require a fixed-location receiver and a dish antenna. In all cases, the antenna must have a clear view to the satellites. In areas where tall buildings, bridges, or even parking garages obscure the signal, repeaters can be placed to make the signal available to listeners.

Radio services are usually provided by commercial ventures and are subscription-based. The various services are proprietary signals, requiring specialized hardware for decoding and playback. Providers usually carry a variety of news, weather, sports, and music channels, with the music channels generally being commercial-free.

In areas with a relatively high population density, it is easier and less expensive to reach the bulk of the population with terrestrial broadcasts. Thus in the UK and some other

countries, the contemporary evolution of radio services is focused on Digital Audio Broadcasting (DAB) services or HD Radio, rather than satellite radio.

### ***Business applications***

Satellite radio, particularly in the United States, has become a major provider of background music to businesses such as hotels, retail chains, and restaurants. Compared to old-line competitors such as Muzak, satellite radio's significantly lower price, commercial-free channel variety, and more reliable technology make it a very attractive option. Both North American satellite radio providers offer business subscriptions, though given the merger of XM Satellite Radio with Sirius, the future of XM for Business is uncertain. Sirius's commercial services are provided nationally by third-party partner Applied Media Technologies Corporation.

### ***System design***

Satellite radio uses the 2.3 GHz S band in North America and generally shares the 1.4 GHz L band with local Digital Audio Broadcasting (DAB) stations elsewhere. It is a type of direct broadcast satellite and is strong enough that it requires no satellite dish to receive. Curvature of the earth limits the reach of the signal, but due to the high orbit of the satellites, two or three are usually sufficient to provide coverage for an entire continent.

Local repeaters similar to broadcast translator boosters enable signals to be available even if the view of the satellite is blocked, for example, by skyscrapers in a large town. Major tunnels can also have repeaters. This method also allows local programming to be transmitted such as traffic and weather in most major metropolitan areas, as of March 2004.

Each receiver has an Electronic Serial Number (ESN) Radio ID to identify it. When a unit is activated with a subscription, an authorization code is sent in the digital stream telling the receiver to allow access to the blocked channels. Most services have at least one "free to air" or "in the clear" (ITC) channel as a test. For example, Sirius uses channel 184, Sirius Weather & Emergency.

Most (if not all) of the systems in use now are proprietary, using different codecs for audio data compression, different modulation techniques, and/or different methods for encryption and conditional access.

Like other radio services, satellite radio also transmits program-associated data (PAD or metadata), with the artist and title of each song or program and possibly the name of the channel.

## **Satellite radio vs. other formats**

Satellite radio differs from AM or FM radio and digital television radio (or DTR) in the following ways. The table applies primarily to the United States.

<b>Radio format</b>	<b>Satellite radio</b>	<b>AM/FM</b>	<b>Digital television radio (DTR)</b>
<b>Monthly fees</b>	US\$12.95 and up	None	None for terrestrial. Very low for cable or satellite — DTR represents a small portion of the total monthly television fee.  None — a typical set consists of a stereo attached to a television set-top box (the primary function of the set top-box is normally designed for viewing digital television on an analogue set).
<b>Portability</b>	Available	Prominent	
<b>Listening availability</b>	Very high — a satellite signal's footprint covers millions of square kilometres.	Low to moderate — implementation of FM service requires moderate to high population densities and is thus not practical in rural and/or remote locales; AM travels great distances at night.	Very high
<b>Sound quality</b>	Varies <sup>2</sup>	AM: Usually very low, but can be the highest FM: Usually Moderate, but can be very high	Varies <sup>2</sup>
<b>Variety and depth of programming</b>	Highest	Variable — highly dependent upon economic/demographic factors	Variable - dependent on location and the television provider - for cable and satellite, dependent on the various packages they provide and on the user's subscription.

<b>Frequency of programming interruptions (by DJs or commercial advertising)<sup>3</sup></b>	None to high - mostly dependent on the channels, some of which have DJs; most channels are advertisement-free because of the paid subscription model of satellite radio.	Highest <sup>4</sup>	None to low - dependent on the provider; however, it is common that some stations will have DJs. Usually no advertisements on subscription services (DirecTV and Dish Network both claim to provide advertisement-free content).
<b>Governmental regulation</b>	Yes <sup>5</sup>	Yes — significant governmental regulations regarding content <sup>6</sup>	Yes for terrestrial. For cable and satellite, low to none <sup>5</sup>

<sup>2</sup> The sound quality with both satellite radio providers and DTR providers varies with each channel. Some channels have near CD-quality audio, and others use low-bandwidth audio suitable only for speech. Since only a certain amount of bandwidth is available within the licenses available, adding more channels means that the quality on some channels must be reduced. Both the frequency response and the dynamic range of satellite channels can be superior to most, but not all AM or FM radio stations, as most AM and FM stations clip the audio peaks to sound louder; even the worst channels are still superior to most AM radios, but a very few AM tuners are equal to or better than the best FM or satellite broadcasts when tuned to a local station, even if not capable of stereo. AM does not suffer from multipath distortion or flutter in a moving vehicle like FM, nor does it become silent as you go behind a big hill like satellite radio.

<sup>3</sup> Some satellite radio services and DTR services act as *in situ* repeaters for local AM/FM stations and thus feature a high frequency of interruption.

<sup>4</sup> Nonprofit stations and public radio networks such as CBC/Radio-Canada, NPR, and PRI-affiliated stations and the BBC are commercial-free. In the US, all stations are required to have periodic station identifications and public service announcements.

<sup>5</sup> In the United States, the FCC regulates technical broadcast spectrum only. Program content is unregulated. However, the FCC has tried in the past to expand its reach to regulate content to satellite radio and cable television, and its options are still open to attempt such in the future. The FCC does issue licenses to both satellite radio providers (XM and Sirius) and controls who holds these licenses to broadcast.

<sup>6</sup> Degree of content regulation varies by country; however, the majority of industrialized nations have regulations regarding obscene and/or objectionable content.

## **Portable Satellite Radio**

Portable satellite radios let you listen to satellite radio just about anywhere you go. They are very similar to standard portable music players, designed for music on the go. These however, feature built-in antennas that receive the satellite signal, and come with rechargeable batteries. In fact, all you have to do is plug in headphones, and you can easily listen to and carry them around easily. Reception can be tricky however, being blocked by buildings and tall trees, and sometimes by your own body depending you the way you are facing and how you are carrying it. However, the best reception will be received outdoors in the open.

### ***United States***

In the United States and Canada, one holding company, Sirius XM Radio, operates the two satellite radio services, after a merger (technically the acquisition of XM by Sirius) in July 2008. A monthly fee is charged for both services (as of 2005, Sirius also offers a one-time fee of nearly \$500 valid for the lifetime of the equipment; however, there is a \$70.00 USD fee for switching receiver, and this may be done only three times ever). Some XM music channels have commercials, while Sirius is commercial-free. Both services have commercial-free music stations, as well as talk and news stations, some of which include commercials. XM uses fixed-location geostationary satellites in two positions, and Sirius uses three geosynchronous satellites in highly elliptical orbits passing over North and South America, to transmit the digital streams. The net difference is that the Sirius signal comes from a higher elevation angle in the northern part of the U.S. and even more so in Canada. (This higher angle makes Sirius' signal less likely to drop out on cities, but more likely to drop out in parking garages, gas stations, tunnels, and other covered spaces.)

Both services are available mainly via portable receivers in automobiles, but both have many accessories so one can listen at home through a home stereo, with a portable boombox, or online through a personal computer. Both services now have some form of receiver that is completely portable.

Satellite radio's chief asset is the fact that it is not localized: drivers can receive the same programming anywhere in the footprint of the service. A stop at any truck stop will demonstrate the popularity of Sirius XM among long-haul drivers. In addition, both XM and Sirius carry programming that is simply not feasible on commercial radio stations. Specialty stations cover things such as family talk, radio drama, classical music, and live events.

The footprint of both Sirius and XM is only the United States (not including Alaska), Canada, and the upper third of Mexico; it does not cover Hawaii as satellite TV does.

## Success so far

As of July 29, 2008 Sirius XM claims over 18.5 million subscribers. One critical factor for the success of satellite radio is the deployment of in-car receivers. Sirius XM has attempted to convince automakers to equip vehicles with their receiver. As of 2008, the following manufacturers offer satellite radio as original equipment:

Provider	BMW MINI Rolls- Royce	Chrysler Dodge Mercedes- Benz Jeep	Ford Lincoln Mercury Volvo Land Rover Jaguar Mazda	GM Cadillac Chevrolet Buick Pontiac GMC Saturn Saab	Honda Acura	Hyundai Kia	Mitsubishi	Nissan Infiniti	Porsche	Toyota Lexus Scion	VW Audi Bentley	Suzuki
Sirius	Yes	Yes	Yes	No	No	Yes	Yes	?	No	Yes	Yes	No
XM	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes

Sirius has an exclusive contract for VW and Audi vehicles from 2007 through 2012. Those brands previously offered both services. GM, Honda and Suzuki are all major investors in XM; Sirius is not offered as options in their vehicles. Bentley and Rolls-Royce come not only with receivers but lifetime subscriptions for Sirius service as well. XM is featured in select Harley-Davidson motorcycle models, while Sirius can be heard in several brands of recreational vehicles and boats.

One of the challenges for satellite radio has been to move away from cars and into the homes of consumers. Several portable satellite radio receivers have been made for this purpose. XM satellite radio has developed the XM2go line of "Walkman-like" portable receivers, such as the Delphi MyFi, the Pioneer AirWare and Giant International's Tao. Polk Audio makes a component-style home XM Reference Tuner and a tabletop entertainment system, the I-Sonic, with XM capability. Sirius has developed the Kenwood Portable Satellite Radio Tuner, Sirius S50, Here2Anywhere and the Sirius Stiletto 100. The Pioneer Inno and Samsung Helix for XM were among the first portable receivers to offer the ability of recording live content for playback later. Thus allowing for satellite radio to compete more fully with MP3 players.

While key agreements with automobile manufacturers are still being made, both companies have made the leap away from satellite radio only in the car and into the homes of consumers. One bump in the road to becoming more widely used in the home was both Sirius and XM running into legal issues in early 2006 with the FCC about their internal FM Transmitters. This required Sirius and XM to pull several of their models off the shelf and fix the problem. The FCC was claiming that the emissions of the internal FM Transmitters were too powerful and needed to be lowered. With these changes any customer buying a new satellite radio receiver doesn't achieve nearly the broadcast distance as the old models. Since this is a key point in the ability to use a satellite radio in the home (i.e. by taking the signal received and then broadcasting it to multiple points throughout the home at the same time and avoid having to bring the satellite radio with them as they move around the home) it has led many subscribers to use an external

Personal FM transmitter to replace the lower powered internal FM Transmitter. Since these external FM Transmitters are Part 15 compliant they can broadcast the signal further than the new internal FM Transmitters now included in the satellite radios and still be legal. These external FM transmitters may prevent a slow down in the progress already made into the home consumer market for Sirius and XM satellite radio.

Satellite radio technology was inducted into the Space Foundation Space Technology Hall of Fame in 2002.

## **Canada**

On November 1, 2004, the Canadian Radio-television and Telecommunications Commission (CRTC) began hearing applications for Canada's first satellite radio operations. Three applications were filed: one by Standard Broadcasting and the CBC in partnership with Sirius, one by Canadian Satellite Radio in partnership with XM, and one at the last minute by CHUM Limited and Astral Media.

The first two would use the same systems already set up for the U.S., while CHUM's application was for a subscription radio service delivered through existing terrestrial DAB transmitters rather than directly by satellite (although satellites would be used to deliver programming to the transmitters). The CHUM service is all-Canadian; the other two applications propose to offer a mix of Canadian-produced channels and existing channels from their American partner services.

A small "grey market" already exists for Sirius and XM receivers in Canada in which a Canadian would have an American order their receiver and setup.

On June 16, 2005, the CRTC approved all three services.

In its decision, the CRTC required the following conditions from the satellite radio licensees:

- A minimum of eight channels must be produced in Canada, and for each Canadian channel, nine foreign channels can be broadcast.
- At least 85% of the content on the Canadian-produced channels (whether musical or spoken word) must be Canadian.
- At least 25% of the Canadian channels must be French-language stations.
- At least 25% of the music aired on the Canadian channels must be new Canadian music.
- At least 25% of the music played on the Canadian channels must be from up-and-coming Canadian artists.

These conditions were an extension of the existing Canadian content rules applicable to all broadcasters in Canada. The applicants had until 13 November 2005, to notify the CRTC of their decision. Both companies managed to negotiate the standards a little to their favor, and in return, they would instead play 50% French content as opposed to

25%. Also, XM Canada succeeded in getting an extra five channels of National Hockey League Play-by-Play onto their platform, without an additional channel creation, by agreeing to cover every Canadian team's game during the season.

CHUM appealed the decision, claiming they would not survive if Sirius and XM both were allowed in the Canadian market, and that the licence conditions regarding Canadian content imposed on Canadian Satellite Radio and Sirius Canada were too lax. Canadian Satellite Radio and Sirius Canada countered that CHUM was simply trying to create a monopoly in the Canadian market.

In late August 2005, Heritage Minister Liza Frulla asked the Federal Cabinet to review the CRTC decision and possibly send it back to the CRTC for further review. Lobbyists complained that the CRTC decision did not require enough Canadian content from the broadcasters. The broadcasters responded by promising to add additional Canadian and French content.

After vigorous lobbying from both sides, the federal cabinet officially accepted the CRTC decision on September 10, 2005.

XM satellite radio was launched in Canada on November 29, 2005. Sirius followed later on December 1, 2005. Monthly subscription rates are \$12.99 for XM (85 channels) with a one-time activation fee of \$19.99 and \$14.99 for Sirius with a one-time activation fee of \$19.99 (100 channels). (All prices are in Canadian dollars.) The CHUM/Astral service never launched, and its license expired on June 16, 2007.

## Chapter 4

# Continuous Tone-Coded Squelch System

In telecommunications, **Continuous Tone-Coded Squelch System** or **CTCSS** is a circuit that is used to reduce the annoyance of listening to other users on a shared two-way radio communications channel. It is sometimes called **tone squelch**. Where more than one user group is on the same channel (called *co-channel users*), CTCSS filters out other users if they are using a different CTCSS tone or no CTCSS.

Receivers equipped with a CTCSS circuit usually have a switch that selects normal mode or CTCSS mode. When enabled, the CTCSS radio circuit, instead of opening the receive audio for any signal, causes the two-way radio receiver's audio to open only in the presence of the normal RF signal AND the correct sub-audible audio tone (sub-audible meaning that the receiver circuitry can detect it, but is not apparent to the users in the audio output). This is akin to the use of a lock on a door. A carrier squelch or noise squelch receiver not configured with CTCSS has no lock on its door and will let any signal in. A receiver with CTCSS circuitry (and with it enabled) locks out all signals except ones encoded with the correct tone. CTCSS can be regarded as a form of in-band signaling.

### **Example**

As a simple example, suppose a two-way radio frequency is shared by a pizza delivery service and a landscape maintenance service. Conventional radios without CTCSS would hear all transmissions from both groups. The landscapers would have to listen to the pizza shop. The pizza shop would have to hear about landscape customer complaints. If both installed CTCSS, units from each group would only hear radios from their own group. This is supposed to reduce missed messages and the distraction of unnecessary radio chatter.

Note that in the example above there are only two co-channel users. In dense two-way radio environments a large number of groups may be present on a single radio channel.

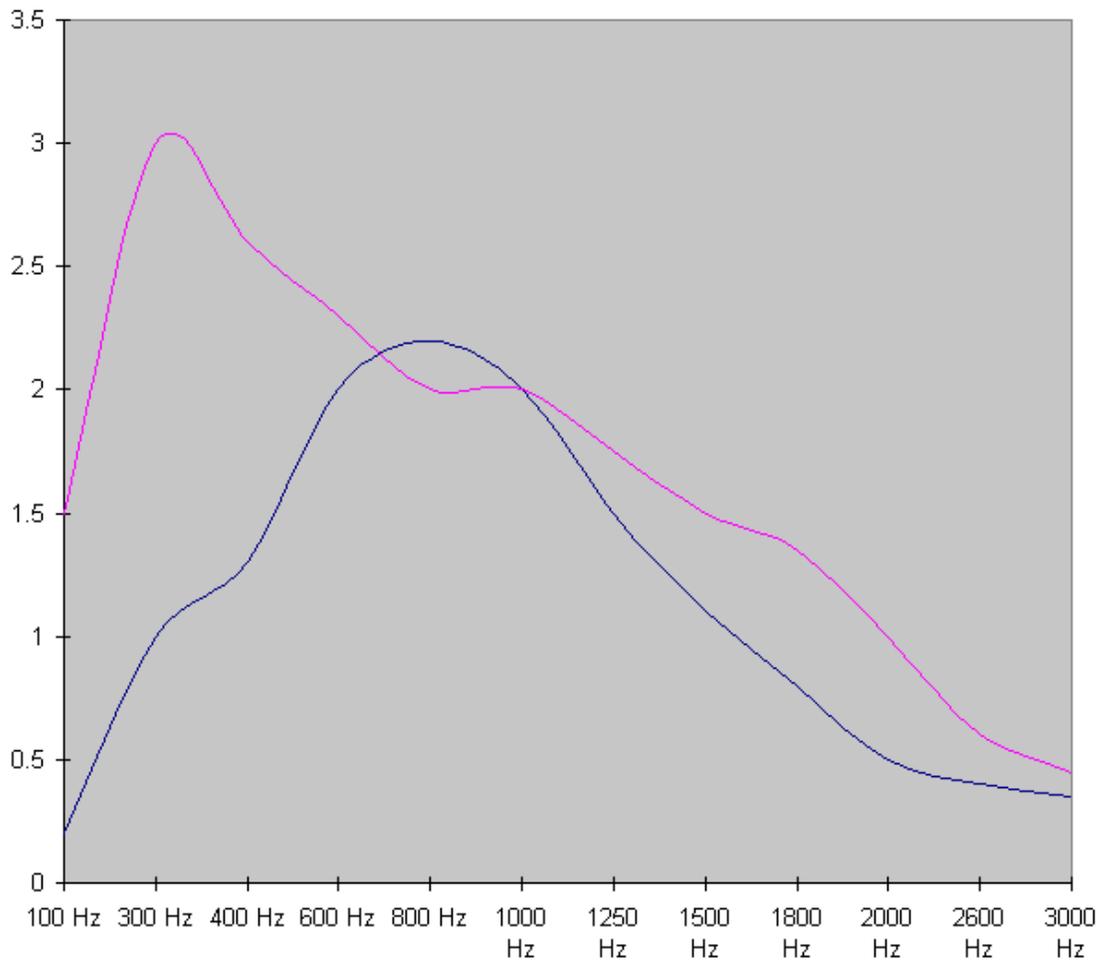
A disadvantage of using CTCSS in shared frequencies is that since users cannot hear transmissions from other groups, they may assume that the frequency is open when it is not and transmit simultaneously with another user, thus accidentally overriding or interfering with the other group's transmission. For example, in the above situation a landscaper might be communicating with another landscaper. Meanwhile, a pizza delivery driver—not hearing any transmissions—assumes that the frequency is clear and calls his dispatch office. Depending on several factors (locations, power, etc.), the two simultaneous transmissions could easily interfere with each other—resulting in one or both not being clearly understood. The more separate groups that share a single frequency and the more frequently that they transmit, the more likely that this accidental interference will occur.

### ***Theory of operation***

Radios in a professional two-way radio system using CTCSS always transmit their own tone code whenever the transmit button is pressed (simultaneously with the voice). This is called CTCSS *encoding*. CTCSS continuously superimposes any one of 32, 38 or 40 (depending on which "standard" is used) precise, low distortion, low-pitch audio tones on the transmitted signal, ranging from 67 to 257 Hz. The tones are usually referred to as *sub-audible tones*. In an FM two-way radio system, CTCSS encoder levels are usually set for 15% of system deviation. For example, in a 5 kHz deviation system, the CTCSS tone level would normally be set to 750 Hz deviation. Engineered systems may call for different level settings in the 500 Hz to 1 kHz (10-20%) range.

The ability of a receiver to mute the audio until it detects a carrier with the correct CTCSS tone is called *decoding*. Receivers are equipped with features to allow the CTCSS "lock" to be disabled. In professional USA licensed systems, Federal Communications Commission rules require CTCSS users on shared channels to disable their receiver's CTCSS to check if co-channel users are talking before transmitting. On a base station console, a microphone may have a split push-to-talk button. Pressing one half of the button, (often marked with a speaker icon or the letters "MON", short for "MONitor") disables the CTCSS decoder and reverts the receiver to hearing any signal on the channel. This is called the *monitor* function. There is sometimes a mechanical interlock: the user must push down the monitor button or the transmit button is locked and cannot be pressed. This interlock option is referred to as *compulsory monitor before transmit* (the user is forced to monitor by the equipment design.) On mobile radios, the microphone is usually stored in a hang-up clip or hang-up box. When the user pulls the microphone out of the hang-up clip to make a call, a switch in the clip (box) forces the receiver to revert to conventional carrier squelch mode ("monitor"). Some designs relocate the switch into the body of the microphone itself. In hand-held radios, an LED indicator may glow green, yellow, or orange to indicate another user is talking on the channel. Hand-held radios usually have a slide switch or push-button to monitor. Some modern radios have a feature called "Busy Channel Lockout", which will not allow the user to transmit as long as the radio is receiving another signal.

A CTCSS decoder is based on a very narrow bandpass filter which passes the desired CTCSS tone. The filter's output is amplified and rectified, creating a DC voltage whenever the desired tone is present. The DC voltage is used to turn on or unmute the receiver's audio stages. When the tone is present, the receiver is unmuted, when it is not present the receiver is silent.



In a professional communications receiver designed for CTCSS, a high-pass audio filter is supposed to block CTCSS tones (below 300 Hz) so they are not heard in the speaker. Since audio curves vary from one receiver to another, some radios may pass an audible level of the CTCSS tone to the speaker. Lower tone frequencies generally are less audible. If the magenta audio curve shown at right were plotted from a CTCSS-equipped receiver, it would drop nearly straight down below 300 Hz.

Because period is the inverse of frequency, lower tone frequencies take longer to decode. Receivers in a system using 67.0 Hz will take noticeably longer to decode than ones using 203.5 Hz, and they will take longer than one decoding 250.3 Hz. In some repeater systems, the time lag can be significant. The lower tone may cause one or two syllables to be clipped before the receiver audio is unmuted (is heard). This is because receivers are

decoding in a chain. The repeater receiver must first sense the carrier signal on the input, then decode the CTCSS tone. When that occurs, the system transmitter turns on, encoding the CTCSS tone on its carrier signal (the output frequency). All radios in the system start decoding after they sense a carrier signal then recognize the tone on the carrier as valid. Any distortion on the tone encoder will also affect the decoding time.

Engineered systems often use tones in the 127.3 Hz to 162.2 Hz range to balance fast decoding with keeping the tones out of the audible part of the receive audio. Most amateur radio repeater controller manufacturers offer an audio delay option - this delays the repeated speech audio for a selectable number of milliseconds before it is retransmitted. During this fixed delay period (the amount of which is adjusted during installation, then locked down), the CTCSS decoder has enough time to recognize the right tone. This way the problem with lost syllables at the beginning of a transmission can be overcome without having to use high tones.

In early systems, it was common to avoid the use of adjacent tones. On channels where every available tone is not in use, this is good engineering practice. For example, an ideal would be to avoid using 97.4 Hz and 100.0 Hz on the same channel. The tones are so close that some decoders may periodically false trigger. The user occasionally hears a syllable or two of co-channel users on a different CTCSS tone talking. As electronic components age, or through production variances, some radios in a system may be better than others at rejecting nearby tone frequencies.

CTCSS is an analog system. A later digital system was developed by Motorola and is called Digital Private Line, or DPL. General Electric responded with the same system under the name of Digital Channel Guard. The use of digital squelch on a channel that has existing tone squelch users precludes the use of the 131.8 and 136.5 Hz tones as the digital bit rate is 134.4 bits per second and the decoders set to those two tones will sense an intermittent signal (referred to in the two-way field as "falsing" the decoder).

### ***List of tones***

CTCSS tones are standardized by the EIA/TIA. The full list of the tones can be found in their standard RS-220; the CTCSS tones also may be listed in equipment manuals. Some systems use non-standard tones. The US Military uses 150.0 Hz, as do many other world military users, also note that in the UK the tone of 100.0 Hz is avoided since this is twice the UK mains frequency; an improperly-smoothed power supply may cause unwanted squelch opening. Squelch tones typically come from one of three series as listed below along with the two character PL code used by Motorola to identify tones. The most common set of supported squelch tones is a set of 38 tones including all tones with Motorola PL codes, except for the tones WZ, 8Z, 9Z, and 0Z. The lowest series has adjacent tones that are roughly in the harmonic ratio of  $2^{0.05}$  to 1 ( $\approx 1.035265$ ), while the other two series have adjacent tones roughly in the ratio of  $10^{0.015}$  to 1 ( $\approx 1.035142$ ).

NS <sup>1</sup>	PL	Hz	NS <sup>1</sup>	PL	Hz	NS <sup>1</sup>	PL	Hz	Notes
1	XZ	67.0	12	1Z	100.0			159.8	<sup>1</sup> Non-standard numerical codes. Many radios use a matching set of numerical codes to represent corresponding tones; however, there is no published standard and only partial industry adoption.
	WZ	<sup>2</sup> 69.3	13	1A	103.5			165.5	
2	XA	71.9	14	1B	107.2			171.3	
3	WA	74.4	15	2Z	110.9			177.3	
4	XB	77.0	16	2A	114.8			183.5	
5	WB <sup>3</sup>	79.7	17	2B	118.8			189.9	
6	YZ	82.5	18	3Z	123.0			196.6	
7	YA	85.4	19	3A	127.3	32	M1	203.5	
8	YB	88.5	20	3B	131.8	33	M2	210.7	
9	ZZ	91.5	21	4Z	136.5	34	M3	218.1	
10	ZA	94.8	22	4A	141.3	35	M4	225.7	
11	ZB	<sup>4</sup> 97.4	23	4B	146.2	36	M5	233.6	<sup>2</sup> Some radios use 69.4 Hz instead, which better fits the harmonic sequence, and this tone is often omitted as a choice. <sup>3</sup> Also known by the code SP. <sup>4</sup> Not actually in this harmonic sequence, but an average of the ZA and 1Z tones used to fill the gap between the lower and middle sequences. <sup>5</sup> The 8Z, 9Z, and 0Z ("zero-Z") tones are often
			24	5Z	151.4	37	M6	241.8	
			25	5A	156.7	38	M7	250.3	
			26	5B	162.2				
			27	6Z	167.9				
			28	6A	173.8				
			29	6B	179.9				
			30	7Z	186.2				
			31	7A	192.8				
					199.5				
				8Z <sup>5</sup>	206.5				
				<sup>6</sup>	213.8				
				<sup>6</sup>	221.3				
				9Z <sup>5</sup>	229.1				
				<sup>6</sup>	237.1				
				<sup>6</sup>	245.5				
				0Z <sup>5</sup>	254.1				

omitted from radios that use the M1-M7 series of tones.

<sup>6</sup> Not known to have been used, but included to place the 9Z and 0Z tones in the proper position in the harmonic series.

## **Vendor names**

CTCSS is often called *PL tone* (for *Private Line*, a trademark of Motorola), or simply *tone*. General Electric's and Bendix King's implementation of CTCSS is called *Channel Guard* (or *CG*). Vintage RCA radios called their implementation *Quiet Channel*. Kenwood radios call the feature *Quiet Talk* or *QT*. Johnson used "TG" for "ToneGuard", and later "CG" for "CallGuard". Zetron literature refers to "ToneLock". There are many other company-specific names used by radio vendors to describe compatible options. Any CTCSS system that has compatible tones is interchangeable. Old and new radios with CTCSS and radios across manufacturers are compatible.

In amateur radio, the terms *PL tone*, *PL* and simply *tone* are used most commonly. Often, there is a distinction between the terms *tone* and *tone squelch*, in which the former refers to the use of transmitting a CTCSS tone while using standard carrier squelch on the receiver. Use of transmit-only CTCSS allows stations to communicate with repeaters and other stations using CTCSS while the link is marginal and the CTCSS tones may not be properly decoded. The term *tone squelch* most often includes *tone* and your radio will not only transmit a CTCSS tone to the distant station or repeater, but will squelch all incoming signals that do not also include the CTCSS tone. This is helpful in areas where multiple repeaters may be sharing the same output frequency but have different CTCSS tones, or where local interference is too strong for the front-end of your radio.

One caveat about all CTCSS being interchangeable is that some professional systems use a phase-reversal of the CTCSS tone at the end of a transmission to eliminate the squelch crash or squelch tail. This is common with General Electric Mobile Radio and Motorola systems. The CTCSS tone does a phase shift for about 200 milliseconds at the end of a transmission. In old systems, decoders used mechanical reeds to decode CTCSS tones. When audio at a resonant pitch was fed into the reed, it would vibrate on a set of springs, turning on the speaker audio. The end-of-transmission phase reversal (called "reverse burst" by Motorola and "squelch tail elimination" or "STE" by GE ) caused the reed to abruptly stop vibrating and the receive audio would mute. Initially, a phase shift of 180 degrees was used, but experience showed that a shift of  $\pm 120$  to 135 degrees was optimal in halting the mechanical reeds. These systems often have audio muting logic set for

CTCSS only. If a non-Motorola transmitter, (without the phase reversal feature,) is used, the squelch can remain unmuted for as long as the reed continues to vibrate — up to 1.5 seconds at the end of a transmission as it coasts to a stop (sometimes referred to as the "flywheel effect" or called "freewheeling").

## ***Interference and CTCSS***

In non-critical uses, CTCSS can also be used to hide the presence of interfering signals such as receiver-produced intermodulation. Receivers with poor specifications — such as scanners or low-cost mobile radios — cannot reject the strong signals present in urban environments. The interference will still be present and may block the receiver, but the decoder will prevent it from being heard. It will still degrade system performance but by using selective calling the user will not have to hear the noises produced by receiving the interference.

CTCSS is very commonly used in amateur radio for this purpose. Wideband and extremely sensitive radios are common in the amateur radio field, which imposes limits on achievable intermodulation and adjacent-channel performance. Often all repeaters in a geographical region share the same CTCSS tone as a method of reducing co-channel interference from adjacent regions and increasing frequency reuse. This is a practice linked back to an old FCC practice of coordinating CTCSS tones for business services. In many rural areas of the USA where no coordination is necessary, a default of 100 Hz has become a de facto standard.

Family Radio Service (FRS), PMR446 and other "bubble pack" radios often use from 10 to 38 different CTCSS tones (the number depends on the manufacturer), usually erroneously called "sub-channels", or "privacy codes" in the sales literature. While these do not add to the available number of conversations which can take place at once in a given area, they do reduce annoying interference experienced by users. However they *do NOT afford any privacy or security*, no matter what the sales literature says. A receiver with the tone squelch turned off (i.e. in carrier squelch mode) will hear everything.

It is a bad idea to use any coded squelch system to hide interference issues in systems with life-safety or public-safety uses such as police, fire, search and rescue or ambulance company dispatching. Adding tone or digital squelch to a radio system doesn't solve interference issues, it just covers them up. The presence of interfering signals should be corrected rather than masked. Interfering signals masked by tone squelch will produce apparently random missed messages. The intermittent nature of interfering signals will make the problem difficult to reproduce and troubleshoot. Users will not understand why they cannot hear a call, and will lose confidence in their radio system. In a worst case scenario in a life safety environment a missed message, or a misunderstood message, may result in casualties.

## Chapter 5

# Frequency Coordination and Grid-Leak Detector

## Frequency coordination

**Frequency Coordination** is a technical and regulatory process which is intended to remove or mitigate radio-frequency interference between different radio systems which utilize the same operational frequency.

Normally frequency coordination is undertaken by "administrations" (i.e. national governmental spectrum regulators) as part of a formal regulatory process under the procedures of the Radio Regulations (an intergovernmental treaty text regulating the use and sharing of the radio frequency spectrum).

Before an "administration" allows an operator to commence operation of a new radiocommunications network it must in principle undergo coordination. This involves the following steps:

- Inform other operators about the plans
- Receive comments if appropriate
- Conduct technical discussions with priority networks
- Agree technical and operational parameters
- Gain international recognition and protection on the Master International Frequency Register
- Bring the network into use

Coordination thus ensures:

- All administrations know the technical plans of other administrations
- All operators (satellite and terrestrial) have the opportunity to determine if unacceptable interference is likely to be caused to their existing and planned "priority" networks
- An opportunity to object

- An opportunity to discuss and review
- An opportunity to reach technical and operational sharing agreements

Coordination is thus closely bound to "date of protection" or "priority", defined by the date on which complete coordination data is received by the ITU. New planned networks must coordinate with all networks with an earlier "date of protection" but are protected against all networks with a later "date of protection". Planned (but not implemented) networks acquire status under this procedure but time limits ensure that protection is not for ever if networks are not implemented.

### **Congress Authorizes FCC**

In 1982, Congress also provided the FCC with the authority to use frequency coordinators:

- Assist in developing and managing spectrum.
- Recommend appropriate frequencies (designated under Part 90)

### ***List of Coordinators***

For Public Safety frequency coordination -

AASHTO \*

APCO \*

FCCA \*

IMSA \*

For Business and special emergency -

AAA \*

AAR \*

EWA \*

FIT \*

UTC \*

# Grid-leak detector

A **grid-leak detector** is a combination diode rectifier and audio amplifier used as a detector in vacuum tube AM radio receivers.

## *History*

The heyday for grid-leak detectors was the 1920s, when battery-operated, multi-dial tuned radio frequency receivers using low-mu triodes with directly heated cathodes were the norm. The Zenith Models 11, 12, and 14 are examples of these kinds of radios. When indirectly heated cathodes and AC powered receivers were introduced in 1927, most manufacturers switched to Plate detectors, and later to diode detectors.

Although the regenerative grid-leak detector was one of the more sensitive detectors of its day, its ability to radiate radio frequency energy when improperly adjusted limited its use in urban settings where multiple receivers would be operated in close proximity. The RCA Radiola III and IIIa and the Crosley Model 51 are examples of regenerative receivers from this period.

## *Operation*

In the circuit, the grid of the detector (usually a low-mu or medium-mu triode) is connected to the secondary of the final RF or IF transformer through a capacitor (100 pF to 330 pF, with 250 pF being typical). A resistor of a few 100K - 10M ohms is connected either in parallel with this capacitor, or from the detector's grid to ground. The resistor-capacitor combination, in concert with the nearly unidirectional current flow of the detector's grid-to-cathode (or grid-to-filament, if it's directly heated) circuit, forms a clamp circuit. The incoming modulated radio frequency signal voltage swings both positive and negative with respect to ground as it emerges from the final RF or IF stage. The detector's grid-to-cathode circuit will only conduct current when the grid is positive with respect to the cathode. The resulting current flow charges the capacitor to maintain a voltage which biases the detector grid negative with respect to its cathode. The amount of bias varies based on the received signal strength. The grid leak resistor - capacitor circuit is designed to have a time constant which is slightly slower than the rate of change of the audio program and much slower than the rate of change of the carrier.

The nearly unidirectional current flow of the received, modulated signal results in a separate audio signal that is said to be **detected** or **demodulated**. The triode detector tube also amplifies this audio signal, thereby providing two processes in one tube. Regenerative detectors often used grid leak, especially in the detection of amplitude modulated signals.

The grid leak detector circuit output, often taken from the plate of the detector tube, may require additional filtering to remove remnants of the carrier portion of the received signal. RF chokes and/or capacitors may be employed.

## ***Advantages***

A grid-leak detector provides demodulation as well as amplification of the audio signal, unlike a classical diode/crystal detector.

## ***Disadvantages***

Most receivers with grid-leak detectors lack automatic volume control (AVC) biasing circuitry. As a result, RF signal levels must be adjusted to vary audio output levels. Manufacturers used various circuits to control volume levels:

- Battery-operated radios of the 1920s varied the filament voltages of the RF tubes to adjust volume.
- In early AC sets, and in many of the early-1930s Philco radios mentioned above, the volume control adjusted signal levels at the antenna input connection.
- In some early sets equipped with tetrode or pentode RF amplifiers, the volume control adjusts the screen grid voltage.
- In later radios, the volume control adjusts the cathode bias voltage of at least one RF amplifier.

Because RF signal levels are adjusted to change volume levels, constant manipulation of the volume control is required to find weak signals.

But none of the above is inherently native to grid leak detector circuits. It is possible to construct radio receiver with a grid leak detector and provide automatic volume control (AVC). Historically, though, this did not occur.

One potential disadvantage of the grid leak detector is that the input impedance of the detector may be affected by the need to self bias the detector tube with grid current. This loads the received signal. Although this may be mitigated to some degree by circuit design and component optimization, plate detectors isolate the detector load from the input circuit more effectively and may be employed where sensitivity is thought to be otherwise compromised by a grid leak or diode detector circuit.

## Chapter 6

# Near-Field Electromagnetic Ranging and Operation RAFTER

## Near-field electromagnetic ranging

**Near-field electromagnetic ranging** (NFER) refers to any radio technology employing the near-field properties of radio waves as a Real Time Location System (RTLS).

### *Overview*

Near-field electromagnetic ranging is an emerging RTLS technology that employs transmitter tags and one or more receiving units. Operating within a half-wavelength of a receiver, transmitter tags must use relatively low frequencies (less than 30 MHz) to achieve significant ranging. Depending on the choice of frequency, NFER has the potential for range resolution of 30 cm (1 ft) and ranges up to 300 m (1,000 ft).

### *Technical Discussion*

The phase relations between the EH components of an electro-magnetic field ((E and H are the components E=electric and H=magnetic)) vary with distance around small antennas. This was first discovered by Heinrich Hertz and is formulated with Maxwell's field theory.

Close to a small antenna, the electric and magnetic field components of a radio wave are 90 degrees out of phase. As the distance from the antenna increases, the EH phase difference decreases. Far from a small antenna in the far-field, the EH phase difference goes to zero. Thus a receiver that can separately measure the electric and magnetic field components of a near-field signal and compare their phases can measure the range to the transmitter.

## **Advantages**

NFER technology is a different approach for locating systems. It has several inherent advantages over other RTLS systems.

- First, no signal modulation is required, so baseband signals with an arbitrarily small bandwidth may be used for ranging.
- Second, precise synchronization is not required between different receivers: in fact, a local range measurement can be made with just a single receiver.
- Third, since EH phase differences are preserved when a signal is down-converted to baseband, high range precision may be achieved with relatively low time precision.

For instance, a radio wave at 1 MHz has a period of 1  $\mu$ s, and the EH phase difference changes about 45 degrees between 30 m (100 ft) to 60 m (200 ft). Thus, a 1 degree EH phase difference in a 1 MHz signal corresponds to a range difference of about 67 cm (26 in) and 1/360 of the period or 27.78 ns difference in time between the electric and magnetic signals. Down-converted to a 1 kHz audio signal, the period becomes 1 ms, and the time difference required to measure becomes 27.78  $\mu$ s. A comparable time-of-flight (TOF) or differential time-of-arrival (DTOA) system would require 2 ns to 4 ns to make the same measurement.

Using relatively low frequencies also conveys additional advantages. First, low frequencies are generally more penetrating than higher frequencies. For instance, at 2.4 GHz a reinforced concrete wall might attenuate signals as much as 20 dB. Second, the long wavelengths associated with low frequencies are far less vulnerable to multipath. In dense metallic structures, multipath obscures or destroys the ability of microwave or UHF signals to be used for reliable positioning. Low frequencies are less affected by this problem.

## **Disadvantages**

Operation at low frequencies faces challenges as well. In general, antennas are most efficient at frequencies whose wavelengths are comparable to the antennas' dimensions (e.g., a quarter-wavelength monopole antenna). Therefore, since higher frequencies have smaller wavelengths, high frequency antennas are typically smaller than low frequency antennas. The larger size of practically efficient low frequency antennas is a significant hurdle that near-field electromagnetic ranging systems must overcome.

## **Applications**

The low-frequency, multipath-resistant characteristics of NFER make it well suited for tracking in dense metallic locations, such as typical office and industrial environments. Low frequencies also readily diffract around the human body, which makes tracking people possible without the body blockage experienced by microwave systems like Ultra-wideband (UWB). Systems deployed in complicated indoor propagation environments

reportedly achieve 60 cm (2 ft) accuracy or better at ranges of 46 m (150 ft) or more. There is also an indication that multiple frequency implementations may yield increased accuracy.

## **Operation RAFTER**

**RAFTER** was a code name for the MI5 radio receiver detection technique, mostly used against clandestine Soviet agents and monitoring of domestic radio transmissions by foreign embassy personnel from the 1950s on.

### ***Explanation***

Since most radio receivers are of the superhet design, they typically contain local oscillators which generate a radio frequency signal in the range of 455 kHz above or sometimes below the frequency to be received. There is always some radiation from such receivers, and in the initial stages of RAFTER, MI5 simply attempted to locate clandestine receivers based on picking up the superhet signal with a quiet sensitive receiver that was custom built. This was not always easy because of the increasing number of domestic radios and televisions in people's homes.

By accident, one such receiver for MI5 mobile radio transmissions was being monitored when a passing transmitter produced a powerful signal. This overloaded the receiver, producing an audible change in the received signal. Quickly the agency realized that they could identify the actual frequency being monitored if they produced their own transmissions and listened for the change in the superhet tone.

### ***Soviet transmitters***

Since Soviet short-wave transmitters were extensively used to broadcast messages to clandestine agents, the transmissions consisting simply of number sequences read aloud and decoded using a one-time pad, it was realized that this new technique could be used to track down such agents. Specially equipped aircraft would fly over urban areas at times when the Soviets were transmitting, and attempt to locate receivers tuned to the Soviet transmissions.

### ***Tactics***

Like many secret technologies, RAFTER's use was attended by the fear of over-use, alerting the quarry and causing a shift in tactics which would neutralize the technology. As a technical means of intelligence, it was also not well supported by the more traditional factions in MI5. Its part in the successes and failures of MI5 at the time is not entirely known.

In his book *Spycatcher*, MI5 officer Peter Wright related one incident in which a mobile RAFTER unit in a van, or panel truck, was driven around the backstreets in an attempt to

locate a receiver. What with interference and the effects of large metal objects in the surroundings, such as lamp posts, this proved futile. Later, however, they concluded that the receiver itself had been mobile, and may at one point have been parked next to the van, hidden by a high fence.

## Chapter 7

# Plate Detector (Radio) and Program-Associated Data

## Plate detector

A **plate detector** is a vacuum tube detector circuit used in A.M. radios. This circuit employs a tube with an indirectly heated cathode, typically a medium-mu triode, or a tetrode or pentode with a sharp cut-off control grid. Rectification of R.F. signals occurs in the plate of the detector tube. This differs from a grid-leak detector, which achieves rectification in the control grid. It also differs from the diode detector circuit commonly used to provide both R.F. rectification and automatic volume control (A.V.C.) bias to the R.F. amplifier tubes.

### **Overview**

Plate detectors are used in both T.R.F. and superheterodyne receivers. The grid is connected directly to the secondary of the final R.F. or I.F. transformer. The cathode is connected to ground through a circuit consisting of a parallel-connected bias resistor (usually 10 k $\Omega$  to 50 k $\Omega$ ) and bypass capacitor (usually 0.25  $\mu$ F to 0.5  $\mu$ F). When sufficient negative bias is applied to the grid, the plate current is pushed almost to the cut-off point. When a modulated R.F. signal is applied to the grid under these conditions, a corresponding increase in plate current occurs. As the signal amplitude varies, the plate current also varies, causing the plate to act as a diode detector while the tube as a whole also acts as an audio amplifier. A plate bypass capacitor (usually 500 pF to 0.002  $\mu$ F for triodes, or 250 pF to 0.001  $\mu$ F for tetrodes and pentodes) is used to regulate plate current.

Like most A.F. amplifiers in radios, the plate voltage is usually less than 60 volts. When a tetrode or pentode is used, the screen grid voltage is usually about one-half the plate voltage.

Plate detector circuits were commonly used from the introduction of indirectly heated cathode tubes in the late 1920s until the start of World War II. As R.F. tubes became more sensitive, grid-leak detectors (which are more sensitive than plate detectors) became

less practical. Diode detectors were popular because, unlike plate detector circuits, they could also provide A.V.C. bias. However, the dual-diode/triode and dual-diode/pentode tubes commonly used in these circuits had bulk wholesale costs that were as much as twice the cost of the tubes commonly used as plate detectors. This made plate detector circuits more practical for low-priced radios sold during the depths of the Great Depression.

Because an indirectly heated cathode is required for this circuit to operate, it is not used in battery-operated radios.

## Controlling volume levels

Plate detector circuits usually lack an A.V.C. bias circuit. In receivers equipped with A.V.C., volume levels are adjusted by a potentiometer (typically 500 k $\Omega$  to 2 M $\Omega$  audio taper) that controls audio signal levels at the control grid of the A.F. amplifier. In receivers not equipped with A.V.C., the most common connection of the volume control potentiometer (typically 4 k $\Omega$  to 15 k $\Omega$  linear taper) is as follows:

- The low side of the potentiometer is connected to the antenna connection at the antenna input coil;
- The center wiper is connected to ground (in A.C. receivers) or B- (in A.C./D.C. receivers);
- The high side is connected to the cathode of at least one R.F. amplifier (in T.R.F. receivers) or to the converter and/or the I.F. amplifier (in superheterodyne receivers).

To assure that proper cathode bias is maintained, many non-A.V.C. volume controls are usually equipped with a "stop" that maintains a small amount of resistance between the center wiper and the high end connection.

- Other volume control circuits in non-A.V.C. receivers include:
  - A potentiometer (typically 500 k $\Omega$  audio taper) where the high end and center wiper are connected as above, but where the low end is connected to the control grid of audio output tube. (In this circuit, the potentiometer replaces the bias resistor for the output tube's control grid);
  - A linear taper potentiometer that adjusts the screen grid voltages of the set's R.F. amplifiers (if they are tetrodes or pentodes);
  - A linear taper potentiometer connected to the antenna (high end), ground (low end) and the antenna input coil (center wiper).

Because the volume control in non-A.V.C. receivers adjusts R.F. signal levels rather than A.F. signal levels, the volume control must be manipulated while tuning the radio in order to find weak signals.

## Tubes commonly used as plate detectors

- 6C6
- 6J7
- 6SJ7
- 12F5
- 12J5
- 12J7
- 12SF5
- 12SJ7
- 24 and 24-A
- 27
- 36
- 37
- 56
- 57
- 76
- 77

## Program-associated data

**Program Associated Data (PAD)** or **Program Service Data (PSD)** is a concept related to broadcasting which consists of a number of different fields or streams which are displayed on many HD Radio & satellite radio receivers in order to describe the program being transmitted, including different information such as:

- song title.
- program title.
- artist name.
- album name.
- music genre.

This is intended to be seen by the listener as the program is heard.

The HD radio & satellite radio systems provides a data path for this programming data to be delivered and read by the listener as part of visual display in near real time. HD radio & satellite radio receivers should provide PAD decoders and visual screens for displaying the information in a correct way.

A lot of local radios which are transmitting in digital, are using PAD capacity to increase the value of the service they are giving.

## Chapter 8

# Radio Transmitter Design

**Radio transmitter design** is a complex topic which can be broken down into a series of smaller topics. A radio communication system requires two tuned circuits each at the transmitter and receiver, all four tuned to the same frequency. The transmitter is an electronic device which, usually with the aid of an antenna, propagates an electromagnetic signal such as radio, television, or other telecommunications.

### **Methods**

At the beginning of the 20th century, there were four chief methods of arranging the transmitting circuits:

1. The transmitting system consists of two tuned circuits such that the one containing the spark-gap is a persistent oscillator; the other, containing the aerial structure, is a free radiator maintained in oscillation by being coupled to the first (Nikola Tesla and Guglielmo Marconi).
2. The oscillating system, including the aerial structure with its associated inductance-coils and condensers, is designed to be both a sufficiently persistent oscillator and a sufficiently active radiator (Oliver Joseph Lodge).
3. The transmitting system consists of two electrically coupled circuits, one of which, containing the air-gap, is a powerful but not persistent oscillator, being provided with a device for quenching the spark so soon as it has imparted sufficient energy to the other circuit containing the aerial structure, this second circuit then independently radiating the train of slightly damped waves at its own period (Oliver Joseph Lodge and Wilhelm Wien).
4. The transmitting system, by means either of an oscillating arc (Valdemar Poulsen) or a high-frequency alternator (Rudolf Goldschmidt), emits a persistent train of undamped waves interrupted only by being broken up into long and short groups by the operator's key.

## ***Frequency synthesis***

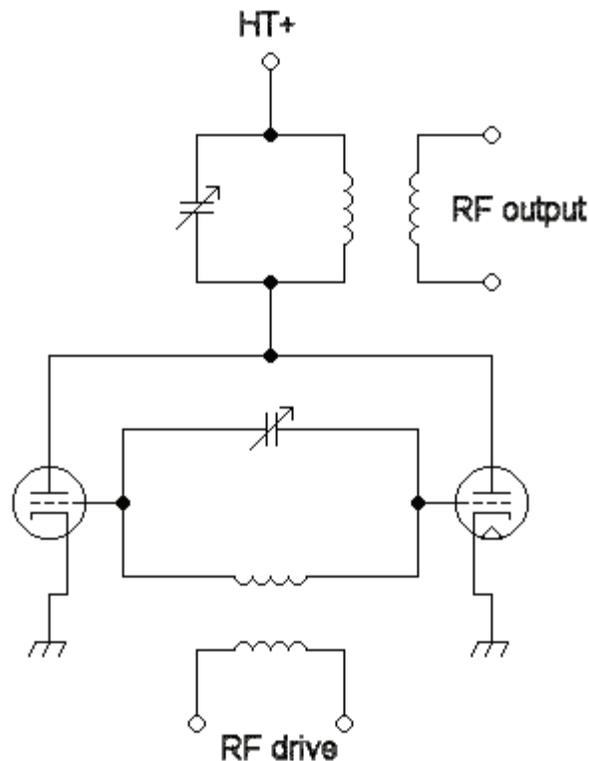
### **Fixed frequency systems**

For a fixed frequency transmitter one commonly used method is to use a resonant quartz crystal in a Crystal oscillator to fix the frequency. Where the frequency has to be variable, several options can be used.

### **Variable frequency systems**

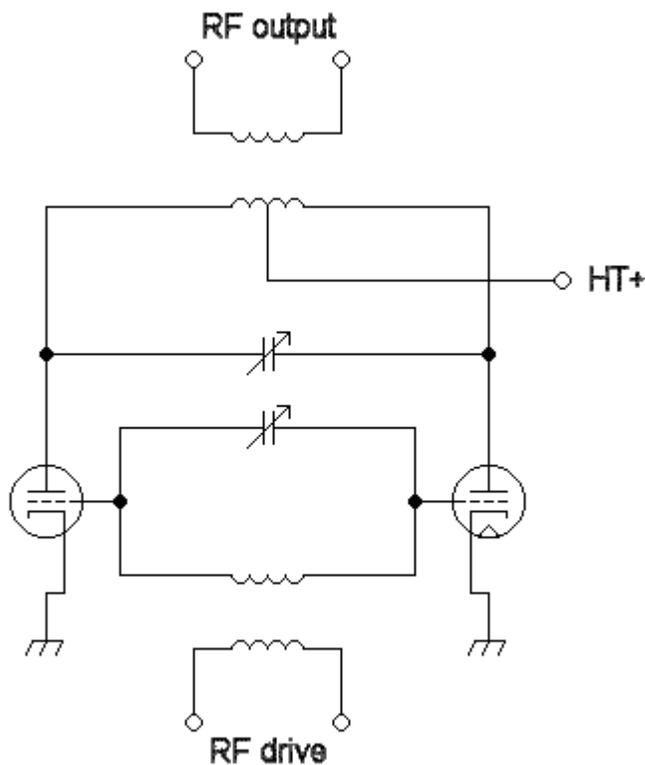
- An array of crystals – used to enable a transmitter to be used on several different frequencies; rather than being a truly variable frequency system, it is a system which is fixed to several different frequencies (a subset of the above).
- Variable-frequency oscillator (VFO)
- Phase-locked loop frequency synthesiser
- Direct digital synthesis

### ***Frequency multiplication***



### **Frequency doubler**

A basic design for a frequency doubler (screen grids, bias supplies and other elements are not shown).



### Frequency tripler

A basic design for a frequency tripler (screen grids, bias supplies and other elements are not shown).

For VHF transmitters, it is often not possible to operate the oscillator at the final output frequency. In such cases, for reasons including frequency stability, it is better to multiply the frequency of the free running oscillator up to the final, required frequency.

If the output of an amplifier stage is tuned to a multiple of the frequency with which the stage is driven, the stage will give a larger harmonic output than a linear amplifier. In a push-push stage, the output will only contain *even* harmonics. This is because the currents which would generate the fundamental and the odd harmonics in this circuit (if one valve was removed) are canceled by the second valve. In the diagrams, bias supplies and neutralization measure have been omitted for clarity. In a real system, it is likely that tetrodes would be used, as plate-to-grid capacitance in a tetrode is lower, thereby reducing stage instability.

In a push-pull stage, the output will contain only *odd* harmonics because of the canceling effect.

## ***Frequency mixing and modulation***

The task of many transmitters is to transmit some form of information using a radio signal (carrier wave) which has been modulated to carry the intelligence. A few rare types of transmitter do not carry information: the RF generator in a microwave oven, electrosurgery, and induction heating. RF transmitters that do not carry information are required by law to operate in an ISM band.

### **AM modes**

In many cases the carrier wave is mixed with another electrical signal to impose information upon it. This occurs in Amplitude modulation (AM). Amplitude Modulation: In Amplitude modulation the instantaneous change in the amplitude of the carrier Frequency with respect to the amplitude of the modulating or Base band signal.

### **Low level and high level**

#### ***Low level***

Here a small audio stage is used to modulate a low power stage, the output of this stage is then amplified using a linear RF amplifier.

- Advantages

The advantage of using a linear RF amplifier is that the smaller early stages can be modulated, which only requires a small audio amplifier to drive the modulator.

- Disadvantages

The great disadvantage of this system is that the amplifier chain is less efficient, because it has to be linear to preserve the modulation. Hence class C amplifiers cannot be employed.

An approach which marries the advantages of low-level modulation with the efficiency of a Class C power amplifier chain is to arrange a feedback system to compensate for the substantial distortion of the AM envelope. A simple detector at the transmitter output (which can be little more than a loosely coupled diode) recovers the audio signal, and this is used as negative feedback to the audio modulator stage. The overall chain then acts as a linear amplifier as far as the actual modulation is concerned, though the RF amplifier itself still retains the Class C efficiency. This approach is widely used in practical medium power transmitters, such as AM radiotelephones.

#### ***High level***

- Advantages

One advantage of using class C amplifiers in a broadcast AM transmitter is that only the final stage needs to be modulated, and that all the earlier stages can be driven at a constant level. These class C stages will be able to generate the drive for the final stage for a smaller DC power input. However, in many designs in order to obtain better quality AM the penultimate RF stages will need to be subject to modulation as well as the final stage.

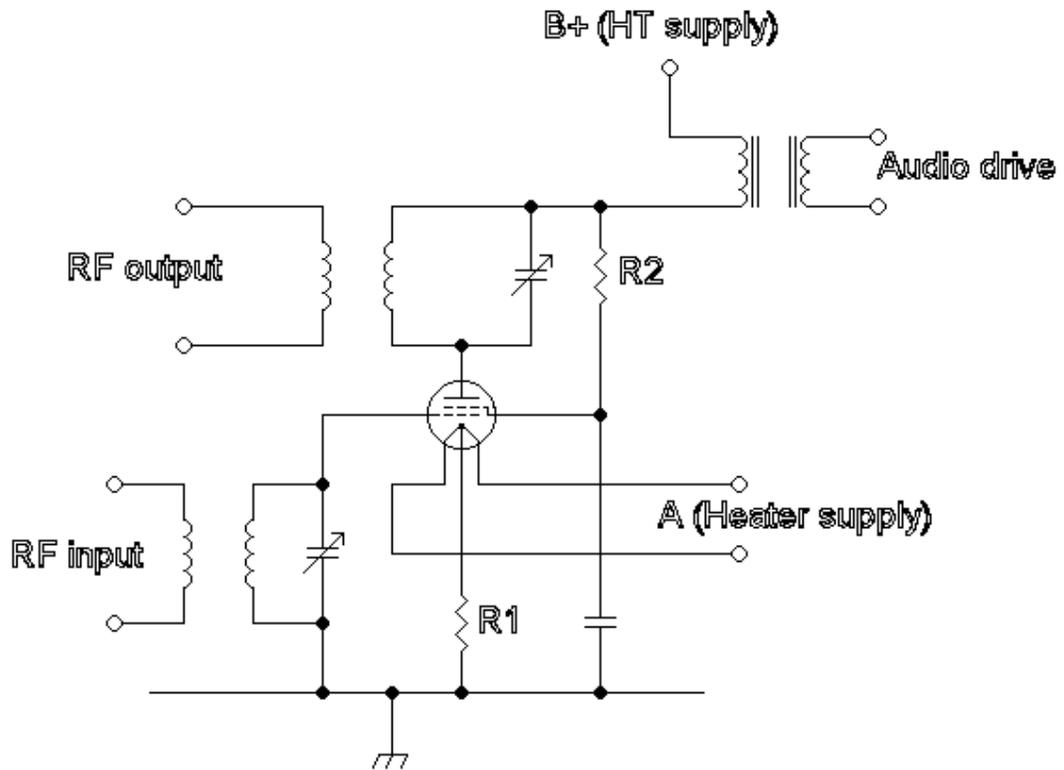
- Disadvantages

A large audio amplifier will be needed for the modulation stage, at least equal to the power of the transmitter output itself. Traditionally the modulation is applied using an audio transformer, and this can be bulky. Direct coupling from the audio amplifier is also possible (known as a cascode arrangement), though this usually requires quite a high DC supply voltage (say 30 V or more), which is not suitable for mobile units.

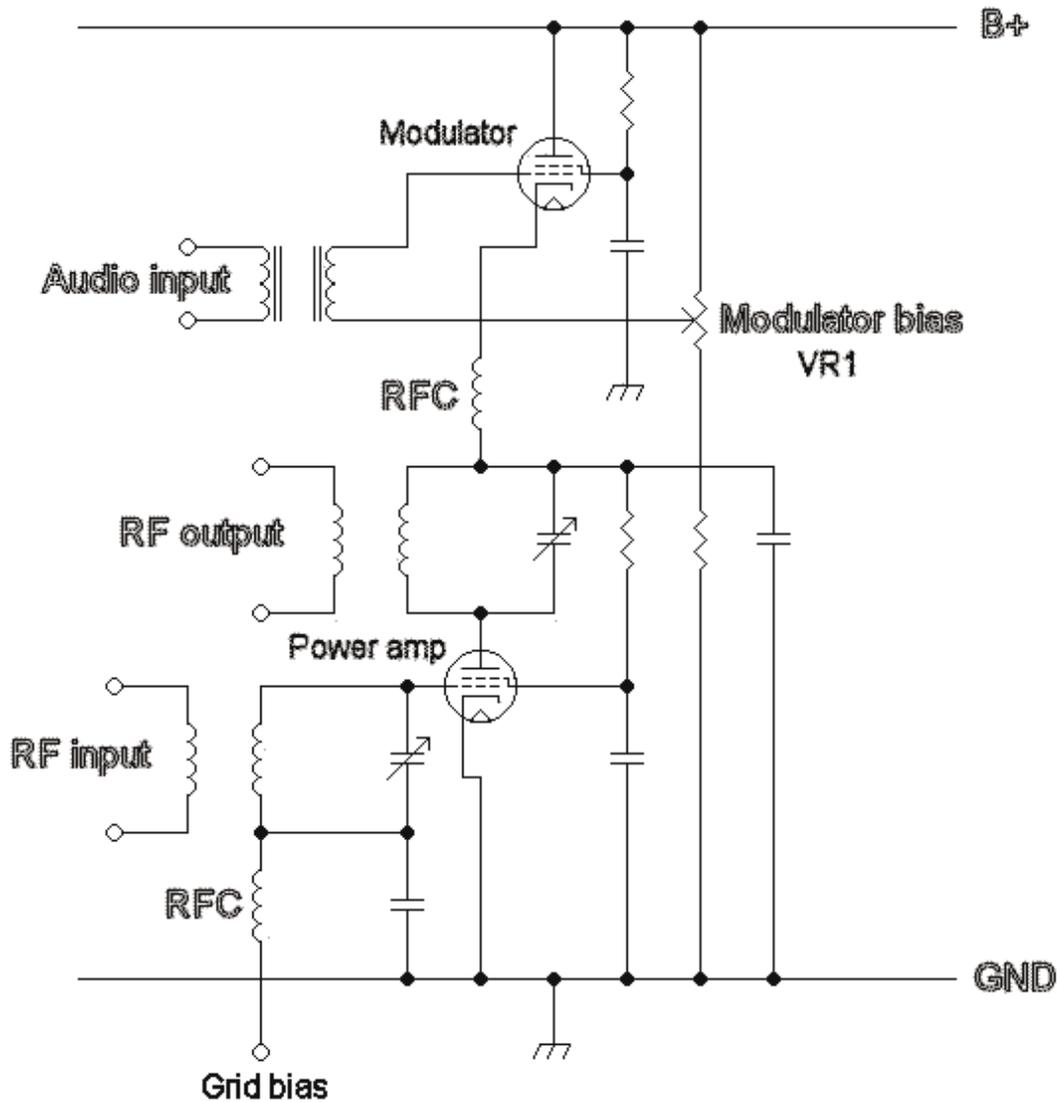
### **Types of AM modulators**

A wide range of different circuits have been used for AM. While it is perfectly possible to create good designs using solid-state electronics, valved (tube) circuits are shown here. In general, valves are able to easily yield RF powers far in excess of what can be achieved using solid state. Most high-power broadcast stations still use valves.

*Plate AM modulators*



Anode modulation using a transformer.

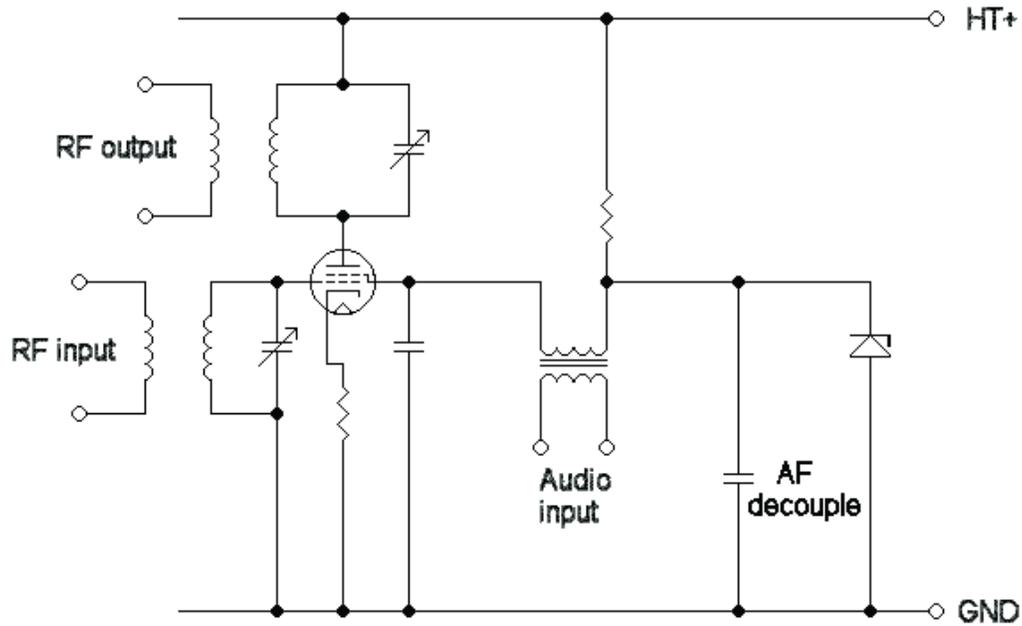


An example of a series modulated amplitude modulation stage.

In plate modulation systems the voltage delivered to the stage is changed. As the power output available is a function of the supply voltage, the output power is modulated. This can be done using a transformer to alter the anode (plate) voltage. The advantage of the transformer method is that the audio power can be supplied to the RF stage and converted into RF power. With anode modulation using a transformer, the tetrode is supplied with an anode supply (and screen grid supply) which is modulated via the transformer. The resistor R1 sets the grid bias, both the input and outputs are tuned LC circuits which are tapped into by inductive coupling. In series modulated amplitude modulation, the tetrode is supplied with an anode supply (and screen grid supply) which is modulated by the modulator valve. The resistor VR1 sets the grid bias for the modulator valve, both the RF input (tuned grid) and outputs are tuned LC circuits which are tapped into by inductive coupling.

When the valve at the top conducts more than the potential difference between the anode and cathode of the lower valve (RF valve) will increase. The two valves can be thought of as two resistors in a potentiometer.

### *Screen AM modulators*



Screen AM modulator.

Under steady state conditions (no audio driven) the stage will be a simple RF amplifier where the grid bias is set by the cathode current. When the stage is modulated the screen potential changes and so alters the gain of the stage.

### **Other modes which are related to AM**

Several derivatives of AM are in common use. These are

#### **Single-sideband modulation**

SSB, or SSB-AM single-sideband full carrier modulation, is very similar to single-sideband suppressed carrier modulation (SSB-SC)

#### ***Filter method***

Using a balanced mixer a double side band signal is generated, this is then passed through a very narrow bandpass filter to leave only one side-band. By convention it is normal to use the upper sideband (USB) in communication systems, except for HAM radio when the carrier frequency is below 10 MHz here the lower side band (LSB) is normally used.

### ***Phasing method***

This method is an alternative method for the generation of single sideband signals. One of the weaknesses of this method is the need for a network which imposes a constant 90° phase shift on audio signals throughout the entire audio spectrum. By reducing the audio bandwidth the task of designing the phaseshift network can be made more easy.

Imagine that the audio is a single sine wave  $E = E^\circ \sin(\omega t)$

The audio signal is passed through the phase shift network to give two identical signals which differ by 90°.

So as the audio input is a single sine wave the outputs will be

$$E = E^\circ \cdot \sin(\omega t)$$

and

$$E = E^\circ \cdot \cos(\omega t)$$

These audio outputs are mixed in non linear mixers with a carrier, the carrier drive for one of these mixers is shifted by 90°. The output of these mixers is combined in a linear circuit to give the SSB signal.

### **Vestigial-sideband modulation**

Vestigial-sideband modulation (VSB, or VSB-AM) is a type of modulation system commonly used in analogue TV systems. It is normal AM which has been passed through a filter which reduces one of the sidebands. Typically, components of the lower sideband more than 0.75 MHz or 1.25 MHz below the carrier will be heavily attenuated.

### **Morse**

Strictly speaking the commonly used 'AM' is double-sideband full carrier. Morse is often sent using on-off keying of an unmodulated carrier (Continuous wave), this can be thought of as an AM mode.

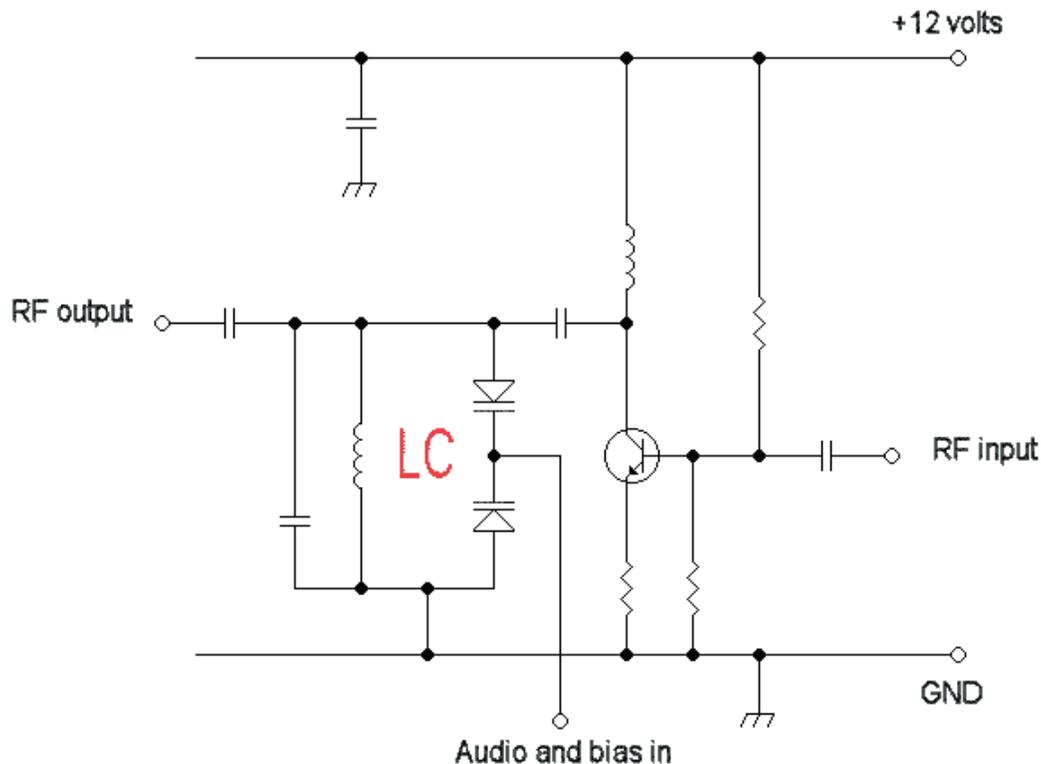
### **FM modes**

Angle modulation is the proper term for modulation by changing the instantaneous frequency or phase of the carrier signal. True FM and phase modulation are the most commonly employed forms of analogue angle modulation.

## Direct FM

Direct FM (true Frequency modulation) is where the frequency of an oscillator is altered to impose the modulation upon the carrier wave. This can be done by using a voltage-controlled capacitor (Varicap diode) in a crystal-controlled oscillator or frequency synthesiser. The frequency of the oscillator is then multiplied up using a frequency multiplier stage, or is translated upwards using a mixing stage, to the output frequency of the transmitter.

## Indirect FM



Indirect FM solid state circuit.

Indirect FM employs a varicap diode to impose a phase shift (which is voltage-controlled) in a tuned circuit that is fed with a plain carrier. This is termed phase modulation. The modulated signal from a phase-modulated stage can be understood with an FM receiver, but for good audio quality, the audio is applied to the phase modulation stage. The amount of modulation is referred to as the deviation, being the amount that the frequency of the carrier instantaneously deviates from the centre carrier frequency.

In some indirect FM solid state circuits, an RF drive is applied to the base of a transistor. The tank circuit (LC), connected to the collector via a capacitor, contains a pair of varicap diodes. As the voltage applied to the varicaps is changed, the phase shift of the output will change.

Phase modulation is mathematically equivalent to direct Frequency modulation with a 6dB/octave high-pass filter applied to the modulating signal. This high-pass effect can be exploited or compensated for using suitable frequency-shaping circuitry in the audio stages ahead of the modulator. For example, many FM systems will employ pre-emphasis and de-emphasis for noise reduction, in which case the high-pass equivalency of phase modulation automatically provides for the pre-emphasis. Phase modulators are typically only capable of relatively small amounts of deviation while remaining linear, but any frequency multiplier stages also multiply the deviation in proportion.

- Sigma-delta modulation ( $\Sigma\Delta$ )

## ***RF power amplifiers***

### **Valves**

#### **Advantages of valves**

- Good for high power systems
- Electrically very robust, they can tolerate overloads for minutes which would destroy bipolar transistor systems in milliseconds

#### **Disadvantages of valves**

- Heater supplies are required for the cathodes
- High voltages (*risk of death*) are required for the anodes
- Valves often have a shorter working life than solid state parts because the heaters tend to fail

### **Solid state**

For low and medium power it is often the case that solid state power stages are used. For higher power systems these cost more per watt of output power than a valved system.

## ***Linking the transmitter to the aerial***

The majority of modern transmitting equipment is designed to operate with a resistive load fed via coaxial cable of a particular characteristic impedance, often 50 ohms. To connect the aerial to this coaxial cable transmission line a matching network and/or a balun may be required. Commonly an SWR meter and/or an antenna analyzer are used to check the extent of the match between the aerial system and the transmitter via the transmission line (feeder). An SWR meter indicates forward power, reflected power, and the ratio between them.

## **EMC matters**

While this section was written from the point of view of an amateur radio operator with relation to television interference it applies to the construction and use of all radio transmitters, and other electronic devices which generate high RF powers with no intention of radiating these. For instance a dielectric heater might contain a 2000 watt 27 MHz source within it, if the machine operates as intended then none of this RF power will leak out. However, if the device is subject to a fault then when it operates RF will leak out and it will be now a transmitter. Also computers are RF devices, if the case is poorly made then the computer will radiate at VHF. For example if you attempt to tune into a weak *FM* radio station (88 to 108 MHz, band II) at your desk you may lose reception when you switch on your PC. Equipment which is not intended to generate RF, but does so through for example sparking at switch contacts is not considered here.

### **RF leakage (defective RF shielding)**

All equipment using RF electronics should be inside a screened metal box, all connections in or out of the metal box should be filtered to avoid the ingress or egress of radio signals. A common and effective method of doing so for wires carrying DC supplies, 50/60 Hz AC connections, audio and control signals is to use a feedthrough capacitor. This is a capacitor which is mounted in a hole in the shield, one terminal of the capacitor is its metal body which touches the shielding of the box while the other two terminal of the capacitor are the on either side of the shield. The feed through capacitor can be thought of as a metal rod which has a dielectric sheath which in turn has a metal coating.

In addition to the feed through capacitor, either a resistor or RF choke can be used to increase the filtering on the lead. In transmitters it is vital to prevent RF from entering the transmitter through any lead such as an electric power, microphone or control connection. If RF does enter a transmitter in this way then an instability known as motorboating can occur. Motorboating is an example of a self inflicted EMC problem.

If a transmitter is suspected of being responsible for a television interference problem, then it should be run into a dummy load; this is a resistor in a screened box or can which will allow the transmitter to generate radio signals without sending them to the antenna. If the transmitter does not cause interference during this test, then it is safe to assume that a signal has to be radiated from the antenna to cause a problem. If the transmitter does cause interference during this test then a path exists by which RF power is leaking out of the equipment, this can be due to bad shielding. This is a rare but insidious problem and it is vital that it be tested for. Such leakage is most likely to occur on homemade equipment or equipment that has been modified. RF leakage from microwave ovens may also sometimes be observed, especially when the oven's RF seal has been compromised.

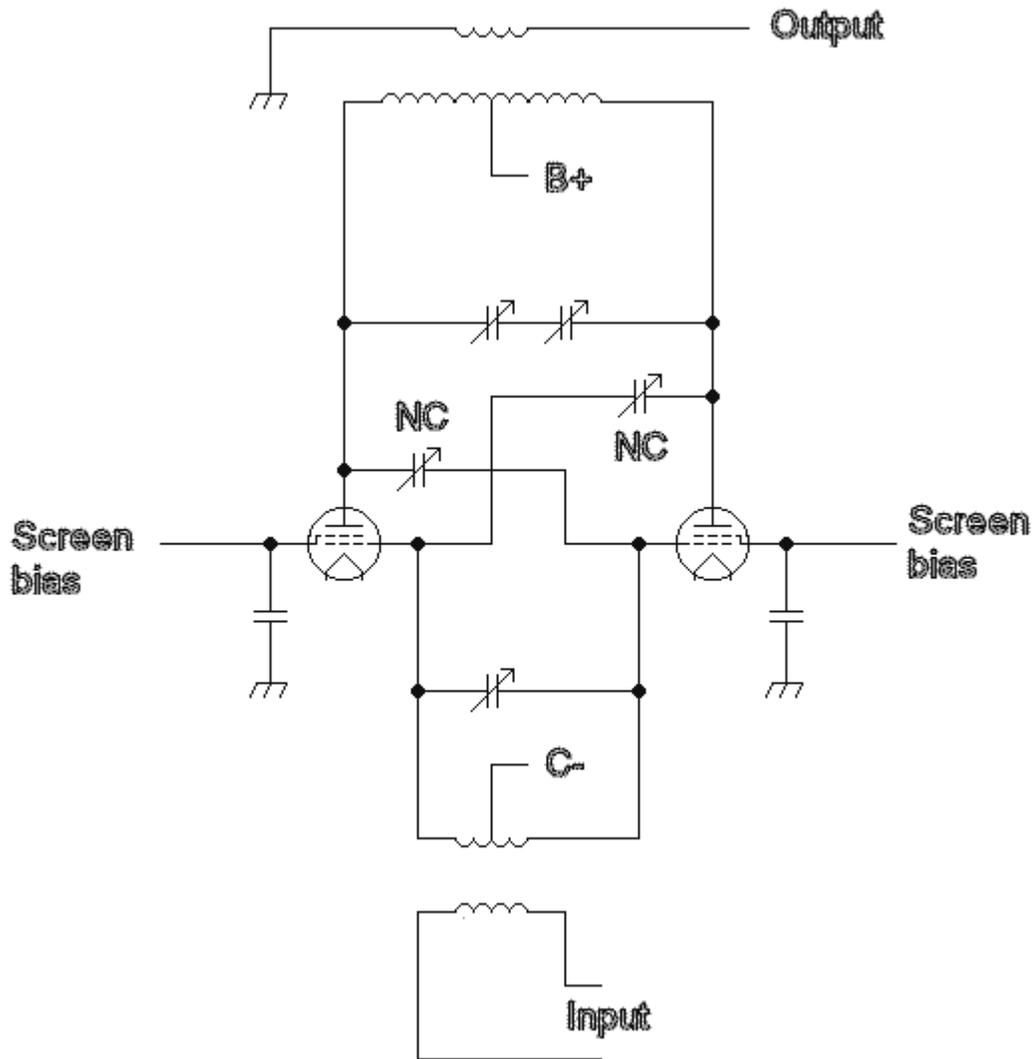
## **Spurious emissions**

- Early in the development of radio technology it was recognised that the signals emitted by transmitters had to be 'pure'. For instance Spark-gap transmitters were quickly outlawed as they give an output which is so wide in terms of frequency. In modern equipment there are three main types of spurious emissions.
- The term spurious emissions refers to any signal which comes out of a transmitter other than the wanted signal. The spurious emissions include harmonics, out of band mixer products which are not fully suppressed and leakage from the local oscillator and other systems within the transmitter.

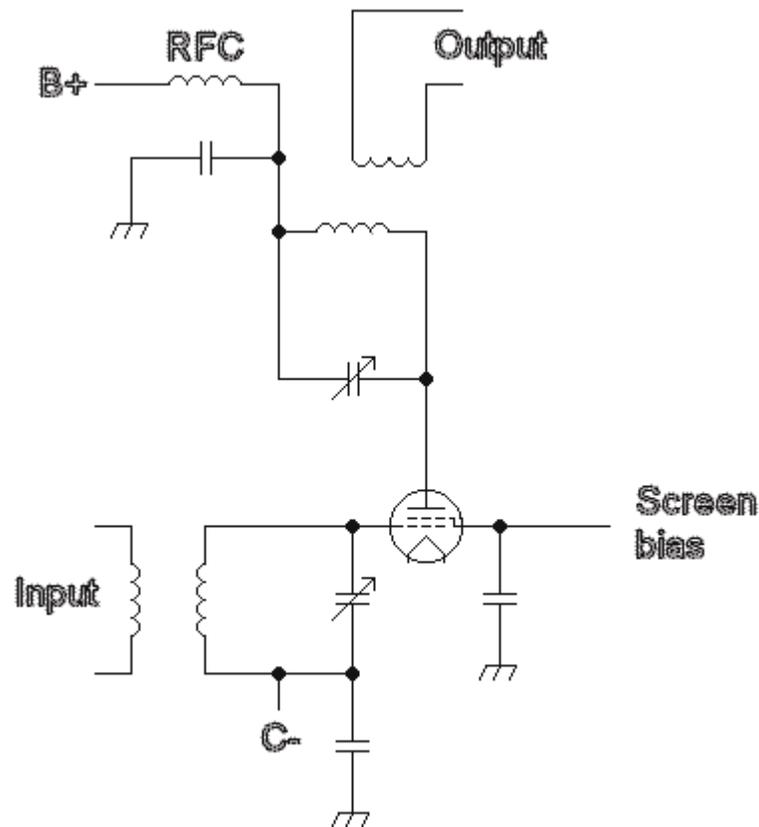
## **Harmonics**

These are multiples of the operation frequency of the transmitter, they can be generated in a stage of the transmitter even if it is driven with a perfect sine wave because no real life amplifier is perfectly linear.

### *Avoiding harmonic generation*



Note that B+ is the anode supply, C- is the grid bias. While the circuit shown here uses tetrode valves (for example 2 x 4CX250B) many designs have used solid state semiconductor parts (such as MOSFETS). Note that NC is a neutralization capacitor.



Note that B+ is the anode supply, C- is the grid bias. While the circuit shown here uses a tetrode valve (for example the 4CX250B) many designs have used solid state semiconductor parts (such as MOSFETS).

It is best if these harmonics are designed out at an early stage. For instance a push-pull amplifier consisting of two tetrode valves attached to an anode tank resonant LC circuit which has a coil which is connected to the high voltage DC supply at the centre (Which is also RF ground) will only give a signal for the fundamental and the odd harmonics.

### ***Removal of harmonics with filters***

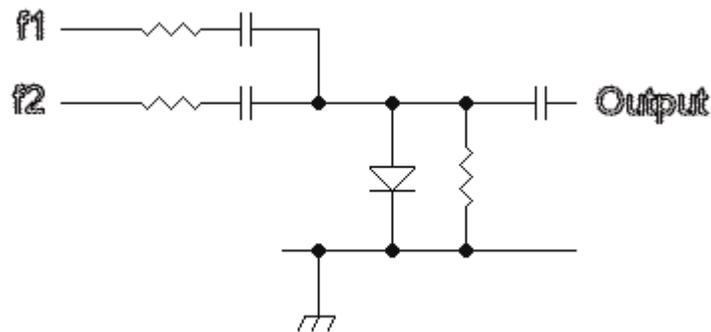
In addition to the good design of the amplifier stages, the transmitter's output should be filtered with a low pass filter to reduce the level of the harmonics.

### ***Detection***

The harmonics can be tested for using an RF spectrum analyser (expensive) or with an absorption wavemeter (cheap). If a harmonic is found which is at the same frequency as the frequency of the signal wanted at the receiver then this spurious emission can prevent the wanted signal from being received.

## Local oscillators and unwanted mixing products

Imagine a transmitter, which has an intermediate frequency (IF) of 144 MHz, which is mixed with 94 MHz to create a signal at 50 MHz, which is then amplified and transmitted. If the local oscillator signal was to enter the power amplifier and not be adequately suppressed then it could be radiated. It would then have the potential to interfere with radio signals at 94 MHz in the FM audio (band II) broadcast band. Also the unwanted mixing product at 238 MHz could in a poorly designed system be radiated. Normally with good choice of the intermediate and local oscillator frequencies this type of trouble can be avoided, but one potentially bad situation is in the construction of a 144 to 70 MHz converter, here the local oscillator is at 74 MHz which is very close to the wanted output. Good well made units have been made which use this conversion but their design and construction has been challenging, for instance in the late 1980s Practical Wireless published a design (Meon-4) for such a transverter. This problem can be thought of as being related to the Image response problem which exists in receivers.



Simple but poor mixer

One method of reducing the potential for this transmitter defect is the use of balance and double balanced mixers. If the equation is assumed to be

$$E = E_1 E_2$$

and is driven by two simple sine waves,  $f_1$  and  $f_2$  then the output will be a mixture of four frequencies

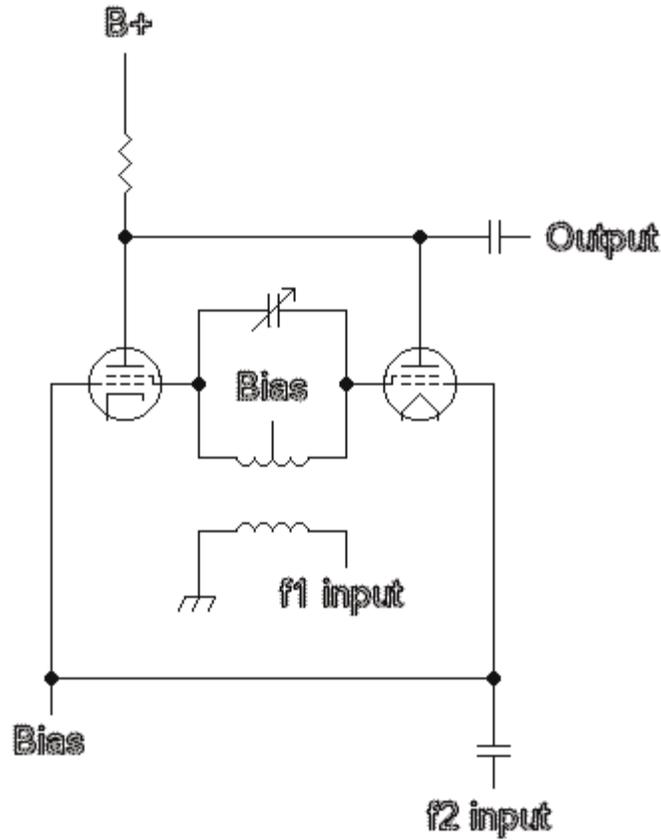
$$f_1$$

$$f_1 + f_2$$

$$f_1 - f_2$$

$$f_2$$

If the simple mixer is replaced with a balanced mixer then the number of possible products is reduced. Imagine that two mixers which have the equation  $\{I = E_1 E_2\}$  are wired up so that the current outputs are wired to the two ends of a coil (the centre of this coil is wired to ground) then the total current flowing through the coil is the difference between the output of the two mixer stages. If the  $f_1$  drive for one of the mixers is phase shifted by  $180^\circ$  then the overall system will be a balanced mixer.



Note that while this hypothetical design uses tetrodes many designs have used solid state semiconductor parts (such as MOSFETS).

$$E = K \cdot E_{f2} \cdot \Delta E_{f1}$$

So the output will now have only three frequencies

$$f_1 + f_2$$

$$f_1 - f_2$$

$$f_2$$

Now as the frequency mixer has fewer outputs the task of making sure that the final output is *clean* will be simpler.

### **Instability and parasitic oscillations**

If a stage in a transmitter is unstable and is able to oscillate then it can start to generate RF at either a frequency close to the operating frequency or at a very different frequency. One good sign that it is occurring is if an RF stage has a power output even without being driven by an exciting stage. Another sign is if the output power suddenly increases wildly when the input power is increased slightly, it is noteworthy that in a class C stage that this behaviour can be seen under normal conditions. The best defence against this transmitter defect is a good design, also it is important to pay good attention to the neutralization of the valves or transistors.

## Chapter 9

# Radio Jamming

**Radio jamming** is the (usually deliberate) transmission of radio signals that disrupt communications by decreasing the signal to noise ratio. Unintentional jamming occurs when an operator transmits on a busy frequency without first checking whether it is in use, or without being able to hear stations using the frequency. Another form of unintentional jamming occurs when equipment accidentally radiates a signal, such as a cable TV plant that accidentally emits on an aircraft emergency frequency. The concept can be used in wireless data networks to disrupt information flow. It is a common form of censorship in totalitarian countries, in order to prevent foreign radio stations in border areas from reaching the country.

### ***Distinction between "jamming" and "interference"***

Originally the terms were used interchangeably but nowadays most radio users use the term "jamming" to describe the *deliberate* use of radio noise or signals in an attempt to disrupt communications (or prevent listening to broadcasts) whereas the term "interference" is used to describe *unintentional* forms of disruption (which are far more common). However the distinction is still not universally applied.

### ***Method***

Intentional communications jamming is usually aimed at radio signals to disrupt control of a battle. A transmitter, tuned to the same frequency as the opponents' receiving equipment and with the same type of modulation, can, with enough power, override any signal at the receiver.

The most common types of this form of signal jamming are random noise, random pulse, stepped tones, warbler, random keyed modulated CW, tone, rotary, pulse, spark, recorded

sounds, gulls, and sweep-through. These can be divided into two groups – obvious and subtle.

Obvious jamming is easy to detect because it can be heard on the receiving equipment. It usually is some type of noise such as stepped tones (bagpipes), random-keyed code, pulses, music (often distorted), erratically warbling tones, highly distorted speech, random noise (hiss) and recorded sounds. Various combinations of these methods may be used often accompanied by regular morse identification signal to enable individual transmitters to be identified in order to assess their effectiveness. For example, China, which used jamming extensively and still does, plays a loop of traditional Chinese music while it is jamming channels (c.f. Attempted jamming of number stations).

The purpose of this type of jamming is to block out reception of transmitted signals and to cause a nuisance to the receiving operator. One early Soviet attempt at jamming western broadcasters used the noise from the diesel generator that was powering the jamming transmitter.

Subtle jamming is jamming during which no sound is heard on the receiving equipment. The radio does not receive incoming signals yet everything seems superficially normal to the operator. These are often technical attacks on modern equipment, such as "squelch capture". Thanks to FM capture effect, Frequency Modulated broadcasts may be jammed, unnoticed, by a simple unmodulated carrier.

## ***History of Jamming***

During World War II ground radio operators would attempt to mislead pilots by false instructions in their own language, in what was more precisely a spoofing attack than jamming. Radar jamming is also important to disrupt use of radar used to guide an enemy's missiles or aircraft. Modern secure communication techniques use such methods as spread spectrum modulation to resist the deleterious effects of jamming.

Jamming of foreign radio broadcast stations has often been used in wartime (and during periods of tense international relations) to prevent or deter citizens from listening to broadcasts from enemy countries. However such jamming is usually of limited effectiveness because the affected stations usually change frequencies, put on additional frequencies and/or increase transmission power.

Jamming has also occasionally been used by the Governments of Germany (during WW2), Israel, Cuba, Iraq, Iran (Iraq and Iran war, 1980–1988), China, North and South Korea and several Latin American countries, as well as by Ireland against pirate radio stations such as Radio Nova. The United Kingdom government used two coordinated, separately located transmitters to jam the offshore radio ship, Radio North Sea International off the coast of Britain in 1970.

## World War Two

In occupied Europe the Nazis attempted to jam broadcasts to the continent from the BBC and other allied stations. Along with increasing transmitter power and adding extra frequencies, attempts were made to counteract the jamming by dropping leaflets over cities instructing listeners to construct a directional loop aerial that would enable them to hear the stations through the jamming. In the Netherlands such aerials were nicknamed "moffenzeef" (English: "kraut sieve" )

## Cold War era

During much of the Cold War Soviet (and Eastern Bloc) jamming of some Western broadcasters led to a "power race" in which broadcasters and jammers alike repeatedly increased their transmission power, utilised highly directional antennas and added extra frequencies to the already heavily overcrowded shortwave bands to such an extent that many broadcasters not directly targeted by the jammers (including pro-Soviet stations) suffered from the rising levels of noise and interference.

A further method used was operating transmitters for domestic radio stations on the same or nearby frequencies. For example, for many years the GDR operated at Wiederau a transmitter on the same mediumwave frequency (575 KHz) that Mühlacker radio transmitter used with an output power of 100 kW, which made it difficult to receive the AFN Mühlacker radio transmitter in much of the GDR.

Radio Free Europe and its sister service Radio Liberty were the main target of Soviet jammers followed by Voice of America and the BBC World Service.

Other stations targeted by the Soviet jammers (but not to the same extent as RFE/RL/VOA/BBC) included Deutsche Welle and occasionally Radio Vaticana, Kol Yisrael and Radio Canada International. The jamming usually only took place during programming in languages widely spoken in Eastern Bloc countries (*e.g.*, Russian, Polish, Czech, Lithuanian, etc.). Programmes in English or other major Western languages were rarely (if ever) jammed intentionally.

There were also periods when China and the USSR jammed each other's programmes. The USSR also jammed Albanian programmes at times.

Some parts of the world were more impacted by these broadcasting practices than others

- Eurasia (worst affected, including mediumwave frequencies particularly 720 kHz used by RFE)
- North Asia, Americas and Sub-Saharan Africa (partly affected)
- Australasia, South America (rarely affected)

Meanwhile some listeners in the Soviet union and Eastern bloc devised ingenious methods (such as homemade directional loop antennas) to hear the Western stations

through the noise. Because radio signal propagation on shortwave can be difficult to predict reliably listeners sometimes found that there were days/times when the jamming was particularly ineffective because radio fading (due to atmospheric conditions) was affecting the jamming signals but favouring the broadcasts. On other days of course the reverse was the case. There were also times when jamming transmitters were (temporarily) off air due to breakdowns or maintenance. The Soviets (and most of their Eastern bloc allies) used two types of jamming transmitter. Skywave jamming covered a large area but for the reasons described was of limited effectiveness. Groundwave jamming was more effective but only over a small area and was thus only used in/near major cities throughout the Eastern bloc. Both types of jamming were less effective on higher shortwave frequencies (above 15 MHz) however many radios in the USSR didn't cover the higher bands. Skywave jamming was usually accompanied by morse signals in order to enable (coded) identification of the jamming station in order that Soviet monitoring posts could assess the effectiveness of each station.

In 1987 after decades of generally refusing to acknowledge that such jamming was even taking place the Soviets finally stopped jamming western broadcasts with the exception of RFE/RL which continued to be jammed for several months into 1988. Previously there had been periods when some individual Eastern bloc countries refrained from jamming Western broadcasts but this varied widely by time and country. In general outside of the USSR itself Bulgaria was one of the most prolific operators of jamming transmitters in the Eastern bloc with East Germany the least.

While western governments may have occasionally considered jamming broadcasts from Eastern Bloc stations, it was generally accepted that doing so would be a pointless exercise. Ownership of shortwave radios was less common in western countries than in the USSR where due to the vast physical size of the country many domestic stations were relayed on shortwave as it was the only practical way to cover remote areas. Additionally western governments were generally less afraid of intellectual competition from the communist bloc.

However in Latin America there were instances of communist radio stations such as Radio Venceremos being jammed, allegedly by the CIA, while there were short lived instances where Britain jammed some Egyptian (during the Suez crisis), Greek (Prior to Cyprus gaining independence) and Rhodesian stations.

## **Post Cold War (1989 -- Present)**

### **People's Republic of China**

In 2002, China acquired standard short-wave radio-broadcasting equipment designed for general public radio-broadcasting and technical support from Thales Broadcast Multimedia, a former subsidiary of the French state-owned company Thales Group.

- It is assumed that China is using ALLISS technology for jamming foreign radio stations broadcasting into China.

- Thales jamming technology only operates at power levels below 500 kW (for its shortwave jamming products).
- Adele Milna (BSEE) of Continental Electronics (in an audio file held at [shortwave.org](http://shortwave.org)) claims that China has duplicated his companies 100 kW, 250 kW shortwave transmitters. It is unclear if these products were indeed duplicated or if broadcast jamming (as opposed to future product sales) were a reason for the duplication.

## **United States of America**

In 2007, the United States of America scrambled a signal of a European television satellite (Eutelsat Hotbird 8). The US was misled to believe that this satellite was transmitting a Television channel which is publicly presented in radical Islamic countries ([Az-Zawraa]). This act from the USA caused a disturbance in many European Television channels.

## **Islamic Republic of Iran**

Islamic Republic of Iran has frequently used jamming of satellite TV (as well as filtering the Internet and restricting Internet connectivity speed and other methods) as a strategy to prevent the consequences of freedom of expression in the last decade. Most of the jamming took place in the year 2009 after the controversial presidential election in Iran to control the flow of information and updates about the protests. Although most of the jamming is done on news channels or political ones, another famous series of jamming started around July 2010 on a non-political, Persian language satellite TV channel called "Farsi1" which airs Persian-dubbed popular TV series.

## **Other Countries**

- Since the early 1960s, the practice of radio jamming has been very common in Cuba, blocking not only American government funded radio stations (such as VOA) but also radio stations owned and/or operated by (or selling airtime to) Cuban exile groups transmitting from Miami, Florida, such as La Cubanisima, Radio Mambi, and Cadena Azul. The same practice has been applied to Radio Marti and TV Marti, operated by the U.S. Information Agency since 1985.
- North Korea and South Korea still regularly jam some of each other's radio (and sometimes television) stations. (See: Radio jamming in Korea)
- Several middle eastern countries (particularly Iran) jam shortwave broadcasts (and even occasionally attempt to jam satellite TV signals ) targeted at their countries.
- Pakistan has recently stated its intention to begin jamming clandestine radio stations operated by the Taliban
- Ethiopia has jammed the DW and VOA transmissions as well as ESAT Ethiopian Satellite Television
- In Argentina, aerial TV channel Canal 13, cable TV news channel Todo Noticias and AM radio Radio Mitre were jammed by an unidentified source coming from

South America. All of these stations belong to the Artear media company, which belongs to Grupo Clarín. This media corporation gained international notoriety for their ongoing confrontation with the Argentine Government which started during the 2008 Argentine government conflict with the agricultural sector.

## Chapter 10

# Radio Teleswitch, Radio Frequency Sweep and Datacasting

## Radio teleswitch



Economy 7 Meter and radio teleswitch, right

A *Radio Teleswitch* is a device used in the United Kingdom to allow electricity suppliers to switch large numbers of electricity meters between different tariffs, by broadcasting an

embedded signal in broadcast radio signals. Radio Teleswitches are also used to switch on/off consumer appliances to make use of cheaper baseload tariffs, such as economy 7.

## **Operation**

Each of the user companies (The *RTS Users*, or *Service Providers*) have their own database on the Central Teleswitch Control Unit (CTCU), which is a HP Integrity computer running OpenVMS on IA-64 for reliability and clustering technology to minimise downtime. The database defines how each group of teleswitches belonging to the user-company will control the loads and meter registers connected to it. The CTCU uses the database and certain rules to generate and control a continuous string of messages which it forwards to the BBC for transmission. Although each message will be received by all installed teleswitches, the unique user and group-codes carried by the message ensure that only teleswitches carrying the same combination of codes will act on it.

## **History**

The **Radio Teleswitch Service (RTS)** has its origins in the energy management projects initiated in the United Kingdom by the Electricity Council in the early 1980s. Three projects investigated the feasibility of using the telephone network, the distribution network and national radio for large scale energy management purposes. The radio teleswitch project was chaired by Walter Waring deputy chairman of Eastern Electricity and supported by the BBC. The idea of phase modulating control and data signals onto the low frequency carrier wave used for broadcasting the BBC Radio 4 programmes was tested. The BBC was satisfied that there was no discernible distortion of its broadcast service and no infringement of its Royal Charter. The technique won the Queen's award for technology while its application for controlling consumer tariffs and loads was approved by the Home Office. The project was funded by the CEGB and the mainland electricity boards who were each allocated one of 16 message channels. One channel was reserved for testing and the final one was allocated to Northern Ireland when it joined the project.

The Central Teleswitch Control Unit (CTCU) has recently been updated to replace the obsolete hardware with brand new, modern, fully supported equipment. The old DEC MicroVAX machines have been replaced with HP Integrity 2600s. The operating system has also been upgraded to OpenVMS 8.3.

All communications lines have also been updated and internet access has been introduced in addition to the dial in access by modem.

The update has markedly improved the performance and stability of the system.

The new system went live at the end of January 2008.

## ***Service Role***

For convenient and practical operation of the system the Users needed to set up or appoint an organisation to take overall responsibility for managing the delivery of the service. The organisation needs to hold nominal ownership of the system and IPR and as an agent to enter into and manage contracts necessary for the delivery of the service. The managing agent also provides co-ordination and liaison roles between all the parties concerned.

## ***Formal Agreements***

The Electricity Association (EA), which was previously known as the Electricity Council, entered into a renewed formal agreement with the BBC in 1996 as an agent of the users. The EA had also negotiated an agreement with the National Grid Company (NGC) concerning the servicing of the CTCU. Since 2004 the functions of EA regarding this contract have been taken over by the Energy Networks Association.

## **Radio frequency sweep**

**Radio frequency sweep** or "Frequency sweep" or "RF sweep" refer to scanning a radio frequency band for detecting signals being transmitted there. This is implemented using a radio receiver having a tunable receiving frequency. As the frequency of the receiver is changed to scan (sweep) a desired frequency band, a display indicates the power of the signals received at each frequency.

### ***Methods and tools***

A spectrum analyzer is a standard instrument used for RF sweep. It includes an electronically tunable receiver and a display. The display presents measured power (y axis) vs frequency (x axis). The power spectrum display is a two-dimensional display of measured power vs. frequency. The power may be either in linear units, or logarithmic units (dBm). Usually the logarithmic display is more useful, because it presents a larger dynamic range with better detail at each value. An RF sweep relates to a receiver which changes its frequency of operation continuously from a minimum frequency to a maximum (or from maximum to minimum). Usually the sweep is performed at a fixed, controllable rate, for example 5 MHz/sec.

Some systems use frequency hopping, switching from one frequency of operation to another. One method of CDMA uses frequency hopping. Usually frequency hopping is performed in a random or pseudo-random pattern.

### ***Applications***

Frequency sweeps may be used by regulatory agencies to monitor the radio spectrum, to ensure that users only transmit according to their licenses. The FCC for example controls

and monitors the use of the spectrum in U.S.A. In testing of new electronic devices, a frequency sweep may be done to measure the performance of electronic components or systems. For example, RF oscillators are measured for phase noise, harmonics and spurious signals; computers for consumer sale are tested to avoid radio frequency interference with radio systems. Portable sweep equipment may be used to detect some types of covert listening device (bugs).

## **Datacasting**

**Datacasting** (data broadcasting) is the broadcasting of data over a wide area via radio waves. It most often refers to supplemental information sent by television stations along with digital television, but may also be applied to digital signals on analog TV or radio. It generally does not apply to data which is inherent to the medium, such as PSIP data which defines virtual channels for DTV or direct broadcast satellite systems; or to things like cable modem or satellite modem, which use a completely separate channel for data.

### ***Overview***

Datacasting often provides news, weather, traffic, stock market, and other information which may or may not relate to the program[s] it is carried with. It may also be interactive, such as gaming, shopping, or education. An electronic program guide is usually included, although this stretches the definition somewhat, as this is often considered inherent to the digital broadcast standard.

The ATSC, DVB and ISDB standards allow for broadband datacasting via DTV, though they do not necessarily define how. The overscan and VBI are used for analog TV, for moderate and low bandwidths (including closed captioning in the VBI) respectively. DirectBand and RDS/RBDS are medium and narrow subcarriers used for analog FM radio. The EUREKA 147 and HD Radio standards both allow for datacasting on digital radio, defining a few basics but also allowing for later expansion.

The term **IP Datacasting** (IPDC) is used in DVB-H for the technical elements required to send IP packets over DVB-H broadband downstream channel combined with a return channel over a mobile communications network such as GPRS or UMTS. The set of specifications for IP Datacast (phase1) was approved by the DVB project in October 2005.

### ***Datacasting services around the world***

#### **North America**

##### **Ambient Information Network**

Ambient Information Network, a datacasting network owned by Ambient Devices presently hosted by U.S.A. Mobility, a U.S. paging service and focuses on information of

interest to the local (or larger) area, such as weather and stock indices, and with a paid subscription Ambient will provide a particular device with more personalized information.

## **RBDS**

A slight variation of the European Radio Data System, RBDS is carried on a 57kHz subcarrier on FM radio stations. While originally intended for program-associated data, it can also be used for datacasting purposes including paging and dGPS.

## **DirectBand**

DirectBand, owned by Microsoft, uses the 67.65 kHz subcarrier leased from FM radio stations. This subcarrier delivers about 12 kbit/s (net after error correction) of data per station, for over 100 MB per day per city. Data includes traffic, sports, weather, stocks, news, movie times, calendar appointments, and local time.

## **MovieBeam**

The now-defunct MovieBeam service used dNTSC technology by Dotcast to transmit 720p HDTV movies in the lower vestigial sideband of NTSC analog TV. The set-top box stored the movies to be viewed on demand for a fee. This was distributed through PBS's National Datacast.

## **TV Guide On Screen**

TV Guide On Screen is an advertising-supported datacast sent by one local station in each media market. It supplements or replaces the limited electronic program guide sent by each TV station, which is already mandated by the U.S. Federal Communications Commission (FCC).

## **ATSC-M/H**

ATSC-M/H is yet another mobile TV standard, although it is transmitted and controlled by the broadcasters instead of a third party, and is therefore mostly free to air (although it can also be subscription-based). From a technical standpoint, it is an IP-encapsulated datacast of MPEG-4 streaming video, alongside the ATSC MPEG transport stream used for over-the-air HDTV/SDTV broadcasting. Heavy error correction, separate from that native to ATSC, compensates for ATSC's poor mobile (and often fixed) reception.

## **UpdateTV**

UpdateTV is a service used by some brands of TV sets and other ATSC tuners to update their firmware via over-the-air programming. This is also transmitted on PBS stations via National Datacast.

## **Australia**

Australian broadcast infrastructure company Broadcast Australia undertook a three year trial in Sydney of a datacasting service using the DVB-T system for use in Australia.

The trial consisted of a number of services on one standard 7MHz multiplex, collectively known as *Digital Forty Four*.

The collection included:

- A combined program guide for the free-to-air broadcasters (Channel 4)
- ABC news, sport, and weather items (Channel 41)
- Channel NSW (link) Government and Public Information, including real time traffic information and life surf webcam images (Channel 45)
- Australian Christian Channel (Channel 46)
- Expo Home Shopping (Channel 49) and
- Federal parliamentary audio broadcasts.

More recently a near-Australia wide broadcast of a datacasting channel called MyTalk commenced on April 13, 2007. Broadcasting as part of the multiplex on Southern Cross and Southern Cross Ten stations, it provided news, weather and other information, available free to anyone able to tune in. The stream consisted of text applicable to the viewer's location and a 4:3 video window of broadcast TV from the relevant Southern Cross/Southern Cross Ten station.

On February 25, 2008, MyTalk ceased broadcasting. Digital Forty Four was shut down at exactly midnight on the night of April 30, 2010.

## **Malaysia**

Malaysian multi-channel pay-TV operator, MiTV Corporation Sdn Bhd has launched its IP over UHF service in September 2005. The full digital broadcast capacity is being used to deliver IP services which such as multicast streaming and datacasting.

## **South Africa**

Mindset Network has developed an IP satellite datacast platform for the distribution of educational and health content to sites around South Africa and increasingly throughout the rest of Africa as well. The model is a forward and store model allowing users of the platform to view content in an on-demand fashion. Content distributed in this way includes video content, print-based content (in the form of PDF files), as well as interactive computer-based multimedia content.

Significantly, the model also includes access to a GPRS network that allows the receiving sites to communicate back to the Mindset central server. Communications include

statistics about the physical health of the machine (e.g. power status, disk drive usage) as well as usage statistics indicating what content has been viewed.

The model also includes a distributed deployment of the Moodle LMS, allowing users to take assessments and then have the results transmitted via GPRS to the Mindset server for accreditation.

## **United Kingdom**

Teletext is used extensively on analogue channels; a type of Datacasting using the Overscan on analogue transmissions. Teletext Limited and Ceefax are the main providers. Within Digital television the Digital Teletext name is used extensively although the technology used to provide this service is unrelated and uses the MHEG-5 UK profile.

## Chapter 11

# Low-Power Broadcasting

**Low-power broadcasting** is electronic broadcasting at very low power and low cost, to a small community area.

The terms "low-power broadcasting" and "**micropower broadcasting**" (more commonly "**microbroadcasting**") should not be used interchangeably, because the markets are not the same. The former term is more often used to describe stations who have applied for and received official licenses. The relationship between broadcasting power and signal range is a function of many things, such as the frequency band it uses e.g., Medium Wave shortwave or FM, the topography of the geographical area in which it operates (mountainous or flat), atmospheric conditions, and finally the amount of radio frequency energy it transmits. As a general rule, the more energy a station transmits, the further its signal goes.

**LPFM**, **LPAM**, and **LPTV** are in various levels of use across the world, varying widely based on the laws and their enforcement.

### ***United States***

#### **FM radio**

In the U.S., the Federal Communications Commission (FCC) partially re-legalized LPFM licenses, after the National Association of Broadcasters (NAB), Corporation for Public Broadcasting (CPB), and National Public Radio (NPR) convinced them to stop issuing the FM class D license in 1978.

The new LPFM licenses in the United States may only be issued to nonprofit educational organizations and state and local governments. (47 CFR 73.853) Also, the one and so far only "window" for applications closed in 2003, and at present, the FCC is not

entertaining any new broadcast license applications, instead conducting auctions of frequencies for full power uses only.

## **LPFM classes**

- Class L1 (LP100) is to 100 watts effective radiated power (ERP). 47 CFR 73.811
- Class L2 (L10) is at least 1 and up to 10 watts ERP. 47 CFR 73.811
- Class D is 10 watts Transmitter power output (TPO) or less, regardless of ERP, and are no longer issued for LPFM services (since 1978).

Officially, class D is still assigned to broadcast translators, though the rules are actually much looser (up to 250 watts ERP) than for true LPFM stations, though they may not broadcast their own programming. This is due to the influence of NPR and religious broadcasting companies, which often rely on translators. Since true class D stations can bump translators, they therefore have less competition in getting or keeping their own translators on the air with new class D stations kept off the air.

New classes L1 and L2 are still considered amateur class D for international purposes, but are considered to be equal in status to translators, and subordinate to full class D stations still operating.

Broadcast Auxiliary-Low Power stations are authorized in the frequency band 76–88 MHz; however, such stations must remain 129 kilometers (80 miles) or more distant from any other Part 73 Broadcast Station or LPTV/TV Translator station on Channel 6 if using the 87.8 to 88.0 MHz segment of the band. [47 C.F.R. 74.802] Therefore, these particular stations authorize the use of FM Channel 200 (87.9 MHz). Such stations permit transmissions of live broadcast events. [47 C.F.R. 74.831] To qualify, you must own another broadcast station, or produce TV/motion picture programming (which, with the proliferation of online TV Webcasting, is not difficult). [47 C.F.R. 74.832] Power is limited to 50 milliwatts (1/20th of 1 watt). [47 C.F.R. 74.861] These stations are licensed through the FCC's Wireless Telecommunications Bureau online by accessing ULS. There are equipment requirements in the FCC's rules, but none are too daunting for the typical citizen with an average level of income and savings. Unusual antennas are not allowed; however, gain antennas (up to about 6 db/D gain) are permitted under the rules. The license fee is currently \$135 for a 4–8 year term license. Such stations are NOT restricted to filing windows, so a qualified applicant could be licensed at any time. These stations are NOT protected from interference by other broadcast entities under Parts 73 or 74 of the FCC's rules, but ARE protected from interference by the Part 15 transmitters described below.

Part 15 rules are quite strict for FM, making it nearly impossible to operate a legally-licensed station that can be heard more than a few yards away. One manufacturer's online guidelines show that an average FM receiver can receive a legal Part 15 FM stereo transmitter over 1000 feet away, barring interference from walls, geography, etc. The rule is a signal strength of 250  $\mu$ V/m at 3 meters from the antenna within the band 88 to 108 MHz, set forth in 47 C.F.R. 15.239. Radiating cable antenna systems do allow for

longer, if still narrow, radiated fields and are commonly used for building broadcast systems (stadiums, dormitories, apartments, etc...) with high success. Such systems are also used for specialized audiences for hearing assistance and language translation at events. Some communities have attempted to have multiple Part 15 stations align to form a sort of neighborhood "syndication" and legally increase the outreach, but it becomes impractical in light of the new technologies that allow for information to reach a wider audience more efficiently.

## **Legislation**

### ***Radio Act of 1912***

The Radio Act of 1912 required all amateur radio operators to be licensed and outlawed their ability to transmit over main commercial and military wavelengths. It also required all seafaring vessels to maintain 24 hour radio watch and maintain contact with ships and coastal radio stations in the area. This act set a model for international and federal legislation of wireless communications. This act also required all nonprofessional radio operators to obtain a license and forbid them from transmitting over the main commercial and military wavelengths. The Radio Act of 1912 also prevented the Marconi Company from dominating and dictating the activities of the people who used its equipment (this company had been forcing operators to refuse to communicate with those who had purchased and were using other companies equipment).

### ***The Radio Act of 1927***

The Radio Act of 1927 placed most of the responsibility for radio to a newly developed Federal Radio Commission. The Federal Radio Commission now had the most control over regulating radio broadcasting. This act showed Congress's acknowledgment of broadcasters' right to "free speech", allowing stations to be free of government censorship and/or government programming. In addition, the broadcaster gained responsibility for their own operation and the government could not legally interfere unless the operator had been failing to meet the standard of public interest. All in all, the Radio Act of 1927 set up licensing and frequency allotment networks for commercial radio stations.

### ***Public Broadcasting Act of 1967***

The Public Broadcasting Act of 1967 was established by President Lyndon B. Johnson on November 7, 1967 to create the Corporation for Public Broadcasting, the Public Broadcasting Service (PBS) and National Public Radio (NPR). Congress declared the Act to be in the "public interest to encourage the growth and development of public radio and television broadcasting . In the 1950s and 1960s, arts and education were often ignored by commercial radio and television producers. Independent, non-profit radio and television stations worked to provide arts education and education broadcasts but they often didn't have the funding . In 1965 the Carnegie Corporation, Ford Foundation and locally owned broadcasting stations lobbied congress to provide the funding for public broadcasting. The goal of the Public Broadcasting Act is to address the entertainment

need of audiences like children and minorities and to nationally distribute high quality radio and television programs that provide education and arts education . Because the Corporation for Public Broadcasting is federally funded,the Corporation is not permitted to schedule, produce or disseminate programs. This prevents federal agencies from interfering with the Corporation or the programming. One of the major flaws of the Public Broadcasting Act is the method of funding. The Corporation for Public Broadcasting must conform to the annual federal budgeting and appropriation process, making adequate funding an issue for the Corporation . This act has been amended several times since 1967.

### ***Telecommunications Act of 1996***

The Telecommunications Act of 1996 was implemented in order to foster competition between the firms in the Telecommunications Sector including those stations of LPFM. Reed Hundt, the FCC chair at the time, said that the FCC imposed the act to encourage “diversity in programming and diversity in the viewpoints expressed on this powerful medium that so shapes our culture.” The act “mandates interconnection of telecommunications networks, unbundling, non-discrimination, and cost-based pricing of leased parts of the network.” However the act relies upon the behaviors of companies to do what is in their best interest and does not enforce punishment towards firms that do not abide by the act. Furthermore research suggests that the Act has led to “less competition, fewer viewpoints, and less diversity in programming.”

### ***Foundation of LPFM***

- Jan. 2000: FCC established new class of stations called Low Power FM (LPFM) Stations. These stations were allowed to operate at 1–10 or 50–100 watts of power (compared to the minimum requirement for commercial stations at 100 watts. 47 CFR 73.211)
- Originally it was supported by activists, music artists (such as Bonnie Raitt), church leaders, and educators (for example, American Library Association, Communication Workers of American labor union, National League of Cities, United Church of Christ).
- Original purpose of LPFM, as described in J&MC Quarterly Journal, as "... Necessary to offset the growing consolidation of station ownership in the wake of the Telecommunications Act of 1996, which removed caps on radio ownership, as well as the decline of locally produced radio programming." (Stavisky, Alan G., Robert K. Avery, and Helena Vanhala. "From Class D to LPFM: The High-Powered Politics of Low-Power Radio." *Journalism & Mass Communication Quarterly* 78 (2001): 340–54.)
- Main opposition came from National Association of Broadcasters (NAB). The reason behind their opposition to the act was to "maintain spectrum integrity" for commercial broadcasting, according to NAB President Edward O. Fritts (Stavisky, Alan G., Robert K. Avery, and Helena Vanhala. "From Class D to LPFM: The High-Powered Politics of Low-Power Radio." *Journalism & Mass Communication Quarterly* 78 (2001): 340–54.).

### ***Radio Broadcasting Preservation Act of 2000***

- Pressure from National Association of Broadcasters urged Congress to slip the Radio Broadcasting Preservation Act of 2000 into a general spending bill that circulated through Congress. In December 2000, President Clinton signed the bill, albeit reluctantly.
  - Here is a copy of the actual bill that went through Congress.
  - This act was meant to tighten standards for LPFM stations, in an effort to make it harder for stations to be approved in order to protect full-power FM stations.
1. The FCC has the ability and jurisdiction to license LPFM stations.
  2. Third adjacent channel interference protections require LPFM stations to be separated by at least 0.6 MHz from all other stations with the intent of preventing signal interference.
  3. Applicants who have engaged in the unlicensed operation of any station cannot receive LPFM licenses.
  4. The FCC agreed to commission studies on the interference effects and economic impact of LPFM on full-power stations. (The findings, later published in the MITRE Corporation Report, suggest that third adjacent channel interference protections may not be necessary.)
- Basically, this act shifts policy making from the FCC to Congress, which was considered an insult against the FCC. (Stavisky, Alan G., Robert K. Avery, and Helena Vanhala. "From Class D to LPFM: The High-Powered Politics of Low-Power Radio." *Journalism & Mass Communication Quarterly* 78 (2001): 340–54.)

### ***Local Community Radio Act of 2005***

- Introduced by U.S. Senators John McCain, Maria Cantwell, Patrick Leahy
- After the FCC complied with the provisions of the Radio Broadcasting Act of 2000 by commissioning the MITRE Report to test if there was significant interference from LPFM stations on the full-power stations, the study showed that the interference of LPFM is minimal and won't have a significant effect on other stations.
- According to Sen. Leahy, "This bill will open up the airwaves to truly local broadcasting while protecting full-power broadcasters from unreasonable interference and preserving important services such as reading services for the blind."

### ***Local Community Radio Act of 2007***

Sponsored in the U.S. House of Representatives by Congressmen Mike Doyle and Lee Terry and in the U.S. Senate by Senators Maria Cantwell and John McCain the Local Community Radio Act of 2007 failed to be voted on. The House bill, H.R. 2802, was referred to the Subcommittee on Telecommunications and the Internet on June 21, 2007.

Since the bill was not passed in FY 2007, the bill was removed from the docket as *Never Passed*.

### ***Local Community Radio Act of 2009***

This bill is an update of the Local Community Radio Act of 2007. It will require FCC to alter current rules in order to get rid of the minimum distance separation between low-power FM stations and third-adjacent channel stations. Previously, there had been a minimum distance requirement, however the FCC found that LPFM stations did not cause any interference on third-adjacent channel stations, thus eliminating the need for such a requirement.

The Local Community Radio Act of 2009 also requires that the FCC keep the rules that offer interference protection to third-adjacent channels that offer a radio reading service (the reading of newspapers, books or magazines for those who are blind or hearing impaired.) This protection will ensure that such channels are not subject to possible interference by LPFM stations.

The final part of the bill requires that when giving out licenses to FM stations, the FCC must make sure that these licenses are also available to LPFM stations and that licensing decisions are made with regard to local community needs.

The bill had unanimous bipartisan support from FCC leadership. It was passed by the House and referred to the Senate.

### **Local Community Radio Act of 2010**

H.R.6533 The Federal Communications Commission, when licensing new FM translator stations, FM booster stations, and low-power FM stations, shall ensure that-- (1) licenses are available to FM translator stations, FM booster stations, and low-power FM stations; (2) such decisions are made based on the needs of the local community; and (3) FM translator stations, FM booster stations, and low-power FM stations remain equal in status and secondary to existing and modified full-service FM stations. In General- The Federal Communications Commission shall modify its rules to eliminate third-adjacent minimum distance separation requirements between-- (1) low-power FM stations; and (2) full-service FM stations, FM translator stations, and FM booster stations.

### **Arguments for LPFM**

- Freepress.net is a "national, nonpartisan organization working to reform the media. Through education, organizing and advocacy, we promote diverse and independent media ownership, strong public media, and universal access to communications." Freepress.net supports LPFM for a variety of reasons:
  - It strengthens community identity.
  - It creates an outlet for amateur musicians to get their music heard.

- It creates diversity on the air because women and racial minorities are represented.
- It creates an opportunity for young people, especially college students, who are interested in radio to learn about the business.
- It provides farmers with up to date agricultural information.
- Prometheus Radio Project is a non-profit organization that "builds, supports, and advocates for community radio stations which empower participatory community voices and movements for social change."
  - The media should not limit democratic participation but should provide a way for communities and movements to express themselves
  - Public airwaves shouldn't be concentrated in private/corporate hands
  - Low Power FM gives a voice to communities
  - Low Power FM needs to be protected from big broadcasters
- President Bill Clinton is a known advocate of LPFM saying it is "giving voice to the voiceless" including schools, community groups, churches, and ethnic groups.
- An average FM station can cost a million dollars and only businesses and very wealthy people can afford it. LPFM stations are affordable. An antenna and transmitter can cost \$2000–\$5000.

### **Arguments against LPFM**

- Signal Interference on FM Station: High-power FM stations express concern that LPFM stations may cause interference with their signals if third adjacent channel interference protections are not observed. While the Mitre Report suggests that the likelihood for interference is not as threatening as previously thought, high-power FM stations question the methodology, scope and validity of the study and its results.
- FM translators: These devices allow a radio station to rebroadcast its signal to reach a greater area. FM translators could benefit religious broadcasters wishing to reach a larger audience, as well as many AM radio stations who, due to ionospheric refraction, are required to emit weaker signals during the night. FM translators are low-power, so compete with LPFM for limited space on the airwaves.
- In some states, the local Department of Transportation operates large networks of LPFM stations that act as highway advisory radio stations—a service traditionally operated at the fringes of the AM band—restricting the number of available channels. (These systems can be licensed to the entire AM band, but the LPFM service provides considerably greater coverage at 100w than the 10w limit on AM—hence the considerable appeal for government agencies).

- Some investors in radio believe LPFM services prevent the development of digital radio.
- NPR is one opponent to low power FM.. Their stance is that allowing more flexible rules for LPFM would burden other stations by forcing them to deal with interference problems and because of the fact that full power broadcasters reach a broader audience and provide a greater service, they should be favored regarding spectrum availability.
- NAB is the other major source of opposition. Their stance is that full power FM broadcasters “enhance localism” by providing community responsive information such as emergency information. Allowing low power FM stations to have equal spectrum rights could be detrimental to these necessary programs.

### **LPFM vs. broadcast translators**

Unlike the former FM class D license, an LPFM station has no priority over broadcast translators in the allocation of available spectrum. This is problematic insofar as a loophole in the regulations for broadcast translators exempts non-commercial stations from the requirement that translators be within the coverage area of the original station that they rebroadcast.

An FCC licensing window for new translator applications in 2003 resulted in over 13,000 applications being filed, most of them coming from a few religious broadcasters. Although many believe that these broadcasters were exploiting a loophole allowing non-commercial stations to feed distant translators from satellite-delivered programming hundreds or even thousands of miles outside the parent station's coverage area, this is incorrect. Except for local fill-in translators and those located on channels 201–220, all translators on commercial frequencies must be fed by a direct, over-the-air source, regardless of who owns the translator per FCC rule 74.1231(b). One station cannot apply for hundreds or thousands of translators nationwide, using automated means to generate license applications for all available channels, unless all of their applications are exclusively on the non-commercial part of the broadcast band (88–91.9 MHz). (47 CFR 74.1231(b)) As with any new service that shares the FM spectrum, when translators are added to an area, they can reduce or eliminate the availability of channels both for new LPFM applicants and for relocation of any existing LPFM stations displaced by full-service broadcasters.

Unlike an LPFM station, a translator is not required to (and legally not authorized to) originate any local content except as permitted by 47 CFR 74.1231(g).

### **AM radio**

LPAM is generally not licensed in the U.S.. There are several manufacturers of "Part 15" AM transmitters with a power of about 0.1 watt. Higher output powers are allowed within the campus of any school, so long as the normal Part 15 rules are adhered to when

measured at the edge of the campus. Many currently licensed college radio stations started out this way. Stations may have freestanding radio antennas, or may use carrier current methods to ride on power lines. These signals cannot pass through transformers, however, and are prone to the electromagnetic interference of the alternating current. Stations may also use 'leaky' or radiating cable transmission systems. Tens of thousands of these stations have been in operation around the country since the 1940s, and many continue to thrive where conventional licensing is unavailable and the operators still desire to conform to Federal laws.

The exception is Travelers' Information Stations (TIS), sometimes also called highway advisory radio (HAR). These are licensed LPAM stations set up by local transport departments to provide bulletins to motorists and other travelers regarding traffic and other delays. These are often near highways and airports, and occasionally other tourism attractions such as national parks. Only governments may have licenses for TIS/HAR stations, and music is disallowed. These operate under FCC Part 90.242 and may be licensed by quasi-governmental agencies as well (many are used by chemical and nuclear facilities for emergency evacuation information systems) as well as by public safety entities for mobile operations.

## **Television**

There are more than 2,450 licensed LPTV stations in the U.S. and they are in markets of all sizes, from New York City (5 stations) down to Junction City, Kansas (2 stations).

LPTV (-LP) is common in the U.S., Canada and most of the Americas where most stations originate their own programming. Stations that do not originate their own programming are designated as translators (-TX). The Community Broadcasters act of 1998 directed the FCC to create classification of LPTV licenses called Class A (-CA). Digital low power and Class-A television stations have an ERP limit of 3000(3KW) watts for VHF, and 15 kilowatts for UHF.

The LPTV service is considered a secondary service by the FCC, which means the licensee is not guaranteed protection from interference or displacement. An LPTV station must accept harmful interference from full-service television stations and may not cause harmful interference to any full-service television station. (The FCC defines what interference levels are deemed to be "harmful".) The problem with potential displacement was made evident during the transition of broadcasting in the United States from analog to digital. All television stations operating on channels 52 and above were required to move to channel 51 or below. Full-service stations were guaranteed a place to land in the new compressed band while LPTV stations operating on channels 52 and above were forced to find their own channel to move to. If a station was not able to find a displacement channel it runs the risk of losing its license.

## **Class A LPTV stations**

The FCC provided for a one-time filing opportunity for existing LPTV stations to become Class A stations. The designation was available only to those LPTV stations that were producing two hours per week of local programming. Class A status provides for protected channel status and Class A stations are required to produce two hours per week of local programming, maintain a production studio within their Grade B contour, and comply with many of the requirements placed on full-service television stations.

## **Must-carry**

One of the key distinctions between full-service television stations and low-power stations is cable and DBS (Direct Broadcast Satellite) carriage. Full-service stations are guaranteed carriage in their local DMA through "must-carry" and LPTV stations are not. In 2008 there was an effort put forward by FCC Chairman Kevin Martin to grant must-carry rights to Class A LPTV stations. The effort failed due to a lack of support from the other FCC Commissioners.

## **Network affiliates**

Though many low-power TV stations are either unaffiliated, or broadcast programming from small networks meant for their use, some LPTV stations are affiliated with major broadcast networks like Fox, The CW or My Network TV. Examples include in Youngstown, Ohio, where a pair of LPTV stations based at WYFX broadcast Fox programming, along with the digital subchannel of the co-owned CBS affiliate, WKBN-TV, or in the Lima, Ohio area, whose low-power stations are affiliates of major networks, such as NBC and ABC.

## **Digital transition**

The FCC has not set a date (as of November 2008) whereby LPTV stations are required to convert to digital broadcasting. Therefore LPTV stations are exempt from the June 12, 2009 deadline to cease analog transmissions. The FCC did open a filing window for existing LPTV stations to file for a secondary digital channel to operate in parallel of its analog channel.

Unlike FM and AM, unlicensed use of TV bands is prohibited for broadcasting. The amateur television channels do allow for some very limited non-entertainment transmissions however, with some repeaters airing NASA TV during Space Shuttle missions when they are not in local use.

The Low Power Television industry was represented by the Community Broadcasters Association (CBA), which held its annual convention each year in October and an annual meeting each year in April at the National Association of Broadcasters Convention in Las Vegas. The meeting was always held on Monday night of the NAB convention in Ballroom B of the Las Vegas Hilton and was open to anyone interested in the Low Power

Television industry. On August 13, 2009, the CBA announced in a statement that it would shut down after 20 years of representing LPTV stations. One reason given was the "restrictive regulations that kept the Class A and LPTV industry from realizing its potential". Another was the inability to reach most viewers, partly due to Multichannel Video Programming Distributors refusing to carry these channels. Also, Amy Brown, former CBA executive director, said, "some 40% of Class A and LPTV station operators believe they will have to shut down in the next year if they are not helped through the digital transition."

## **Update**

In February 2006, the FCC released its Notices of Proposed Rules for Digital Radio. The Commission reaffirms its commitment to provide broadcasters with the opportunity to take advantage of digital audio broadcasting (DAB) technology, proposed criteria for evaluating models and systems, such as the In Band On Channel (IBOC) system, and inquired on the needs for a mandatory DAB transmission standard.

In section 39 of the Notice, the FCC inquires as how to balance incentives for broadcasters to switch to digital systems with incumbents of new entrance opportunities, stating that they "seek analyses of the minimum power levels that would preserve service within protected service areas in an all-digital environment, and alternatively, the levels that would not result in significant disruptions to current listening patterns."

The DAB system that has been identified as the best fit for LPFM is IBOC system. This is a hybrid system that uses existing frequencies and can operate carrying digital information along with analog broadcast signal on the sidebands. However, the digital carriers require the bandwidth to be widened, which would cause interference to stations on the first adjacent channel. If LPFM adopts IBOC, then LPFM would also need to accept a second adjacent channel restriction between two LPFM stations, as there is a potential that the sidebands of two LPFM stations would overlap causing interference. Currently, imposing a second adjacent channel restriction would impact less than 10 LPFM stations.

## **Canada**

Radio communications in Canada are regulated by a branch of Industry Canada called Radio Communications and Broadcasting Regulatory Branch together with Canadian Radio-television and Telecommunications Commission (CRTC). This means, interested parties must apply for both a certificate from Industry Canada and a license from CRTC in order to operate a radio station. Industry Canada manages the technicalities of spectrum space and technological requirements whereas content regulation is conducted more so by CRTC.

LPFM is broken up into two classes in Canada, Low (50w) and Very Low (10w). The transmitters therefore range from 1-50 watts, as opposed to 1-100 watts in the U.S. As of

2000, 500 licenses (very low and low power FM) have been issued. These transmitters are generally only allowed in remote areas.

The regulation of spectrum space is strict in Canada, as well having restrictions on 2nd and 3rd adjacent channels along with other protections for AM and FM commercial radio. In addition, because there have been a few cases that found that FM frequencies have caused interference to the aeronautical navigation and communications (NAV/COM) spectrum, (though evidence is not very concrete presently) pirate radio regulation has remained very strict as well. However, the two regulating bodies do have certain exemptions. For example, low power announcement transmitters that meet the requirement of Broadcasting Equipment Technical Standards 1, Limited Duration Special Events Distribution Undertakings, Temporary Resource Development Distribution Undertakings, and Public Emergency Radio Undertakings are a few instances, which according to certain criteria, may be exempt from certificate/license requirements.

### ***United Kingdom***

Temporary low-power stations are allowed at times via a Restricted Service Licence.

Since 2001 longterm LPFM licences have been available in remote areas of the country. These are currently used for many establishments including military bases, universities and hospitals with fixed boundaries.

### ***New Zealand***

In New Zealand residents are allowed to broadcast licence free at 1 watt EIRP in the FM guardbands from 87.6 to 88.3 and from 106.7 to 107.7 MHz under a General User Radio License (GURL) issued by Radio Spectrum Management. Prior to June 2010, the lower band was located between 88.1 and 88.8. Broadcasters on these frequencies are required to cease operations if they interfere with other, licensed broadcasters and have no protection from interference from other licensed or unlicensed broadcasters. There exists a 25 km rule: You may operate two transmitters anywhere (close together), but a third transmitter must be at least 25 km away from at least one of the first two transmitters.

There are efforts on self-regulation of the broadcasters themselves.

### ***Opinions***

J. H. Snider and Lawrence Lessig say that low power "smart" radio is inherently superior to standard broadcast radio.

"Technologists are increasingly discussing a related kind of gain called 'cooperation gain.' ... think about a party. If I need to tell you that it's time to leave, I could choose to shout that message across the room. Shouting, however, is rude. So instead, imagine I choose to whisper my message to the person standing next to me, and he whispered it to the next person, and she to the next person, and so on. This series of whispers could get my

message across the room without forcing me to shout." — "Wireless Spectrum: Defining the 'Commons'" by Lawrence Lessig 2003 (mirror)

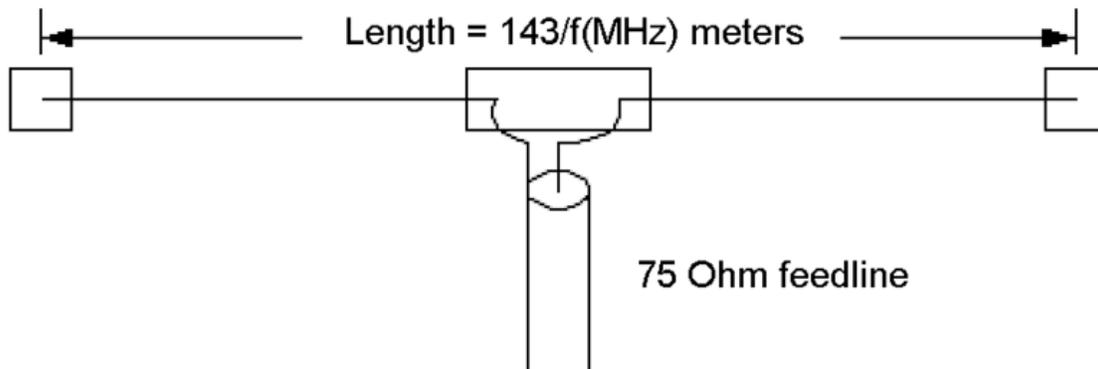
"if nodes repeat each other's traffic. If I want to talk to someone across the room, I don't have to shout. I can just whisper it to someone near me, who can pass it on, and so on. ... as we add more transmitters, the total capacity goes up slightly, but we still have to face the fact that each transmitter's capacity goes down (just slower). Even better, we all end up using less energy (since we don't have to transmit as far), saving battery life." — Open Spectrum: A Global Pervasive Network by Aaron Swartz

"Every time a broadcaster receives a license, the amount of available spectrum goes down. ... New technology, however, increases bandwidth with the number of users." — "Why Open Spectrum Matters: The End of the Broadcast Nation" by David Weinberger

"If we lose ... open spectrum, we're also going to lose the open Internet" — "The war against open spectrum" by Dana Blankenhorn 2007

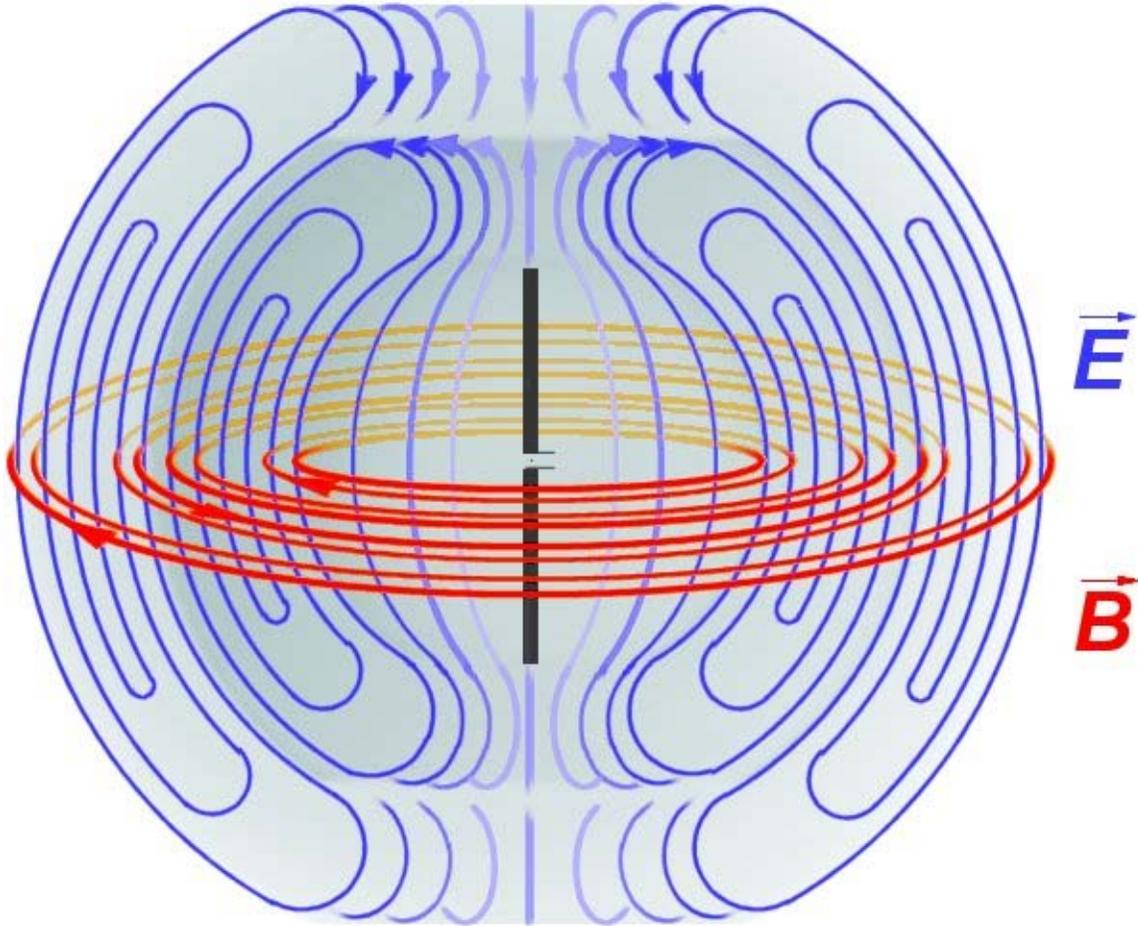
## Chapter 12

# Dipole Antenna



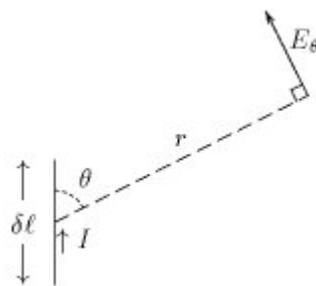
A schematic of a half-wave dipole antenna that a shortwave listener might build.

A **dipole antenna** is a radio antenna that can be made of a simple wire, with a center-fed driven element. It consists of two metal conductors of rod or wire, oriented parallel and collinear with each other (in line with each other), with a small space between them. The radio frequency voltage is applied to the antenna at the center, between the two conductors. These antennas are the simplest practical antennas from a theoretical point of view. They are used alone as antennas, notably in traditional "rabbit ears" television antennas, and as the driven element in many other types of antennas, such as the Yagi. Dipole antennas were invented by German physicist Heinrich Hertz around 1886 in his pioneering experiments with radio waves.



Electric fields (*blue*) and magnetic fields (*red*) radiated by a dipole antenna

### ***Elementary doublet***



An elementary doublet is a small length of conductor  $\delta l$  (small compared to the wavelength  $\lambda$ ) carrying an alternating current:

$$I = I_0 e^{i\omega t}$$

Here  $\omega = 2\pi f$  is the angular frequency (and  $f$  the frequency), and  $i$  is  $\sqrt{-1}$ , so that  $I$  is a phasor.

Note that this dipole cannot be physically constructed because the current needs somewhere to come from and somewhere to go to. In reality, this small length of conductor will be just one of the multiple segments into which we must divide a real antenna, in order to calculate its properties. The interest of this imaginary elementary antenna is that we can easily calculate the electrical far field of the electromagnetic wave radiated by each elementary doublet. We give just the result:

$$E_{\theta} = \frac{-iI_0 \sin \theta \delta \ell}{2\epsilon_0 c r} \frac{1}{\lambda} e^{i(\omega t - k r)}$$

Where,

- $E_{\theta}$  is the far electric field of the electromagnetic wave radiated in the  $\theta$  direction.
- $\epsilon_0$  is the permittivity of vacuum.
- $c$  is the speed of light in vacuum.
- $r$  is the distance from the doublet to the point where the electrical field  $E_{\theta}$  is evaluated.
- $k$  is the wavenumber  $k = \frac{2\pi}{\lambda}$

The exponent of  $e$  accounts for the phase dependence of the electrical field on time and the distance from the dipole.

The far electric field  $E_{\theta}$  of the electromagnetic wave is coplanar with the conductor and perpendicular with the line joining the dipole to the point where the field is evaluated. If the dipole is placed in the center of a sphere in the axis south-north, the electric field would be parallel to geographic meridians and the magnetic field of the electromagnetic wave would be parallel to geographic parallels.

## Near Field

The above formulas are valid for the far field of the antenna ( $r \gg \lambda/(2\pi)$ ), and are the only contribution to the radiated field. The formulas in the near field have additional terms that reduce with  $r^2$  and  $r^3$ . These are,

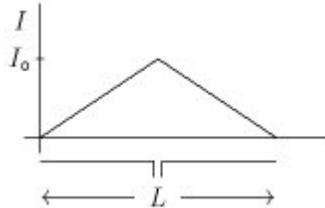
$$E_r = \frac{Z}{2\pi} I_0 \delta \ell \left( \frac{1}{r^2} - i \frac{\lambda}{2\pi r^3} \right) e^{i(\omega t - k r)} \cos(\theta)$$

$$E_{\theta} = i \frac{Z}{2\lambda} I_0 \delta \ell \left( \frac{1}{r} - i \frac{\lambda}{2\pi r^2} - \frac{\lambda^2}{4\pi^2 r^3} \right) e^{i(\omega t - k r)} \sin(\theta)$$

$$H_{\phi} = i \frac{1}{2\lambda} I_0 \delta \ell \left( \frac{1}{r} - i \frac{\lambda}{2\pi r^2} \right) e^{i(\omega t - k r)} \sin(\theta)$$

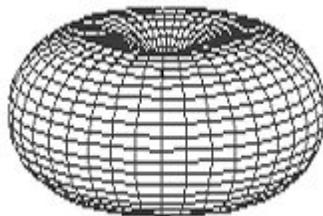
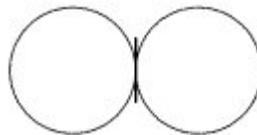
where  $Z = \sqrt{\mu/\epsilon} = 1/(\epsilon c) = \mu c$ . The energy associated with the term of the near field flows back and forward out and into the antenna.

### Short dipole



A short dipole is a physically feasible dipole formed by two conductors with a total length  $L$  very small compared with the wavelength  $\lambda$ . The two conducting wires are fed at the centre of the dipole. We assume the hypothesis that the current is maximal at the centre (where the dipole is fed) and that it decreases linearly to be zero at the ends of the wires. Note that the direction of the current is the same in both the dipole branches - to the right in both or to the left in both. The far field  $E_\theta$  of the electromagnetic wave radiated by this dipole is:

$$E_\theta = \frac{-i I_0 \sin \theta L}{4 \epsilon_0 c r} \frac{1}{\lambda} e^{i(\omega t - k r)}$$



Emission is maximal in the plane perpendicular to the dipole and zero in the direction of wires which is the direction of the current. The emission diagram is circular section torus shaped (right image) with zero inner diameter. In the left image the doublet is vertical in the torus centre.

Knowing this electric field, we can compute the total emitted power and then compute the resistive part of the series impedance of this dipole due to the radiated field, known as the radiation resistance:

$$R_{series} = \frac{\pi}{6} Z_0 \left( \frac{L}{\lambda} \right)^2 \quad (\text{for } L \ll \lambda).$$

where  $Z_0$  is the impedance of free space. Using a common approximation of  $Z_0 = 120\pi$  ohms, we get:

$$R_{series} = 20\pi^2 \left( \frac{L}{\lambda} \right)^2 \quad \text{ohms}$$

## Antenna gain

Antenna gain is the ratio of surface power radiated by the antenna to the surface power radiated by a hypothetical isotropic antenna:

$$G = \frac{\left( \frac{P}{S} \right)_{ant}}{\left( \frac{P}{S} \right)_{iso}}$$

The surface power carried by an electromagnetic wave is:

$$\left( \frac{P}{S} \right)_{ant} = \frac{1}{2} c \epsilon_0 E_{\theta}^2 \simeq \frac{1}{120\pi} E_{\theta}^2$$

The surface power radiated by an isotropic antenna feed with the same power is:

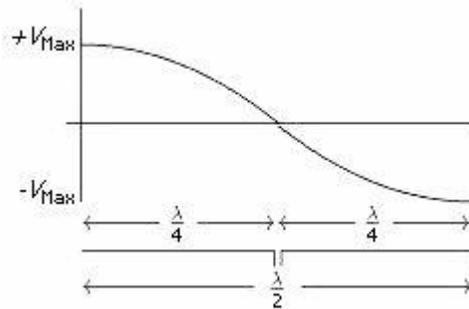
$$\left( \frac{P}{S} \right)_{iso} = \frac{\frac{1}{2} R_{series} I_0^2}{4\pi r^2}$$

Substituting values for the case of a short dipole, final result is:

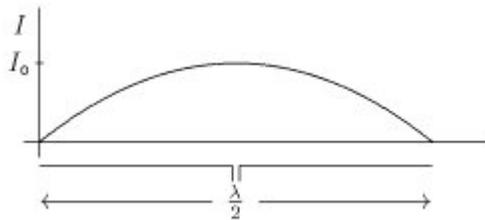
$$G = \frac{\pi \left( \frac{L}{\lambda} \right)^2}{\epsilon_0 c \frac{2\pi}{3\epsilon_0 c} \left( \frac{L}{\lambda} \right)^2} = 1.5 = 1.76 \text{ dBi}$$

**dBi** simply means decibels gain, relative to an isotropic antenna.

## Half-wave antenna



Typically a dipole antenna is formed by two quarter wavelength conductors or elements placed back to back for a total length of  $\lambda/2$ . A standing wave on an element of a length  $\sim \lambda/4$  yields the greatest voltage differential, as one end of the element is at a node while the other is at an antinode of the wave. The larger the differential voltage, the greater the current between the elements.



Assuming a sinusoidal distribution, the current impressed by this voltage differential is given by:

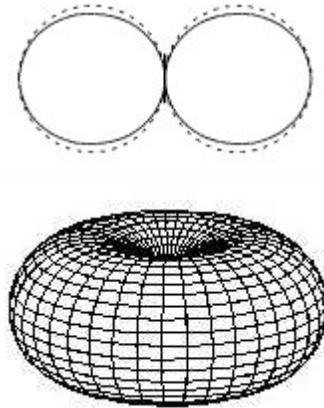
$$I = I_0 e^{i\omega t} \cos k\ell$$

For the far-field case, the formula for the electric field of a radiating electromagnetic wave is somewhat more complex:

$$E_\theta = \frac{-iI_0}{2\pi\epsilon_0 cr} \frac{\cos\left(\frac{\pi}{2} \cos \theta\right)}{\sin \theta} e^{i(\omega t - kr)}$$

But the fraction  $\frac{\cos\left(\frac{\pi}{2} \cos \theta\right)}{\sin \theta}$  is not very different from  $\sin \theta$ .

The resulting emission diagram is a slightly flattened torus.



The image on the left shows the section of the emission pattern. We have drawn, in dotted lines, the emission pattern of a short dipole. We can see that the two patterns are very similar. The image at right shows the perspective view of the same emission pattern.

This time it is not possible to compute analytically the total power emitted by the antenna (the last formula does not allow), though a simple numerical integration or series expansion leads to the more precise, actual value of the half-wave resistance:

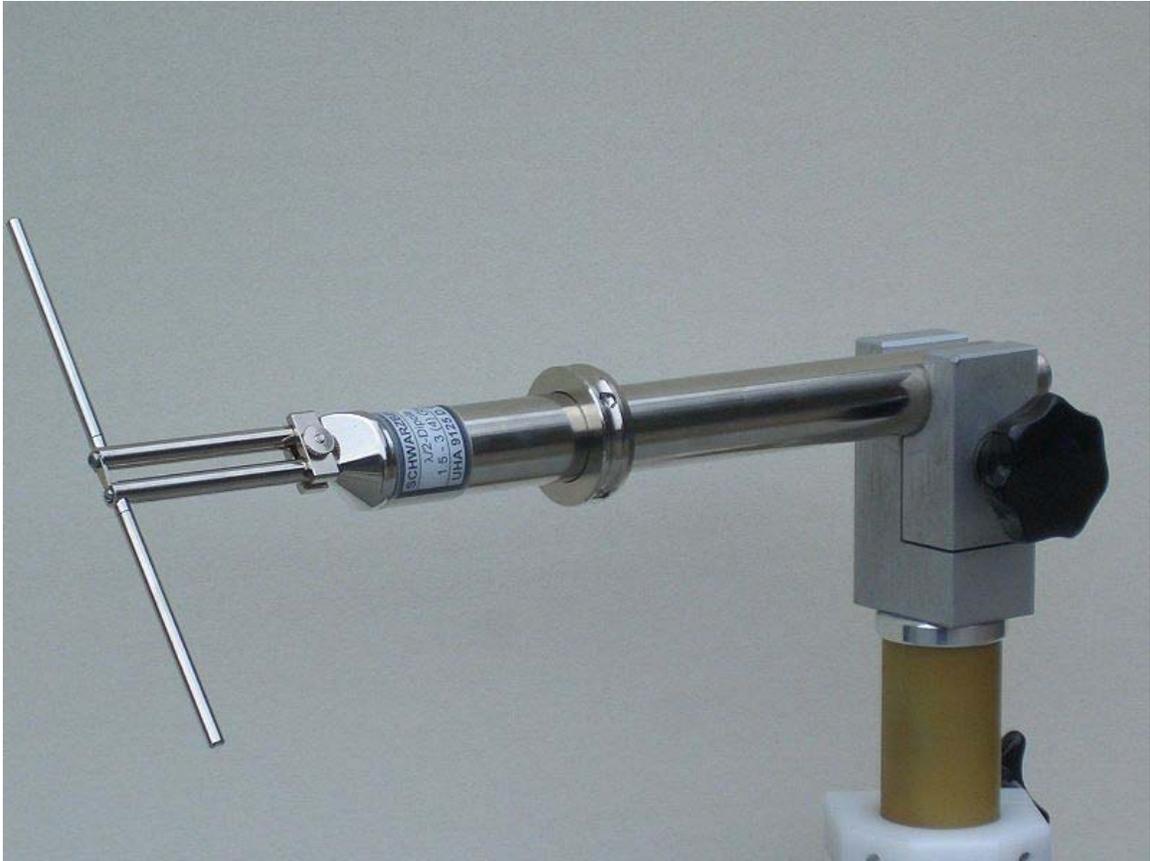
$$\begin{aligned}
 R_{\frac{\lambda}{2}} &= 60\text{Ci}(2\pi) = 60 [\ln(2\pi\gamma) - \text{Ci}(2\pi)] = 120 \int_0^{\frac{\pi}{2}} \frac{\cos\left(\frac{\pi}{2} \cos \theta\right)^2}{\sin \theta} d\theta, \\
 &= 15 \left[ 2\pi^2 - \frac{1}{3}\pi^4 + \frac{4}{135}\pi^6 - \frac{1}{630}\pi^8 + \frac{4}{70875}\pi^{10} \dots - (-1)^n \frac{(2\pi)^{2n}}{n(2n)!} \right], \\
 &\approx 73.13\Omega;
 \end{aligned}$$

This leads to the gain of a dipole antenna,  $G_{\frac{\lambda}{2}}$ :

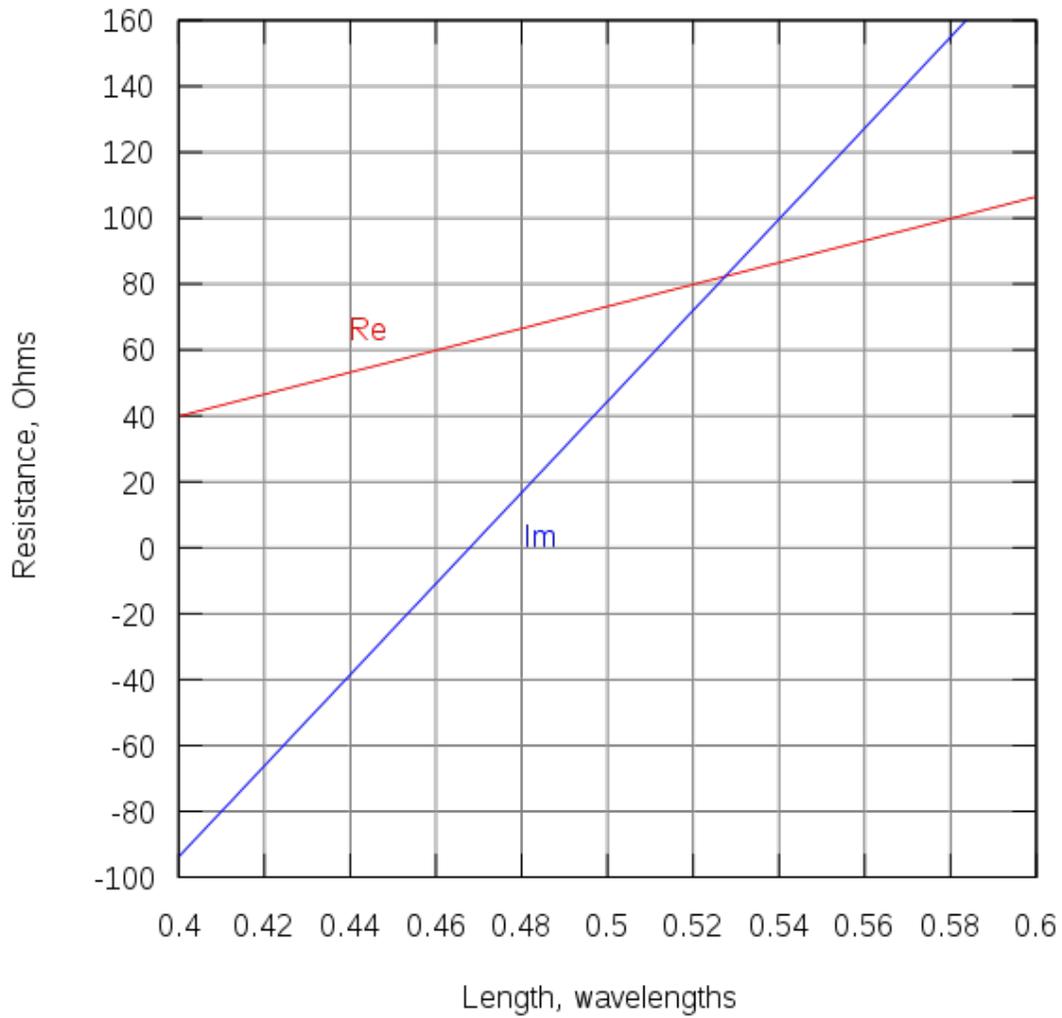
$$\begin{aligned}
 G_{\frac{\lambda}{2}} &= \frac{60^2}{30R_{\frac{\lambda}{2}}} = \frac{3600}{30R_{\frac{\lambda}{2}}} = \frac{120}{R_{\frac{\lambda}{2}}} = \frac{1}{\int_0^{\frac{\pi}{2}} \frac{\cos\left(\frac{\pi}{2} \cos \theta\right)^2}{\sin \theta} d\theta}, \\
 &\approx \frac{120}{73.1296} \approx 1.64 \approx 2.15 \text{ dBi};
 \end{aligned}$$

The resistance, however, is not enough to characterize the dipole impedance, as there is also an imaginary part—it is better to measure the impedance.

In the image below, the real and imaginary parts of a dipole's impedance are drawn for lengths going from  $0.4\lambda$  to  $0.6\lambda$ , accompanied by a chart comparing the gains of dipole antennas of other lengths (note that gains are **not** in dBi but in natural number):



UHF-Half-Wave Dipole, 1.0-4 GHz

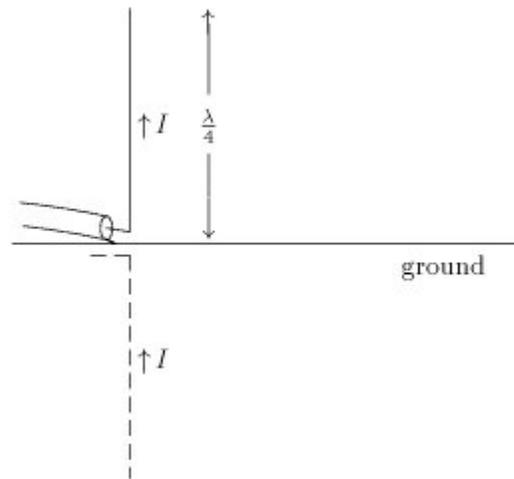


Gain of dipole antennas

length  $L$  in  $\lambda$  Gain Gain(dB)

$\ll 0.1$	1.50	1.76dB
<b>0.5</b>	<b>1.64</b>	<b>2.15dB</b>
1.0	1.80	2.55dB
1.5	2.00	3.01dB
2.0	2.30	3.62dB
3.0	2.80	4.47dB
4.0	3.50	5.44dB
8.0	7.10	8.51dB

## Quarter-wave antenna



The antenna and its image form a  $\frac{\lambda}{2}$  dipole that radiates only upward.

The quarter wave monopole antenna is a single element antenna fed at one end, that behaves as a dipole antenna. It is formed by a conductor  $\frac{\lambda}{4}$  in length. It is fed in the lower end, which is near a conductive surface which works as a reflector. The current in the reflected image has the same direction and phase as the current in the real antenna. The quarter-wave conductor and its image together form a half-wave dipole that radiates only in the upper half of space.

In this upper side of space the emitted field has the same amplitude of the field radiated by a half-wave dipole fed with the same current. Therefore, the total emitted power is one-half the emitted power of a half-wave dipole fed with the same current. As the current is the same, the radiation resistance (real part of series impedance) will be one-half of the series impedance of a half-wave dipole. As the reactive part is also divided by 2, the impedance of a quarter wave antenna is  $\frac{73+i43}{2} = 36+i21$  ohms. Since the fields above ground are the same as for the dipole, but only half the power is applied, the gain is twice (3dB over) that for a half-wave dipole ( $\frac{\lambda}{2}$ ), that is 5.14 dBi.

The earth can be used as ground plane, but it is a poor conductor: the reflected antenna image is only clear at glancing angles (far from the antenna). At these glancing angles, electromagnetic fields and radiation patterns are thus the same as for a half-wave dipole.

Naturally, the impedance of the earth is far inferior to that of a good conductor ground plane -- this can be improved (at cost) by laying a copper mesh.

When ground is not available (such as in a vehicle) other metallic surfaces can serve as a ground plane (typically the vehicle's roof). Alternatively, radial wires placed at the base of the antenna can simulate a ground plane. For VHF bands, the radiating and ground-plane elements can be constructed from rigid rods or tubes.

## **Dipole characteristics**

### **Frequency versus length**

Dipoles that are much smaller than the wavelength of the signal are called *Hertzian, short, or infinitesimal dipoles*. These have a very low radiation resistance and a high reactance, making them inefficient, but they are often the only available antennas at very long wavelengths. Dipoles whose length is half the wavelength of the signal are called *half-wave dipoles*, and are more efficient. In general radio engineering, the term *dipole* usually means a half-wave dipole (center-fed).

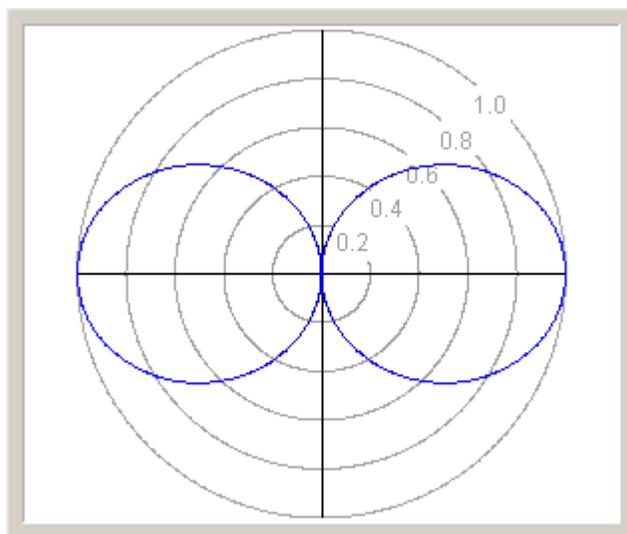
A half-wave dipole is cut to length  $l$  for frequency  $f$  MHz according to the formula

$l = \frac{143}{f}$  where  $l$  is in metres or  $l = \frac{468}{f}$  where  $l$  is in feet. This is because the impedance of the dipole is resistive pure at about this length. The length of the dipole antenna is about 95% of half a wavelength at the speed of light in free space.

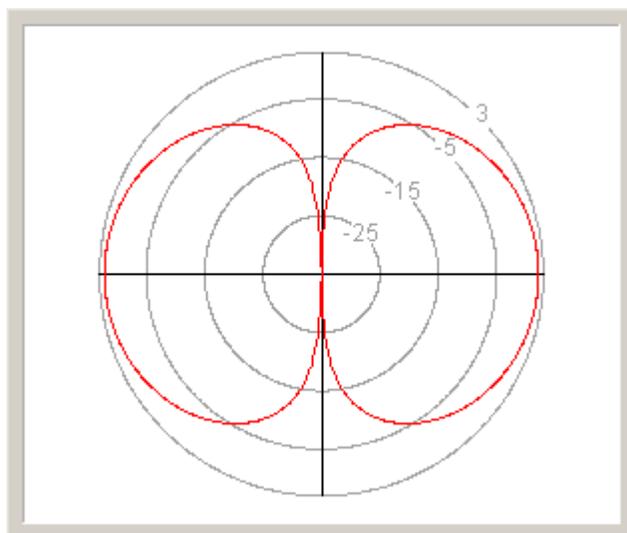
The magic numbers above are derived from a one Hz wavelength which is the distance that light radio travels in one second. Speed of light in vacuum is 299,792,458 m/s, which is divided by 1 million to account for MHz rather than Hz, which is then divided by 2 for a half-wave dipole antenna. A fudge factor of approximately 0.95 is multiplied to account for the damping due to radiation, which results in the magic number of 143 m·MHz or 468 ft·MHz.

### **Radiation pattern and gain**

Dipoles have an omnidirectional radiation pattern, shaped like a toroid (doughnut) symmetrical about the axis of the dipole. The radiation is maximum at right angles to the dipole, dropping off to zero on the antenna's axis. The theoretical maximum gain of a Hertzian dipole is  $10 \log 1.5$  or 1.76 dBi. The maximum theoretical gain of a  $\lambda/2$ -dipole is  $10 \log 1.64$  or 2.15 dBi.



Radiation pattern of a half-wave dipole antenna. The scale is linear.



Gain of a half-wave dipole (same as left). The scale is in dBi (decibels over isotropic).

### Feeder line

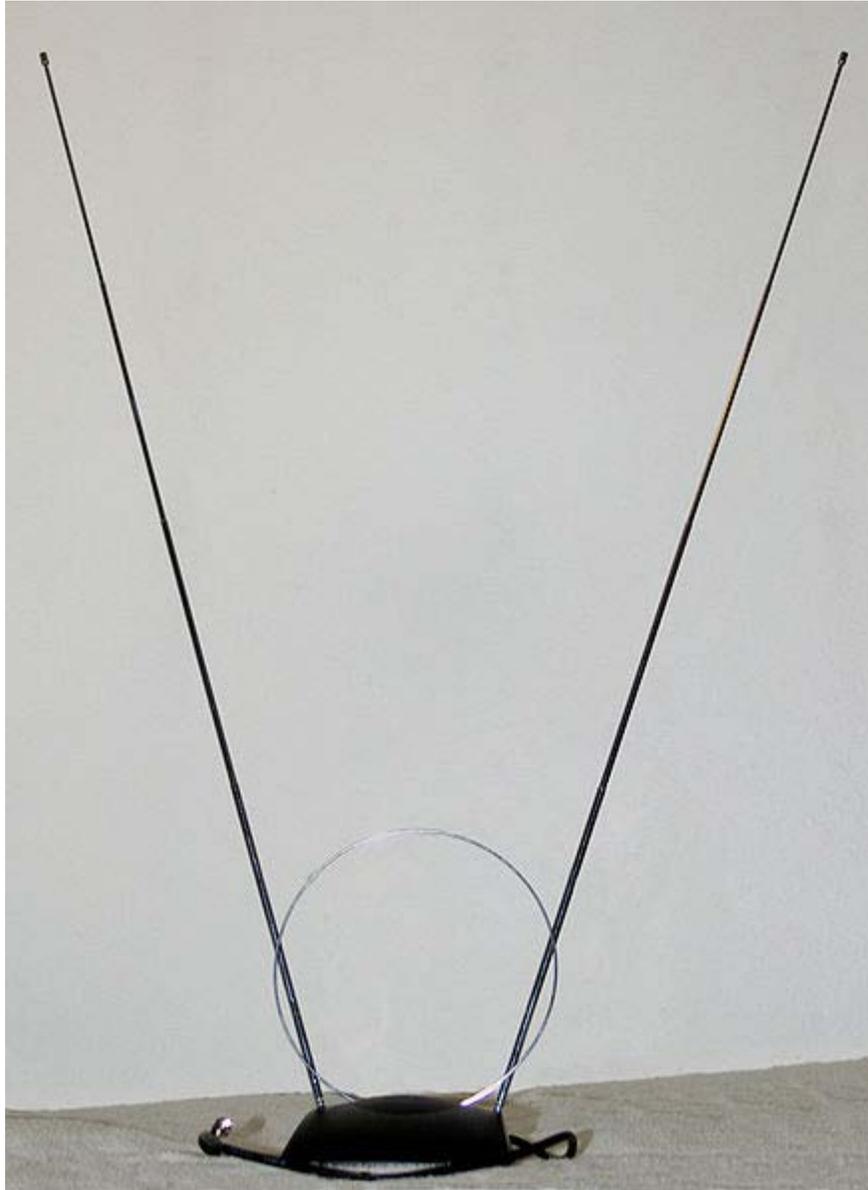
Ideally, a half-wave ( $\lambda/2$ ) dipole should be fed with a balanced line matching the theoretical 73 ohm impedance of the antenna. A folded dipole uses a 300 ohm balanced feeder line.

Many people have had success in feeding a dipole directly with a coaxial cable feed rather than a ladder-line. However, coax is not symmetrical and thus not a balanced feeder. It is unbalanced, because the outer shield is connected to earth potential at the other end. When a balanced antenna such as a dipole is fed with an unbalanced feeder, common mode currents can cause the coax line to radiate in addition to the antenna itself,

and the radiation pattern may be asymmetrically distorted. This can be remedied with the use of a balun.

### ***Common applications***

#### **Set-top TV antenna**



A "rabbit-ears" antenna with a UHF loop antenna.

The most common dipole antenna is the type used with televisions, often colloquially referred to as "**rabbit ears**" or "**bunny ears**." While in most applications the dipole elements are arranged along the same line, rabbit ears are adjustable in length and angle. Larger dipoles are sometimes hung in a V shape with the center near the radio equipment on the ground or the ends on the ground with the center supported. Shorter dipoles can be

hung vertically. Some have extra elements to get better reception such as loops (especially for UHF transmissions), which can be turnable around a vertical axis, or a dial, which modifies the electrical properties of the antenna at each dial position.

### **Folded dipole**



Folded dipole antenna

Another common place one can see dipoles is as antennas for the FM band - these are folded dipoles. The tips of the antenna are folded back until they almost meet at the feedpoint, such that the antenna comprises one entire wavelength. This arrangement has a greater bandwidth than a standard half-wave dipole. If the conductor has a constant radius and cross-section, at resonance the input impedance is four times that of a half-wave dipole.

## Shortwave antenna



A DIY-made dipole antenna with mast

Dipoles for longer wavelengths are made from solid or stranded wire. Portable dipole antennas are made from wire that can be rolled up when not in use. Ropes with weights on the ends can be thrown over supports such as tree branches and then used to hoist up the antenna. The center and the connecting cable can be hoisted up with the ends on the ground or the ends hoisted up between two supports in a V shape. While permanent antennas can be trimmed to the proper length, it is helpful if portable antennas are adjustable to allow for local conditions when moved. One easy way is to fold the ends of the elements to form loops and use adjustable clamps. The loops can then be used as attachment points.

It is important to fit a good insulator at the ends of the dipole, as failure to do so can lead to a flashover if the dipole is used with a transmitter. Various purchased or improvised insulators can be used.

## **Whip antenna**

The whip antenna is probably the most common and simplest-looking antenna. These are monopoles, and the most common and practical is the quarter-wave monopole which could be considered as half of a dipole using a ground plane as the image of the other half. The commonly referred-to end-fed dipole is actually just a half-wave monopole whip antenna.

## **Dipoles versus whip antennas**

Dipoles are generally more efficient than whip antennas (quarter-wave monopoles). The total radiated power and the radiation resistance are twice that of a quarter-wave monopole. Thus, if a whip antenna were used with an infinite perfectly conducting ground plane, then it would be as efficient in half-space as a dipole in free space an infinite distance from any conductive surfaces such as the earth's surface.

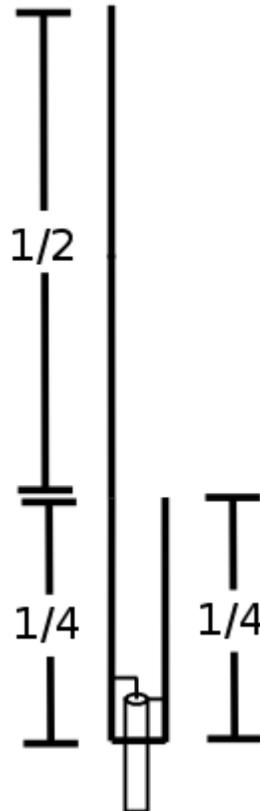
## **Dipole towers**

Large constructed half-wavelength dipole towers include the Warsaw radio mast — the only half-wave dipole for longwave ever built — and Blaw-Knox Towers.

## **Military**

US Military personnel occasionally use a 'doublet' antenna, especially during dismounted unconventional warfare. A radio operator may choose to bring several doublet antennas for different frequencies, such as an antenna cut to length for the set MEDEVAC (medical evacuation) frequency, NCS (net control station) frequency, and tactical frequency (the frequency used by troops in the field). This approach may not be acceptable depending on the mission. Note that a doublet antenna will not work with the standard SINCGARS radio when using frequency hopping(FH) but is effective for single channel (SC). A doublet antenna is more practical for radios not intended for FH.

## ***Collinear antenna systems based on dipoles***



J-Pole Antenna

Dipoles can be stacked end to end in phased arrays to make collinear antenna arrays, which exhibit more gain in certain directions—the toroidal radiation pattern is flattened out, giving maximum gain at right angles to the axis of the collinear array.

### **Slim Jim or J-pole**

A Slim Jim or J-pole is a form of end-fed dipole connected to a quarter-wave stub matching section.

### ***Dipole types***

#### **Ideal half-wavelength dipole**

This type of antenna is a special case where each wire is exactly one-quarter of the wavelength, for a total of a half wavelength. The radiation resistance is about 73 ohms if wire diameter is ignored, making it easily matched to a coaxial transmission line. The directivity is a constant 1.64, or 2.15 dB. Actual gain will be a little less due to ohmic losses.

If the dipole is not driven at the centre then the feed point resistance will be higher. If the feed point is distance  $x$  from one end of a half wave ( $\lambda/2$ ) dipole, the resistance will be described by the following equation.

$$R_r = \frac{75}{\sin^2\left(\frac{2\pi x}{\lambda}\right)}$$

If taken to the extreme then the feed point resistance of a  $\lambda/2$  long rod is infinite, but it is possible to use a  $\lambda/2$  pole as an aerial; the right way to drive it is to connect it to one terminal of a parallel LC resonant circuit. The other side of the circuit must be connected to the braid of a coaxial cable lead and the core of the coaxial cable can be connected part way up the coil from the RF ground side. An alternative means of feeding this system is to use a second coil which is magnetically coupled to the coil attached to the aerial.

### Folded dipole

A folded dipole is a half-wave dipole with an additional wire connecting its two ends. If the additional wire has the same diameter and cross-section as the dipole, two nearly identical radiating currents are generated. The resulting far-field emission pattern is nearly identical to the one for the single-wire dipole described above; however, at resonance its input (feedpoint) impedance  $R_{fd}$  is four times the radiation resistance of a single-wire dipole. This is because for a fixed amount of power, the total radiating current  $I_0$  is equal to twice the current in each wire and thus equal to twice the current at the feed point. Equating the average radiated power to the average power delivered at the feedpoint, we may write

$$\frac{1}{2}R_{\frac{\lambda}{2}}I_0^2 = \frac{1}{2}R_{fd}(I_0/2)^2.$$

It follows that

$$R_{fd} = 4R_{\frac{\lambda}{2}} = 292.52\Omega.$$

The folded dipole is therefore well matched to 300-Ohm balanced transmission lines.

### Hertzian dipole (current element)

The Hertzian dipole is a theoretical short dipole (significantly smaller than the wavelength) with a uniform current along its length. A true Hertzian dipole cannot physically exist, since the assumed current distribution implies an infinite accumulation of charge at its ends.

The radiation resistance is given by:

$$R_r = \frac{2\pi}{3} Z_0 \left( \frac{\ell}{\lambda} \right)^2 .$$

where  $Z_0$  is the impedance of free space. This is precisely four times the radiation resistance of the real short dipole with the linearly tapered current distribution.

The radiation resistance is typically a fraction of an ohm, making the infinitesimal dipole an inefficient radiator. The directivity  $D$ , which is the theoretical gain of the antenna assuming no ohmic losses (not real-world), is a constant of 1.5, which corresponds to 1.76 dB. Actual gain will be much less due to the ohmic losses and the loss inherent in connecting a transmission line to the antenna, which is very hard to do efficiently considering the incredibly low radiation resistance. The maximum effective aperture is:

$$A_e = \frac{3\lambda^2}{8\pi}$$

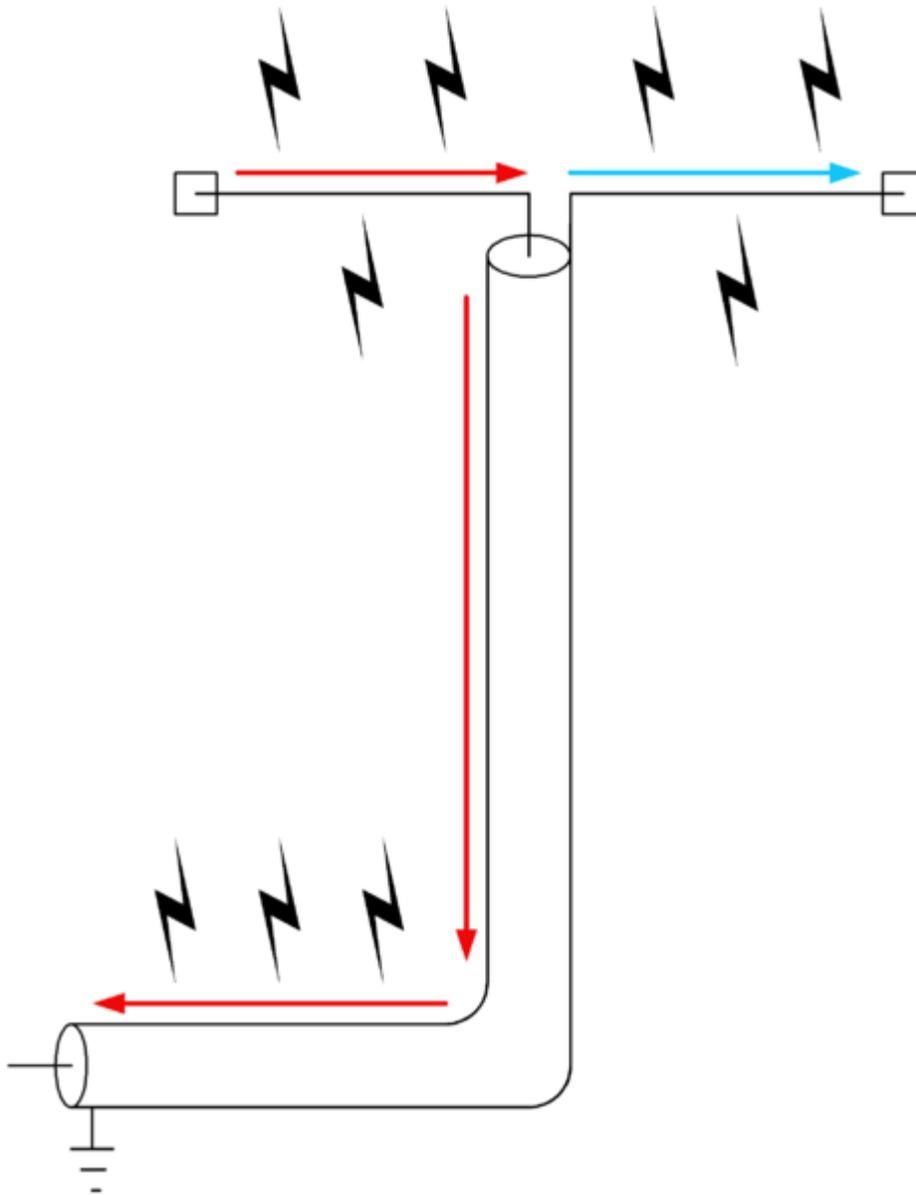
A surprising result is that even though the Hertzian dipole is minute, its effective aperture is comparable to antennas many times its size.

### ***Dipole as a reference standard***

Antenna gain is sometimes measured as "x dB above a dipole", which means that the antenna in question is being compared to a dipole, and has x dB more gain (has more directivity) than the dipole tuned to the same operating frequency. In this case one says the antenna has a gain of "x dBd". More often, gains are expressed relative to an isotropic radiator, which is an imaginary aerial that radiates equally in all directions. In this case one uses dBi instead of dBd. As it is impossible to build an isotropic radiator, gain measurements expressed relative to a dipole are more practical when a reference dipole aerial is used for experimental measurements. 0 dBd is often considered equal to 2.15 dBi.

From Babinet's principle, a dipole antenna is complementary to a slot antenna consisting of a slot the same size and shape as a dipole cut from an infinite sheet of metal; both give the same radiation pattern.

## ***Dipole with baluns***



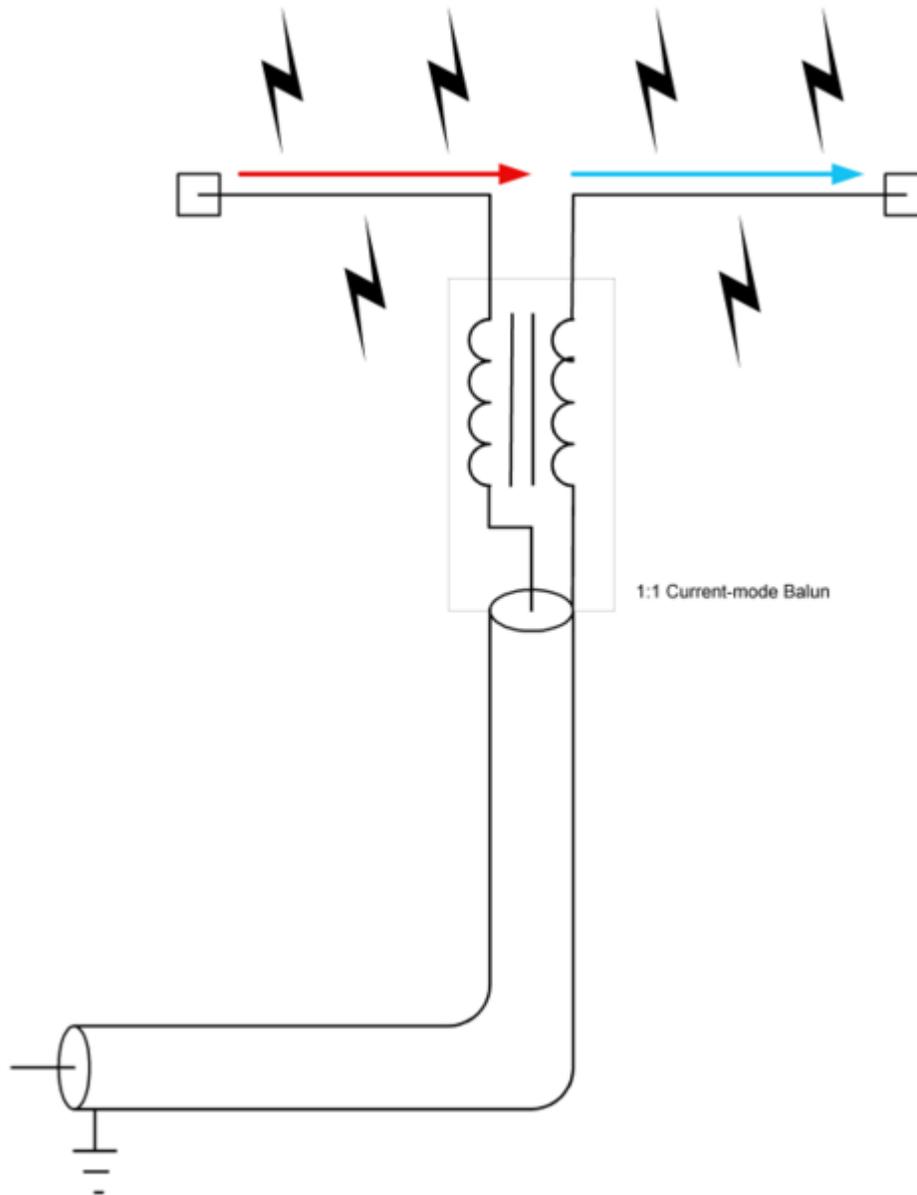
Coax and antenna acting as radiators instead of only the antenna.

A dipole, being composed of two symmetrical ungrounded elements, works best when fed by a balanced transmission line, such as ladder line. When a dipole with an unbalanced feedline such as coaxial cable is used for transmitting, the shield side of the cable, in addition to the antenna, radiates. This can induce RF currents into other electronic equipment near the radiating feedline, causing RF interference. Furthermore, the antenna is not as efficient as it could be because it is radiating closer to the ground and its radiation (and reception) pattern may be distorted asymmetrically. At higher frequencies, where the length of the dipole becomes significantly shorter than the diameter of the feeder coax, this becomes a more significant problem. To prevent this, dipoles fed by coaxial cables have a balun between the cable and the antenna, to convert

the unbalanced signal provided by the coax to a balanced symmetrical signal for the antenna.

Several type of baluns are commonly used to transmit on a dipole: current baluns and coax baluns.

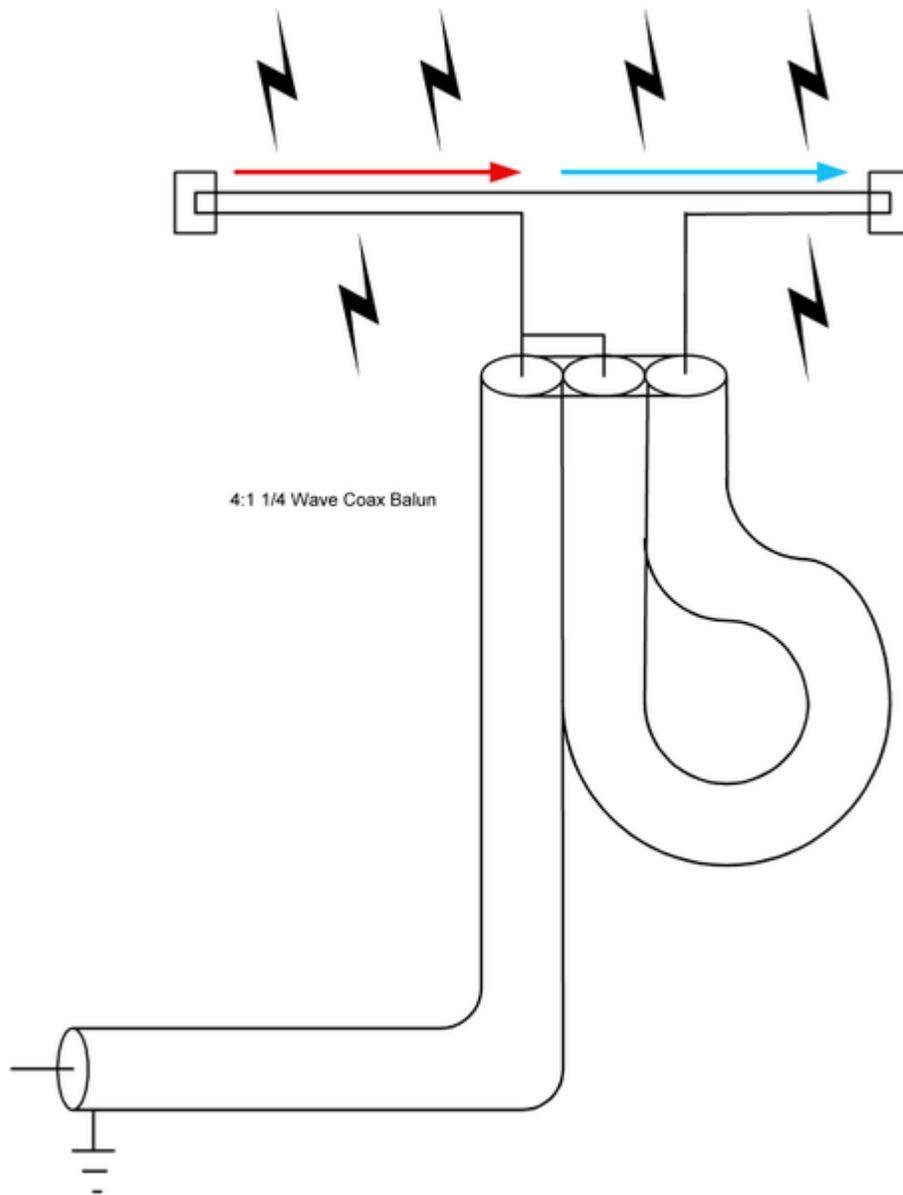
### Current balun



Dipole with a current balun.

A current balun is a bit more expensive but has the characteristic of being more broadband. It can also be as simple as winding the coax cable over a ferrite core. Or nothing but coax cable:

## Coax balun

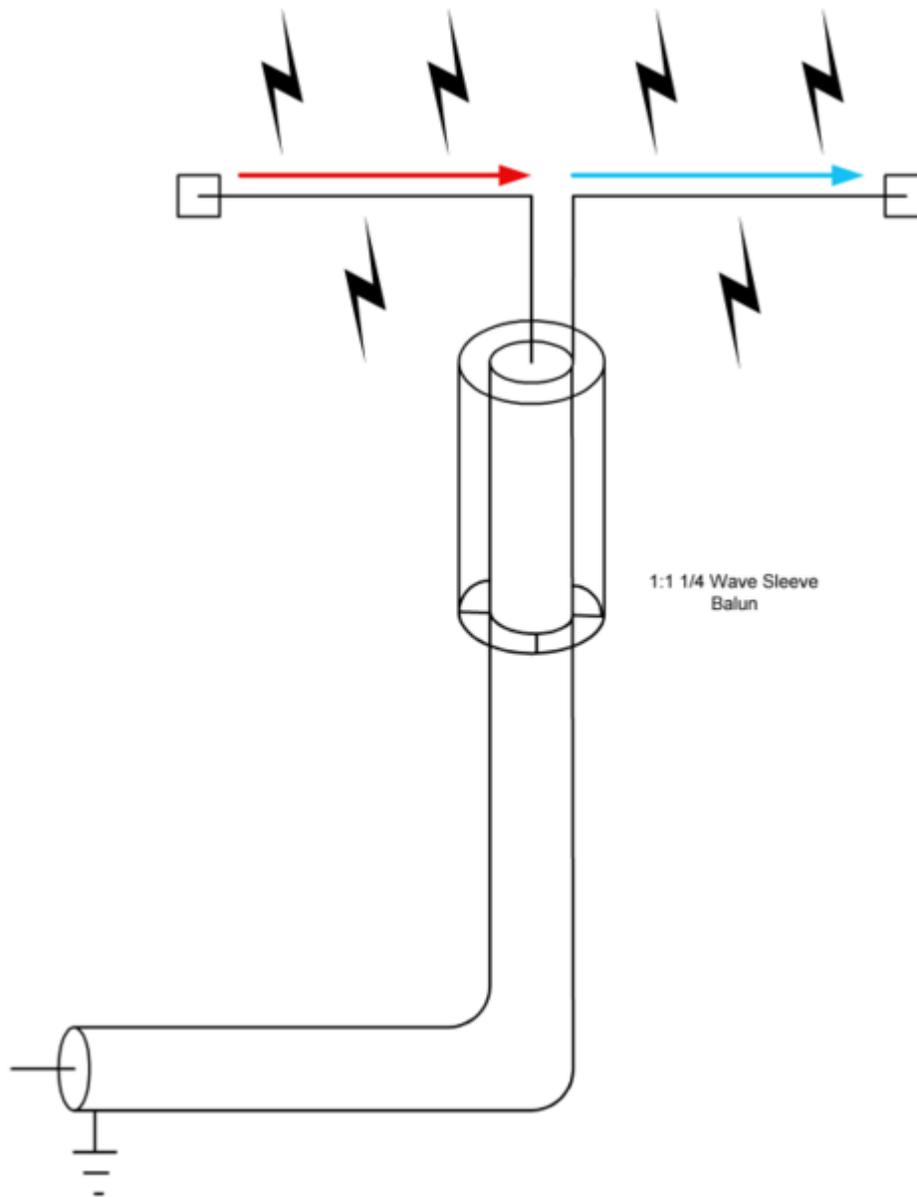


Here is a dipole using a coax balun.

A coax balun is a cost effective method to eliminate feeder radiation, but is limited to a narrow set of operating frequencies.

- One easy way to make a balun is a  $(\lambda/2)$  length of coaxial cable. The inner core of the cable is linked at each end to one of the balanced connections for a feeder or dipole. One of these terminals should be connected to the inner core of the coaxial feeder. All three braids should be connected together. This then forms a 4:1 balun which works correctly at only a narrow band of frequencies.

## Sleeve balun



Here is a dipole using a sleeve balun.

At VHF frequencies, a sleeve balun can also be built to remove feeder radiation.

- Another narrow band design is to use a  $\lambda/4$  length of metal pipe. The coaxial cable is placed inside the pipe; at one end the braid is wired to the pipe while at the other end no connection is made to the pipe. The balanced end of this balun is at the end where the pipe is wired to the braid. The  $\lambda/4$  conductor acts as a transformer converting the infinite impedance at the unconnected end into a zero impedance at the end connected to the braid. Hence any current entering the balun through the connection, which goes to the braid at the end with the connection to

the pipe, will flow into the pipe. This balun design is impractical for low frequencies because of the long length of pipe that will be needed.

## Chapter 13

# Family Radio Service



Motorola T5320 FRS handheld radio

The **Family Radio Service** (FRS) is an improved walkie talkie radio system authorized in the United States since 1996. This personal radio service uses channelized frequencies in the ultra high frequency (UHF) band. It does not suffer the interference effects found on citizens' band (CB) at 27 MHz, or the 49 MHz band also used by cordless phones, toys, and baby monitors. FRS uses frequency modulation (FM) instead of amplitude modulation (AM). Since the UHF band has different radio propagation characteristics, short-range use of FRS may be more predictable than license-free radios operating in the HF CB band.

Initially proposed by Radio Shack in 1994 for use by families, FRS has also seen significant adoption by business interests, as an unlicensed, low-cost alternative to the business band.

Worldwide a number of similar personal radio services exist; these share the characteristics of low power, operation in the UHF (or upper VHF) band using FM, and simplified or no end-user licenses. Exact frequency allocations differ, so equipment legal to operate in one country may cause unacceptable interference in another.

### ***Technical information***

FRS radios are limited to 500 milliwatts according to FCC regulations. Channels 1 to 7 are shared with low-power interstitial channels of GMRS, the General Mobile Radio Service. A license is required for those channels if the power output is over FRS limits.

Unlike Citizens' Band (CB) radios, FRS radios frequently have provisions for using sub-audible tone squelch (CTCSS and DCS) codes, filtering out unwanted chatter from other users on the same frequency. Although these codes are sometimes called "privacy codes" or "private line codes" (PL codes), they offer no protection from eavesdropping and are only intended to help share busy channels. Tone codes also do nothing to prevent desired transmissions from being swamped by stronger signals having a different code.

FRS stations on channels 1 through 7 may communicate with GMRS stations on those shared channels; the GMRS stations may use up to 5 watts of power, while the FRS stations are restricted to 0.5 watts.

FRS radios must use only permanently-attached antennas, such as walkie-talkies; there are also table-top FRS "base station" radios that have whip antennas. This limitation intentionally restricts the range of communications, allowing greatest use of the available channels. The use of duplex radio repeaters and interconnects to the telephone network are prohibited under FRS rules, unlike GMRS and the Amateur Radio Service.

FRS manufacturers generally claim exaggerated range. The presence of large buildings, trees, etc., will reduce range. Under exceptional conditions, (such as hill-top to hill-top) communication is possible over 60 km (40 miles) or more, but that is rare. Normal conditions, with line-of-sight blocked by a few buildings or trees, mean FRS has an actual range of 0.5 to 1.5 km (1/3 to 1 mile).

## ***FRS/GMRS hybrid radios in the United States***



Motorola FV150 FRS and GMRS handheld radio

Hybrid FRS/GMRS consumer radios have been introduced that have 22 channels. Many of these radios have been certified for unlicensed operation (on the 14 FRS frequencies, channels 1-14) under FRS rules.

The FCC rules and statements regarding the use of hybrid radios on channels 1-7 stipulate the need for a GMRS license when operating under the rules that apply to the GMRS. Many hybrid radios have an ERP that is lower than 0.5 watts on channels 1-7, or can be set by the user to operate at low power on these channels. This allows hybrid

radios to be used under the license-free FRS rules if the ERP is less than 0.5 watts and the unit is certified for FRS operation on these frequencies.

In the United States of America operation on channels 15-22 require an FCC GMRS license. Interference to licensed services may be investigated by the FCC.

Channels 8-14 are exclusively for FRS. Accordingly, GMRS operation is not allowed on these channels. Channels 15-22 are reserved exclusively for GMRS. As noted, FRS operation is not allowed on these channels.

### ***List of FRS channels***

<b>Channel</b>	<b>Frequency (MHz)</b>	<b>Notes</b>
1	462.5625	Shared with GMRS.
2	462.5875	Shared with GMRS.
3	462.6125	Shared with GMRS.
4	462.6375	Shared with GMRS.
5	462.6625	Shared with GMRS.
6	462.6875	Shared with GMRS.
7	462.7125	Shared with GMRS.
8	467.5625	FRS use only
9	467.5875	FRS use only
10	467.6125	FRS use only
11	467.6375	FRS use only
12	467.6625	FRS use only
13	467.6875	FRS use only
14	467.7125	FRS use only

Some clubs have recommended FRS Channel 1 as a national emergency/calling channel, such as REACT International, Inc. and the National SOS Radio Network.

Channel 2 is typically used by geocaching groups when trying to connect with other geocachers.

### ***Similar services in other regions***

Personal UHF radio services similar to the American FRS exist in other countries, although since technical standards and frequency bands will differ, usually FCC-approved FRS equipment may not be used in other jurisdictions.

## **Using FRS frequencies**

### **Canada**

American-standard FRS radios have been approved for use in Canada since April 2000. The revised technical standard RSS 210 has essentially the same technical requirements as in the United States. Since September 2004, low-power GMRS radios and dual-standard FRS/GMRS radios have also been approved for use in Canada, giving additional channels. In Canada, no license is required and no restrictions are imposed on the GMRS channels.

### **Mexico**

Since tourists often bring their FRS radios with them, and since trade between the U.S., Canada, and Mexico is of great value to all three countries, the Mexican Secretary of Communication and Transportation has authorized use of the FRS frequencies and equipment similar to that in the US. However, dual-mode FRS/GMRS equipment is not approved in Mexico, so caution should be exercised in operating hybrid FRS/GMRS devices purchased elsewhere.

### **South America**

Dual-mode GMRS/FRS equipment is also approved in Brazil and most South American countries. Portable radios are heavily used in private communications, mainly by security staff in nightclubs and malls, but also in private parking, maintenance, and delivery services.

## **Using other frequencies**

### **Taiwan**

Some manufacturers in Taiwan have radios that carry both FRS and GMRS frequencies, using channels 1 to 99. Channels 1 to 14 are well-known, while channels 15 to 99 are less popular.

channels 15 462.9125, ch16 462.9375, ch17 462.9625, ch18 462.9875, ch19 463.0125,  
ch20 463.0375, ch21 .....  
... ch98 464.9875, ch99 465.0125.

### **Europe**

In Europe, a personal radio service with the same sort of licensing restriction is PMR446 having eight channels in the 446 MHz range. One cannot legally use the FRS radio in Europe or PMR446 in the U.S. The 446 MHz band is allocated to amateur radio in the United States. In Great Britain, FRS frequencies are used for fire brigade communications and this sometimes causes problems when FRS equipment is imported

from the U.S. and used without awareness of the consequences by members of the public. Sweden and Norway have a Kort Distanse Radio service with six UHF channels between 444.600 and 444.975 MHz. European countries also have Low-power communication devices operating in the 433 MHz band, and short-range devcies (SRD) operating on frequencies between 868 and 870 MHz. These devices are restricted to 10 mW output power and are intended to provide an alternative to PMR 446 over short distances.

## **China**

A service similar to the American-style FRS in Hong Kong, Macau, and China is also approved by respective organizations for legal license-free operation, with the name of "Public Radio Service". However, different UHF frequencies with 20 allocated channels near 409 MHz are used. 462 MHz and 446 MHz band are not opened to FRS service, so European, American, and Canadian residents are advised not to use FRS or PMR446 radios for communication when traveling to the aforementioned areas.

List of China Public Radio Service Channels:

### **Channel Frequency (MHz)**

1	409.7500
2	409.7625
3	409.7750
4	409.7875
5	409.8000
6	409.8125
7	409.8250
8	409.8375
9	409.8500
10	409.8625
11	409.8750
12	409.8875
13	409.9000
14	409.9125
15	409.9250
16	409.9375
17	409.9500
18	409.9625
19	409.9750
20	409.9875

## Japan

In Japan, a similar service is limited to 10 milliwatts in the 420, 421, and 422 MHz bands. It is called "Tokutei Shoudenryoku Musen" ("SLPR:Specified Low Power Radio").{

## Australia and New Zealand

In Australia and New Zealand, the UHF CB citizen's band near 477 MHz is used for a similar purpose. The Australian Communications and Media Authority (ACMA) also allocated a band near 434 MHz for low-powered devices with low potential for interference to other users of the band.

## South Africa

South Africa is in the process of conforming to ITC region 1 recommendations. They do allow 8 channels between 446.0-446.1 MHz band currently, this is the same as the European PMR446.

## Philippines

The Philippines has a radio service for use of families and small businesses. This service is called SRRS or Short Range Radio Service. Units are limited to simplex operations and have a power limitation of 2.5 watts.

This service has been allocated 40 channels at 325 MHz:

Channel	Frequency	Channel	Frequency	Channel	Frequency	Channel	Frequency
1	325.0000	11	325.1250	21	325.2500	31	325.3750
2	325.0125	12	325.1375	22	325.2625	32	325.3875
3	325.0250	13	325.1500	23	325.2750	33	325.4000
4	325.0375	14	325.1625	24	325.2875	34	325.4125
5	325.0500	15	325.1750	25	325.3000	35	325.4250
6	325.0625	16	325.1875	26	325.3125	36	325.4375
7	325.0750	17	325.2000	27	325.3250	37	325.4500
8	325.0875	18	325.2125	28	325.3375	38	325.4625
9	325.1000	19	325.2250	29	325.3500	39	325.4750
10	325.1125	20	325.2375	30	325.3625	40	325.4875

## Thailand

Thailand has an 80 channel CB-style service using FM between 245.000 and 245.9875 MHz. Units are allowed up to 5 watts RF power. Besides personal use, the

equipment is used by search and rescue and businesses. Operating rules are less restrictive than amateur radio service, with an initial license fee required. The hand-held units usually have a red case. There are an estimated one million users of the service, often in large cities.

## **Singapore**

Since 3 February 2004, the Infocomm Development Authority of Singapore (IDA) has allocated the 446.0-446.1 MHz frequency band for low-powered walkie-talkies on a non-interference, non-protected and shared-use basis. As these walkie-talkies are low-powered devices which do not potentially cause interference to other licensed radio services, it need not be licensed for use in Singapore. However, the device must be type approved by IDA for local sale.