Digital Communication Systems

Digital Video Broadcasting DVB

The DVB standards are specifications for Digital Video Broadcast transmissions, developed in Europe and governed by ETSI standards. At present there are 4 main standards, all of which are interrelated. The data coding is basically the same. Several individual channels, each containing Video, Audio and Data, or sometimes just audio or data, are combined in a time division multiplexed (TDM) manner as shown in figure 1. MPEG coding is used, but is not part of the DVB standard, but the receivers need to be able to do the required MPEG decoding to be able to receive the images and audio. The number of channels that are multiplexed can vary, so that it is possible to use the same receiver to receive one HDTV channel, 5 SD TV channels or many audio sources. Each of the data can be encrypted, to prevent unauthorised reception. The resulting combined data stream is then spectrally shaped, by multiplying the data with a 15 bit long RPS. That will ensure that channels which are not transmitting and would thus have all 0 data, produce data that conforms to a broader spectrum, so that synchronisation can be carried out easily. The data is then coded using an outer Reed Solomon code and an inner convolutional code. That data is then modulated using the relevant method for the channel in use, as shown in figure 2. Having the same data combination and error encoding allows the same hardware to be used for parts of all the receivers, thus reducing costs.

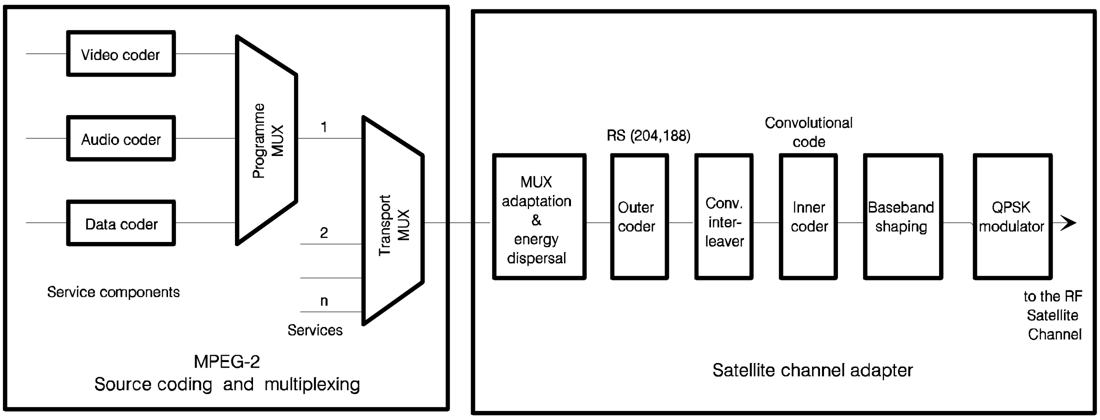

Figure 1. Functional Block Diagram of a DVB-S channel.[TESI:ETS 300421]

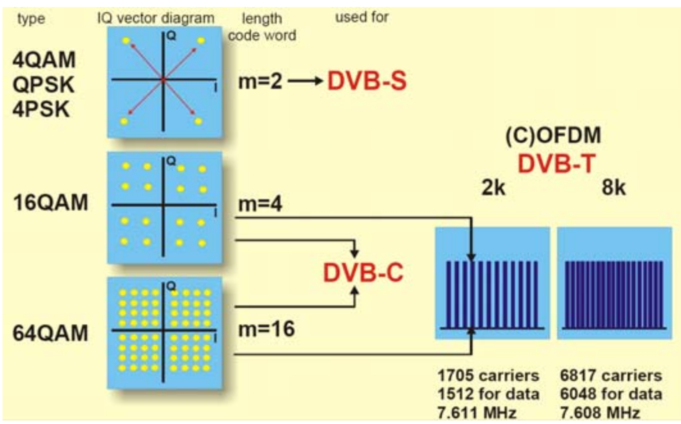

Figure 2. Modulation of DVB systems [T. Jaekel, The basics of Digital TV, R&S, January 2001]

DVB-S for Satellite TV

DVB-S is the DVB transmission for use on Satellite to home transmission. It was developed in 1994 and is implemented throughout the world. Optus has been using DVB-S since 1999. There is no variation in modulation, with QPSK the only one permitted. For DVB-S2 the range of modulation is extended to include QPSK, and 8PSK for broadcast applications and QPSK, 16 APSK and 32 APSK for professional applications (TV stations exchanging program sources). The I-Q constellations for the modulation are shown in the figure below. The PSK modulation is more suited to the nonlinearities caused by the satellite transponder. DVB-S uses Root Raised Cosine filters with alpha = 0.35, for DVB-S2 that is changed to alpha = 0.2 to get a narrower bandwidth. DVB-S2 is now used by most HDTV satellite broadcasters.

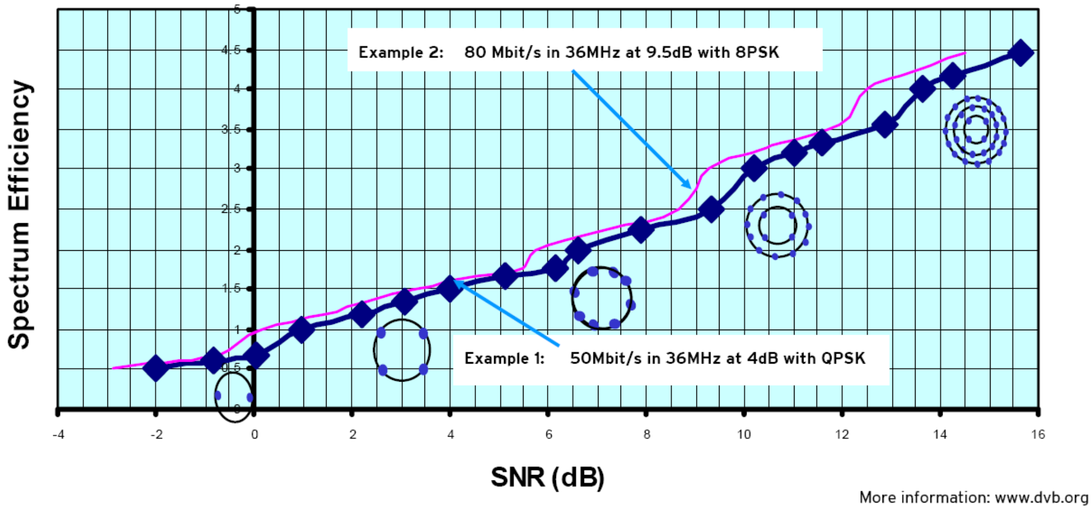

Figure 3. Modulation techniques for DVB-S2 [www.dvb.org, whitepapers on DVB-S2]

BW (at -3 dB) [MHz]	BW' (at -1 dB) [MHz]	R_S (for BW/R_S=1.28) [Mbaud]	R_u (for QPSK + 1/2 convol) [Mbit/s]	R_u (for QPSK + 2/3 convol) [Mbit/s]	R_u (for QPSK + 3/4 convol) [Mbit/s]	R_u (for QPSK + 5/6 convol) [Mbit/s]	R_u (for QPSK + 7/8 convol) [Mbit/s]
54	48,6	42,2	38,9	51,8	58,3	64,8	**68,0**
46	41,4	35,9	33,1	44,2	49,7	55,2	**58,0**
40	36,0	31,2	28,8	38,4	43,2	48,0	**50,4**
36	32,4	28,1	25,9	34,6	38,9	43,2	**45,4**
33	29,7	25,8	23,8	31,7	35,6	39,6	**41,6**
30	27,0	23,4	21,6	28,8	32,4	36,0	**37,8**
27	24,3	21,1	19,4	25,9	29,2	32,4	**34,0**
26	**23,4**	**20,3**	**18,7**	**25,0**	**28.1**	**31,2**	**32,8**

Table 1: Examples of bit rates versus transponder bandwidth for DVB-S [ETSI:ETS 300401]

The data is modulated at a rate that the resulting bandwidth covers 78% (1/1.28) of the entire transponder. Table 1gives the data rates for typical transponder bandwidths and different convolutional coder rates. The default FEC coder rate is ½ with K = 7, and if the transmitted data does not conform to that rate, the receiver searches for other coder rates until the correct one is found.

DVB-C for Cable TV

DVB-C is a standard for Cable TV transmission. Since the noise in cables is less than that for satellite transmission, 16 QAM, 32 QAM and 64 QAM with differential coding is used. In order to achieve a transparent re-transmission of different services on cable systems, the limitations imposed by the System for cable transmission in 8 MHz cable channel bandwidth should be taken into account. With a roll-off factor of 0,15, the theoretical maximum symbol rate in an 8 MHz channel is 6,96 MBaud. The 31.672 Mbit/s bit rate is compatible with terrestrial Plesiochronous Digital Hierarchy (PDH) networks can be re-transmitted in an 8 MHz channel by using 32-QAM. Some of the other bit rates are compatible with DVB-S, so that for conversion a whole data stream can simply be rebroadcast without the data having to be decoded. This is one advantage of having the same data block length, energy dispersal and error correcting coding applied to all the DVB standards.

Useful bit rate R_u (MPEG-2 transport layer) [Mbit/s]	**Total bit rate R_u' incl. RS(204,188) [Mbit/s]**	**Cable symbol rate [MBaud]**	**Occupied bandwidth [MHz]**	**Modulation scheme**
38,1	41,34	6,89	7,92	64-QAM
31,9	34,61	6,92	7,96	32-QAM
25,2	27,34	6,84	7,86	16-QAM
31,672 PDH	34,367	6,87	7,90	32-QAM
18,9	20,52	3,42	3,93	64-QAM
16,0	17,40	3,48	4,00	32-QAM
12,8	13,92	3,48	4,00	16-QAM
9,6	10,44	1,74	2,00	64-QAM
8,0	8,70	1,74	2,00	32-QAM
6,4	6,96	1,74	2,00	16-QAM

Table 2: Examples of useful bit rates R_u and total bit rates R_u' for transparent re-transmission and spectrum efficient use on cable networks [ETSI: EN 300429]

Note not all countries may have 8 MHz cable TV channel bandwidths. Europe has an 8 MHz TV channel bandwith, while Australia has 7 and the US has a 6 MHz bandwidth. In Australia Cable TV is virtually non existent. In countries where cable TV is common then for the earlier analogue TV distribution on cable, the same channel spacing is used as for terrestrial broadcasting, the change to DVB-C has to fit inside those channel allocations.

DVB-T for Terrestrial Broadcasting

COFDM is used for the Digital Video Broadcasting (DVB) or Digital Television in Europe and Australia, where it allows full, constant power, utilisation of the available spectrum for each channel. Theoretically this will give the best performance possible.

In Australia Digital Television was introduced in the capital cities on 1 January 2001, with the progressive introduction into all major regional areas being completed during 2004. At December 2007 91% of the Australian population was covered by Free to Air digital television services. Simultaneous PAL and DVB transmissions will occur to 2010, after which PAL services will be progressively turned off. The complete cessation of PAL services will occur at the end of 2013. In April 2008, 40% of people were watching Digital rather than analogue TV. In December 2007, 66% of receivers used a Set Top Box, 29% had integrated tuners and 3% had a computer with a digital TV tuner.

Parameter	8k mode	2k Mode
Number of Carriers	6817	1705
Data Symbol	1024 μS	256 μS
Carrier Spacing	976.6 Hz	3906 Hz
Total Carrier BW	6.7 MHz	6.7 MHz
Multipath Immunity 1/8 Guard	38.4 km, 128 μS	9.6 km, 32 μS
Multipath Immunity 1/16 Guard	19.2 km, 64 μS	4.8 km, 16 μS

Table 3. Australian DVB parameters for a 7 MHz channel Spacing. [11].

A summary OFDM modulation for the 8k and 2 k modes of DVB is shown in Table 3. This table is for a 7MHz channel spacing as used in Australia. For an 8 MHz channel as used in Singapore, the number of carriers are the same, but the carrier spacing is changed from 976Hz to 1.1 kHz and 3.9kHz to 4.4 kHz respectively, resulting in a corresponding change of symbol length, bandwidth and multipath immunity. The total data rate per channel is not changed.

The 8 k mode will have better multipath immunity, because of the lower data rate. In Australia, for Digital TV, Channels 0 to 5A will not be used, because of electrical noise, and other allocation requirements like FM. There are thus 8 channels available in the VHF band (Band III) and 40 channels available in the UHF band, (Bands IV and V), excluding channel 68 and 69. It will thus be possible to have 48 different HDTV programmes or a minimum of 192 standard definition TV (SDTV), ie PAL quality, programmes to be broadcast in the existing VHF band III and UHF bands IV and V. Using the analogue TV transmissions, it is difficult to allocate more than 5 TV channels in the whole TV band, including Channels 0 to 5A. In Singapore Band 4 (Channel 20 to 39) is available and is used for 5 Analogue TV broadcasts. This band can be used for 19 HD TV services or 76 SD TV services. These figures show that there is a great incentive to convert the existing TV transmissions to a digital format as the spare spectrum can be auctioned off for new applications like Video on Demand. However such decisions are political and economical rather than technical and are influenced by the penetration rate of other services like cable TV.

In Europe cable usage is very high and the demand for terrestrial TV broadcasts is low. As a result during 2003, the analogue service in Berlin and surroundings was changed to a digital one by offering those users who were relying on Analogue broadcasts a free set top box. In Holland 5 adjacent channels were used for a 25 channel SD Pay TV system, with the free to air broadcasts being incorporated as a free service in that system. The DVB-T system is accepted by all South-East Asian counties except South Korea and these countries are formulating a common approach to the introduction of DVB-T broadcasting to minimise the costs of set–top boxes.

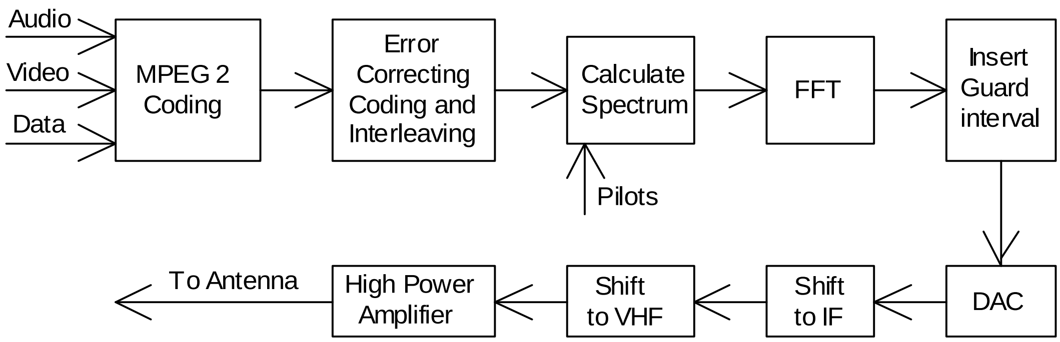

Figure 4. Block Diagram of a Digital TV Transmitter.

TV Type	Hor Pixels	Vert Pixels	Aspect ratio	Frame Rate	Sample MSps	Raw Data MSps	Typ Coded Data MSps	Name
DVB-T HD	1920 1440	1080	16:9	25	51.84 38.88	1244.2 933.1	20	1080i
DVB-T HD	1280	720	16:9	50	46.08	1105.9	15	720p
DVB-T HD	720	576	16:9, 4:3	50	20.74	497.7	10	576p
DVB-T SD	720	576	16:9, 4:3	25	10.37	248.8	5	567i
ATSC	1920	1080	16:9	24 30	49.77 62.21	1194.4 1493.0	20	
DVD	720	576 480	16:9 4:3	25 30	10.37 10.50	248.8 251.9	5 Ave 10 Max	

Table 4. TV resolution for DVD and Digital Broadcasting.

Figure 4 shows a typical block diagram of a Digital Television generator. In Australia [11], the best HDTV definition is 1920x1080 pixels at a frame rate of 25 pictures per second. As shown in Table 4, this corresponds to 51.84 MPixels/sec. At 8 bits per pixel, this corresponds to 414.72 MBit/sec per colour (RGB). This corresponds to 1.244 Gbit per second for the raw data. If required, the data rate can be reduced by sampling the colour information at half the rate, which then results in a raw rate of 829.44 Mbit/sec.

For SDTV the screen definition is 720x576 pixels, at 25 pictures per second, giving a raw data rate of 10368 pixels per second. At 8 bits per pixel, this corresponds to a 248.8 Mbit/sec raw data rate. That data is fed into the Digital Signal Processing (DSP) Unit. The DSP unit takes these RGB data streams and uses the MPEG compression techniques and the relevant transmission formatting to produce the coded video data. Audio data and Data to be transmitted are combined with this signal, to form one data stream of up typically 20 Mbps for HDTV.

That data stream is then coded onto 6817 or 1720 COFDM carriers, using QPSK, 16-QAM or 64-QAM, depending on the data rate requirements of the channel. All the carriers and their phases are generated inside the DSP unit. For a typical single program channel application, the data is split into 256 msec blocks for a 2 k mode and 1024 msec block for an 8 k mode. The data block is then used to calculate the phase of each of the many carriers used in the system and generate the resulting time function. An FFT is then applied to that data. Very high speed Digital Signal Processors are required to perform this in real time. The resulting 6.65625 MHz bandwidth signal is then modulated onto the carrier using conventional frequency shifting techniques.

In Australia a 7 MHz channel spacing is used, and with DVB-T adjacent channels can be used. Under those conditions, the transmitted TV spectrum will thus look like a uniform spectrum with 6.65625 MHz carrier blocks and 343.75 kHz gaps between the carriers from adjacent stations. Figure 5 shows an off-air spectrum of 3 adjacent DVB channels. The Digital receiver must be able to handle the high adjacent channel power levels without distortion to the wanted signals.

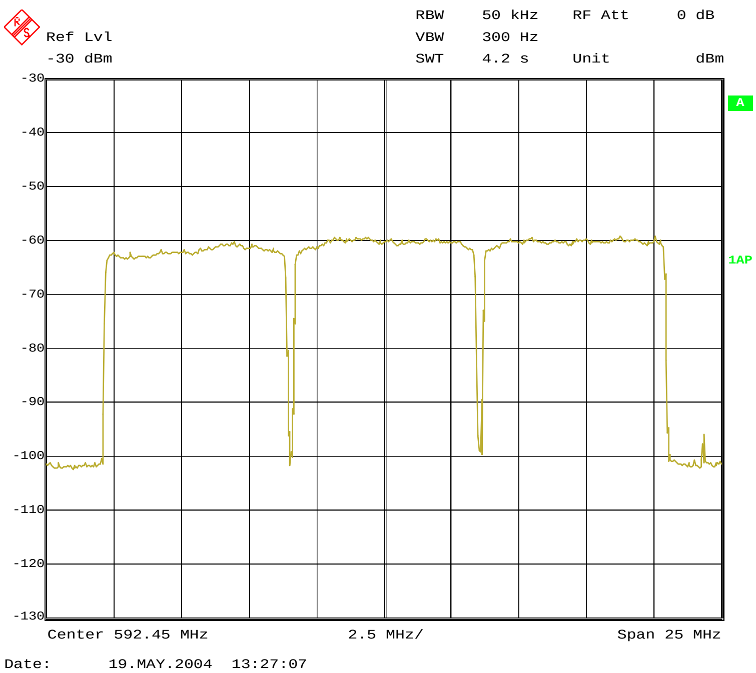

Figure 5. Three adjacent DVB channels (off-air Townsville Mt Stuart).

For the single frequency transmission mode, all the transmitters for a given broadcaster, like the ABC, are operated at the same frequency. For this to occur without performance degradation, the transmitters at the different locations must operate at a frequency difference less than 0.1% of the inter carrier spacing, ie for an 8 k mode at a frequency error of less than 1Hz for a transmitter frequency of up to 800 MHz. This is a significant limitation and requires external synchronisation control, which can be achieved using GPS time standards.

With DVB, different modulation methods (QPSK 16-QAM and 64-QAM) , error correcting rates using 1/2, 2/3, 3/4, 5/6 and 7/8 convolutional coding and quard intervals of 1/4, 1/8, 1/16 and 1/32 of the symbol duration are permitted. Several different sound systems can also be used. This gives a very flexible system.

In Australia, the current requirements are for both SDTV and HDTV to be transmitted on the same channel. If the program material for the SDTV and HDTV is the same, hierarchical coding can be used to achieve this without any overheads. However a SDTV set top box would not be able to decode this signal. As a result two separate data streams need to be coded. The SDTV program will require between 4 and 8 Mbit/s and the HDTV program will be about 16-19 Mbit/s. Using a guard period of 1/16 of the symbol duration and 2/3 convolutional coding results in a data rate of 20.5 Mbit/s and using 3/4 convolutional coding results in a data rate of 23 Mbit/s, both of which fit into the 7 MHz TV channel. It should be noted that even though the HDTV picture has twice the vertical resolution and more than twice the horizontal resolution, the data rate is slightly less than 4 times the SDTV image, since bigger compression ratios can be achieved on the larger picture. This requires a Carrier to Noise Ratio (CNR) of at least 15.4 dB for a BER of 0.02% after the Viterbi decoder.

At present, all stations in Australia use the 8 k mode of transmission with 64 QAM modulation, the SBS uses a 2/3 FEC and a 1/8 guard interval, giving a data rate of 19.353 MBPS. The ABC and the 7, Nine and Ten networks use a 3/4 FEC code and 1/16 guard period, giving a data rate of 23.053 MBPS. In the capital cities, the SBS transmissions are the only VHF transmissions, resulting in more signal path loss. Having a more robust error correction partially compensates for this. In line with the frequency planning proposals for Digital Television in Australia, currently available Digital Set Top Boxes only permit the reception of VHF band III and UHF. In Australia, the 88-108 MHz FM band will thus be free from TV signals once the PAL transmissions are terminated. In Townsville this will be done in the second half of 2011. For capital cities, the switchover will be in 2013.

Station	Ch	Analogue (MHz)	EIRP (kW)	Ch	Digital (MHz)	EIRP (kW)	CR	Guard
ABC	2	63-70	200	12	223-230	50	3/4	1/16
7	7	181-188	200	6	174-181	50	3/4	1/16
9	9	195-202	200	8	188-195	50	3/4	1/16
10	10	209-216	200	11	216-223	50	3/4	1/16
SBS	28	526-533	795	33	561-568	200	2/3	1/8

Table 5 TV frequencies in Adelaide.

These channel allocations are typical for capital cities. To prevent interference to the analogue transmissions, the digital transmissions in the taboo channels of the analogue signals must be of a much lower power, as shown in table 5. The analogue transmissions have 200 kW EIRP and the digital transmissions have 50 kW EIRP in the VHF band and 795 kW and 200kW respectively in the UHF band. Even at the reduced power level, the digital transmissions result in better reception. With the turn off of analogue TV, the TV channels can be reallocated as one 5 channel block, to ease transmitter and receiver antenna constraints and simplifying translator design. Once the analogue TV is turned off, the power levels of the DVB-T TV and the DAB radio can be increased.

In Singapore Mediacorp transmits a TVMobile channel for use in public transport. That system uses the 2k mode (1702 carriers) to allow for Doppler shift of the carriers in moving vehicles. QPSK with a ¼ guard period and 2/3 FEC coding is used to give the system a good performance under low CNR conditions. The channel capacity is approximately 5 MBps under these conditions. Normal set top boxes or Digital TV systems are able to receive both all the DVB transmissions from low data rates like 5 MBps to high data rates in excess of 31 MBps. The DVB-T system is thus very flexible.

DVB-T2- Most DVB-T services use standard definition transmissions. With the switch off of analogue PAL or NTSC services, spectrum is becoming available for other services. The DVB project members are currently looking at a new standard DVB-T2, which includes some enhancements due to advances in technology of video and audio coding, error correction and modulation. The DVB-T2 transmissions are expected to be 30% to 50% more efficient in its spectrum usage. This will allow High Definition TV transmissions to be better adapted to the existing 6, 7 or 8 MHz channel bandwidths. It is expected that the transition to DVB-T2 will be a gradual one, with new receivers being able to receive both DVB-T2 and DVB-T.

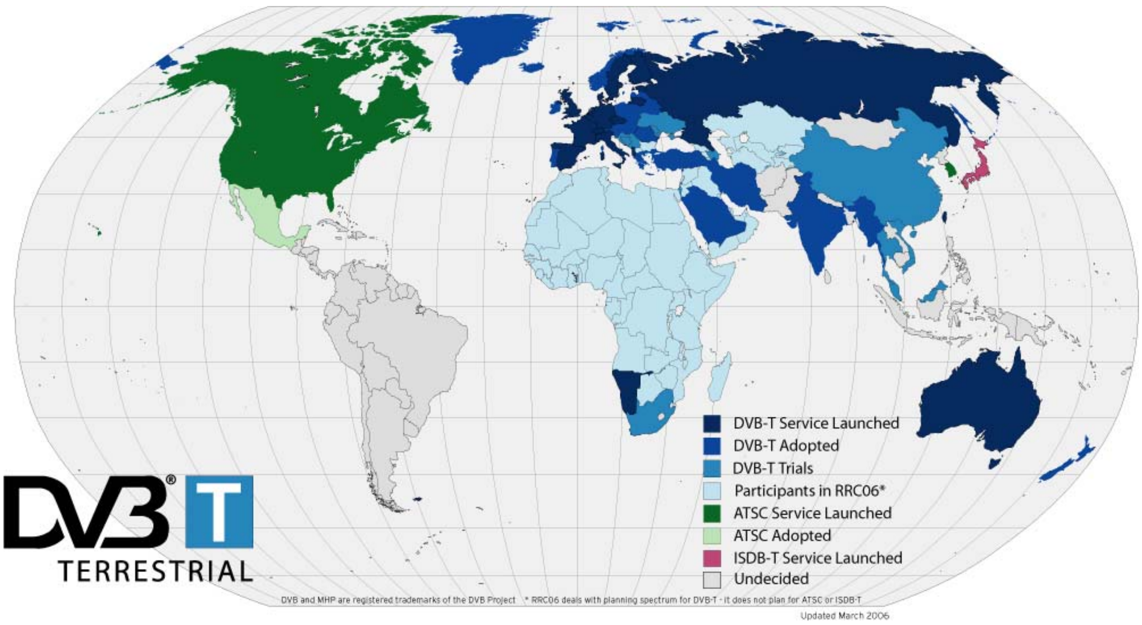

Figure 6. Digital TV system adoption from www.dvb.org, 2008.

The DVB-T2 standard adds 256 QAM modulation and will thus allow QPSK modulation with 16 QAM, 64 QAM and 256 QAM. thus increasing the channel capacity. The OFDM modes are increased to 1k, 2k, 4k, 8k, 16k and 32k. Thus increasing the flexibility for multipath immunity and high mobility applications. There are fewer pilots in different pilot patterns, these pilots are used for equalisation. A concatenation of BCH error correcting coding followed by interleaving and LDPC (Low

Density Parity-Check) error correcting coding is used in conjunction with BCH coding is used is used instead of the Reed Solomon (RS204,188) coding followed by interleaving and convolutional coding for the DVB-T system. The BCH and LDPC coding scheme is also used by DVB-S2 and can be configured to operate to within 0.7 dB of the Shannon limit. Typical capacity increases are of the order of 50% compared with DVB-T. Channel Bandwidths of 1.7, 5,6,7,8 and 10 MHz are permitted in the standard. The standard was published by ETSI in September 2009 (EN 302 755). Table 6 summarises the differences in the modulation parameters between DAB and DAB+

	DVB-T	DVB-T2
FEC	Convolutional Coding + Reed Solomon 1/2, 2/3, 3/4, 5/6, 7/8	LPDC + BCH 1/2, 2/5,2/3,3/4,4/5,5/6
Modes	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM, 256 QAM
Guard Interval	1/4, 1/8, 1/16, 1/32	1/4, 19/256, 1/8, 19/128, 1/16, 1/32, 1/128
FFT	2k, 8k	1k, 2k, 4k, 8k, 16k, 32k
Scattered Pilots	8% of total	1%, 2%, 4%, 8% of total
Continual Pilots	2.6% of total	0.35% of total

Table 6 Comparison DVB-T and DVB-T2 parameters. (from www.dvb.org)

DVB-H for Handheld Devices

DVB-H is a subset of DVB-T parameters specially designed to permit transmission to handheld devices. A PDA can thus be used to watch TV or download video clips etc. Time slicing is used to send the receiver to sleep when it is not receiving, but while it is playing, thus reducing power consumption. If the program content to be watched uses 10% of the channel capacity, then the receiver is only ON during that time giving close to 10% receiver battery saving. The DVB-H transmissions can be multiplexed as part of a standard DVB-T data stream. So that it is easy to introduce DVB-H services.

In addition to the 2K and 8K modes for DVB-T, DVB-H also allows a 4K mode for the transmission. A good overview of DVB-H is a paper “G. Faria, J. A. Henriksson, E. Stare, and P. Talmola, Proc. IEEE, vol. 94, no. 1, pp. 194-209, Jan. 2006.” From which the following paragraph is taken.

“DVB-H is intended to use the same broadcasting spectrum, which DVB-T is currently using. The physical layer of DVB-H is in fact DVB-T and therefore there is a full spectrum compatibility with other DVB-T services. DVB-H can be introduced either in a dedicated DVB-H network or by sharing an existing DVB-T multiplex between DVB-H and DVB-T services. When the final selection of the DVB-H concept was made, the capability to share a multiplex with DVB-T was indeed one of the decisive factors, as it was seen that this would enhance the commercial introduction possibilities of the service in the crowded UHF broadcasting spectrum. Technically almost any DVB-T frequency allotment or assignment can be used also for DVB-H; the only limitations come from interoperability with GSM900 cellular transmitter in the DVB-H terminal. If simultaneous operation is required, the frequencies below about 700–750 MHz are favoured. For broadcasters DVB-H can be seen just as a new means to provide broadcast services for a new, interesting group of customers, namely, the mobile phone users. If this is seen as interesting enough, spectrum will be available. It is in any case expected that the situation will be more relaxed after the analogue TV services will start to close. It should also be noted that DVB-H is very spectrum efficient when compared with the traditional TV-services. One 8-MHz channel can deliver 30–50 video streaming services to the small screen terminals. This is ten times more than standard-definition TV (SDTV) with MPEG-2 or 20 times more than high-definition TV (HDTV) with AVC."

It is also possible for DVB-H to be used for Audio services and DVB-H could be used as a possible system for the introduction of Digital Radio in Australia, though DAB is favoured. There are other possible systems for broadcasting mobile TV. As part of the 3GPP (a third generation mobile phone standard), it is possible to broadcast mobile TV using the "Multimedia Broadcast Multicast Service (MBMS). Phone provider 3 and Ericsson have been conducting trails using this system in August 2007.

ATSC

In the USA, a system with a much simpler modulation technique is used, thus reducing the cost of home receivers, but sacrificing transmission quality. This system was proposed in 1993 by the Digital DHDTV Grand Alliance, a group of companies, including AT&T, General Instruments Corp, MIT, Philips, Sarnoff, Thomson and Zenith. The system used 4 level AM, which is trellis coded to give 8 levels in total. This 8 level AM is then VSB filtered to produce the transmitted waveform. The resulting data rate of the channel is 19.3 MBps and is sufficient to transmit a HDTV image. Because the symbol rate is close to 10 MSymbol per second, the system is much more susceptible to multipath propagation than the DVB-T system. As a consequence external antennas must be used with the ATSC system. Adaptive equalisation must also be used in the TV transmitter, to ensure the group delay remains constant during the VSB filtering and transmission. The ATSC system is more tolerant to Impulse noise than DVB. The cost of ATSC receivers should be less than DVB receivers as no FFT needs to be performed inside the receiver. However a Rake receiver is required as part of the receiver in order to overcome multipath propagation problems. There is no choice of error correction system or sound system type, as this is all fixed in the standard. The initial standard allowed for just one transmission resolution 1920x1080. The 2009 standard now allows other resolutions Since the ATSC system uses VSB, the taboo channels cannot be used, which gives DVB-T a much better spectrum efficiency.

The initial take-up was slow and as a result, the US government has mandated that all 50 cm or larger TV sets sold must be capable of receiving ATSC signals from 1 July 2006. From July 2007, all TV sets had to be capable of receiving ATSC signals. The USA planned to turn off the analogue transmissions on the 17th of February 2009. Despite the mandatory ATSC reception requirements and publicity almost 2 million households were not prepared for the turnoff in February. As a public safety measure, the turnoff of analogue transmissions was delayed to June 2009. Canada, Mexico and South Korea are the only countries using the ATSC system. Canada will switch off analogue TV on 31 August 2011, however Cable TV is far more significant in Canada than terrestrial broadcasting.

ISDB-T

ISDB-T is the digital TV standard developed and adopted by Japan. ISDB-T uses OFDM with a single channel bandwidth of 6 MHz and 5617 carriers spaced 992.06 Hz apart. The channel is split into 13 segments and each of those segments can have a different modulation structure. The modulation choices are QPSK, DQPSK, 16QAM and 64QAM. Rees Solomon (RS204,188) outer coding and 1/2, 2/3, 3/4 and 7/8 convolutional coding is used for the error correcting coding. Guard intervals of 1/4, 1/8 and 1/16 are permitted. ISDB-T does not have the flexibility of transmission modes that DVB-T has, but it shares many advantages with the DVB-T system over ATSC.

ISDB-T has been adopted by Brazil, Peru, Argentina, Venezuela and Equador. With the large size of the ISDB-T market in South America, they are able to produce low cost receivers.

Sound and Video Coding for TV

For Video transmission the Motion Picture Expert Group (MPEG) has been working to produce standards for coding and multiplexing methods for video and audio. The MPEG-2 standards cover the coding and multiplexing of TV signals proposed in ITU-R recommendation 601 and coding for HDTV in a wide variety of applications. Both the DVB and the ASTV systems use MPEG2 coding. The MUSICAM (ISO/IEC 1172/3 MPEG Audio Layer II) process is part of this standard and is used by the DVB system. In the MUSICAM system, sounds which cannot be identifies by the ear, such as a low level frequency component close to a high power signal, are removed. This allows the raw CD stereo rate of 1.41 Mbit/s to be reduced to 256 kbit/s without audible degradation.

The sound options allowed in the Australian standard are Mono, Stereo, 2 channel Dolby surround encoded stereo and Multichannel audio. The multichannel Audio is the AC-3, 5.1 channel sound. This is the same sound system used in movie theatres and the ATSC system, with three speakers in front, two in the back and a sub-woofer to give a sound that you can feel rather than hear. The AC-3 sound option initially was not part of the DVB and ACTV standards but is now included.

Receivers

During 2007 the cost of digital TV SDTV set top boxes dropped to less than $50, increasing the take-up of digital TV. The cost of HDTV set top boxes is less than $200. Personal Video Recorders became available in 2004. These are digital set top boxes with a hard disk drive included so that TV can be recorded and played back at a later time, the price of those is starting at $400. Some of these devices have 2 tuners allowing one channel to be watched while another is being recorded. Most widescreen LCD and Plasma TV's now include DVB tuners. Another big growth area has been TV receivers cards for use with computers. Those cards sell for around $200 and provide PVR capability. At present much of the software still has some limitations, making standard TV's preferred for most users. In march 2010 68% of households in Australia had converted their main TV to digital reception. This is a 21% increase since the first quarter of 2009.

Digital Audio Broadcasting DAB

COFDM is used for the Eureka 147- Digital Audio Broadcasting (DAB) system, which was introduced in the UK during 1995. However it is only recently that receivers have become available at a reasonable cost. In addition different frequency bands are allocated across Europe for DAB, restricting the universal appeal of DAB and resulting in a very slow rate of adoption initially. The changeover from Analogue to Digital TV is freeing up spectrum space in the VHF band III (174 – 230 MHz) and in particular Channel 9A, which is used for current DAB test transmissions in Sydney and Melbourne. DAB transmissions also take place in L band and the 1452 to 1492 MHz spectrum has been set aside for DAB. There is at present a number of transmission frequencies and digital radio broadcasting standards [12,13] around the world. MP2 audio coding is specified for DAB. At present most DAB stations use 128 kbps data rates, which then result in a quality that is slightly inferior to that available from FM.

In February 2007, the DAB+ standard was released. The DAB+ standard uses the HE-AAC version 2 (also known as AAC+) audio codec. This is close to 3 times more efficient, so that more channels of higher quality transmissions can be incorporated in a DAB+ broadcast signal. DAB used convolutional coding, DAB+ incorporates an outer layer of Reed Solomon coding, as well as the convolutional coding used in DAB, thus providing better error correction. Due to the changes in the audio codec and error correcting coding DAB+ is not backward compatible with DAB, however since much of the receiver hardware is the same, the cost of DAB+ receivers will be similar to DAB receivers. For those countries with existing DAB services, simulcast DAB and DAB+ services will be required for several years.

System Parameter	Mode 1	Mode 2	Mode 3
Frequency	< 375 MHz	< 1.5 GHz	< 3GHz
Frame Duration	96 ms	24 ms	24 ms
Guard Interval	246 μs	62 μs	31 μs
Data Symbol	1 ms	250 μs	125 μs
Total Symbol	1.246 ms	312 μs	156 μs
Number Carriers	1536	384	192
Carrier Spacing	1 kHz	4 kHz	8 kHz
Bandwidth	1.536 MHz	1.536 MHz	1.536 MHz

Table 7 Eureka 147 DAB parameters.

The technical standards for DAB and DAB+ are available for free from the ETSI web site [ETSI-DAB]. The Eureka 147- DAB system has a bit rate is be approximately 1.152 Mbps for 9 stereo channels operating at 128 kbps for each stereo channel. Error correcting techniques and administrative overheads bring this bit rate up to just over 2.4 Mbit/s, which fits inside the 1.54 MHz spectrum allocation for each channel. The data period is 1.246 ms, corresponding to a carrier frequency spacing of 1 kHz. As shown in Table 7, the allocated bandwidth of 1.54 MHz allows 1536 carriers at this frequency spacing.

Figure 7. DAB Adoption, Australia introduced DAB+ on 1 June 2009 in all capital cities.

The 44.1 k samples per second 16 bit stereo data from a CD player is coded using the audio coder, MP3 (MUSICAM), MP3(AAC-V1) or HE-AAC-V2 (AAC+). These coders analyse the sound in separate frequency bands and removes sounds which cannot be detected by the ear. For the HE-AAC-V2 coder used in DAB+, lower frequencies which carry the dominant sound energy are processed separately from the higher frequency components. This allows the bit rate to be reduced from 1.41 Mbps for the raw stereo CD data to typically 256 kbps for MP3 and 48 kbps for HE-AAC-V2 for the sound data to be broadcast, with little audible difference. For DAB+, typically 29 such stereo signals will be combined into one RF signal for broadcasting. The resulting data streams, will be coded into a 1.5 MHz bandwidth signal using COFDM.

Since the guard period for mode 1 is 256 μs, signals with an additional multipath length of 76.8 km can still be used as a useful part of the signal frame. Since this length of additional multipath results in very small signals, multipath propagation is not a problem for mode 1 operation. At the higher frequencies used in mode 2 operation, the attenuation of the signal with distance is greater and as a result a smaller guard period can be used. For Satellite broadcasting using mode 3, multipath is not a problem and an even shorter guard period can be used. Since the absolute frequency accuracy of the transmitter is less and Doppler shift are more of a problem with satellite transmission, less carriers and a bigger carrier spacing is used.

For Type 1 transmissions, a single frequency transmission network can be used, DAB is very suitable for car reception and with a single frequency network, the radio can remain tuned to the same station and receives signals from different transmitters as the car travels along, making the handover from one transmitter to the other a gradual and unobtrusive process. The main problem is the frequency accuracy required from all transmitters. The frequency accuracy of each OFDM carrier must be better than 0.1% of the inter-carrier spacing, or better than 1Hz for Mode 1 transmitters and better than 4Hz for L band transmitters. That is a tight requirement.

DAB was initially due for introduction in Australia during 2001, using frequencies at 1.5 GHz. Due to the very slow uptake of DAB in Europe from 1995 to 2002, and the resulting high cost of receivers, the introduction of DAB in Australia was placed on hold. In April 2006, the Federal Government announced it would introduce digital radio in all capital cities of Australia on or before 1 January 2009. That starting date was delayed to 1 June 2009 for transmissions in most capital cities. This timing was fortunate, as it allowed Australia to be the first country to use DAB+.

AD ABC&SBS Radio 9C 206.325 MHz 17 Stations		DAB+ Adelaide 9B 204.640 MHz 14 Stations	
Station	kbps	Station	kbps
891 ABC Adelaide	64	Classic Hits Live	48
ABC Classical	80	Choose the Hits	64
ABC Digital	80	Cruise 1323	48
ABC Digital Radio Extra	72	Edge Digital	48
ABC Jazz	80	Five AA	64
ABC Country	80	Radio GaGa	64
ABC Grandstand	48	Koffee	64
ABC News Radio	48	Mix102.3	48
ABC Radio National	64	Mix102.3 Plus	48
SBS Radio 1	48	Nova 919	64
SBS Radio 1 +2h	40	Nova Nation	64
SBS Radio 2	48	Radar Radio	64
SBS Radio 2 +2h	40	SAFM	64
SBS Eurovision	48	Triple M	64
SBS Chill	80		
SBS PopAsia	80		
Triple J	80		
Total Data rate	1080	Total Data rate	816

Table 8. DAB+ ensembles in Adelaide.

DAB+ receivers in Australia cover the 174-240 MHz frequency band, i.e. VHF TV Band III, used by TV channels 6 to 12. The channel numbering is such that TV channel 10 is occupied by 4 DAB ensembles, 10A, 10B, 10C and 10D. Since the Australian TV channel numbering in Band III is Ch 6, 7, 8, 9, 9A, 10, 11 and 12, the corresponding

DAB ensembles are 5A to 12D, where 5A-5D correspond to TV Ch 6. DAB 9A-9D match TV Ch 9A and the numbers above that match exactly.

The frequency allocation for the TV channels in Adelaide in table 5 can be used as an example of how the DAB and TV channels are intermixed. The DAB transmissions in Adelaide are in the taboo channel of channel 10. This requires the DAB ensembles to be of much lower power than the analogue TV. The present DAB transmissions have an EIRP of 50 kW per ensemble.

The data rate of the ABC and SBS DAB ensemble is close to the maximum for the ensemble, when allowing for FEC and additional data transmission, like station identification, program type, scrolling song titles time of day transmission etc to be included. Note that the music programmes like ABC Classical use a much higher data rate than News Radio or the 2 hour delayed broadcasts from SBS.

The 20MHz FM band can carry 25 different FM stations with 800 kHz frequency spacing. The ABC/SBS DAB+ ensemble carries 17 radio services at close to the same quality in one DAB+ transmission ensemble occupying only 1.5 MHz of bandwidth. This again shows the improvements that are obtained using digital broadcasting compared with analogue transmissions. It is envisaged that FM broadcasts will continue for a very long time. The change to Digital will depend on the uptake of digital receivers and substantially depend on the price of DAB receivers. During the last few years DAB has become accepted in Europe and as a result the cost of receivers has dropped dramatically. In Australia prices for receivers start at $80, with typical receivers costing $200. Most receiver models are simple mono portable receivers, though there are some HiFi type tuners available at around $700. The price of receivers would need to fall to be comparable to the present AM/FM receivers for any significant impact of DAB to occur. In the UK, the government is planning to turn off all analogue radio transmitters, both AM and FM, in 2015, to coincide with the completion of the changeover from DAB to DAB+.

Digital Multimedia Broadcasting (T-DBM)

T-DBM is an offshoot of DAB and developed initially in South Korea as an offshoot of DAB to replace FM broadcasting. Since data is transmitted, the data can also be video. T-DBM is the main competitor to DVB-H for video transmission to mobile phones. The data is coded using MPEG-4 (H.254) for the video and AAC+ for the audio onto a conventional DAB transport medium. In Korea, Transmissions have been in operation since 2005, with 7 TV channels, 12 radio channels and 8 data channels. In Germany a service was launched in 2006 in time for the Soccer World Cup. That service was stopped in April2008 and the provider (MFD) is now favouring DVB-H.

Digital Radio Mondale DRM

Since ETSI is developing the technical standards for DRM, much of the material in this section is based on their material. DRM is an open standard [DRM] digital radio system for short-wave, medium-wave and long-wave. It has been endorsed by the ITU, IEC and ETSI. DRM covers the broadcasting bands below 30 MHz, to provide digital replacements for AM and shortwave broadcasting. The DRM consortium is at present investigating the process of extending the system to the broadcasting bands up to 120 MHz. DRM an open standard digital AM radio system with near-FM quality sound.

Besides providing near-FM quality audio, the DRM system has the capacity to integrate data and text. This additional content can be displayed on DRM receivers to provide for say warnings of road closures, the type of program being listened to etc.

DRM uses existing AM and HF broadcast frequency bands. The DRM signal is designed to fit in with the existing AM broadcast band plan, based on signals of 9 kHz or 10 kHz bandwidth. It has modes requiring as little as 4.5 kHz or 5 kHz bandwidth, plus modes that can take advantage of wider bandwidths, such as 18 or 20 kHz.

Many existing AM transmitters can be easily modified to carry DRM signals. The resulting changeover will result in an improvement in the quality of the received signal with stereo transmission being readily achievable. DRM applications will include fixed and portable radios, car receivers, software receivers and PDAs. Several early prototype DRM receivers have been produced, including a software receiver. At present the ABC at Wollongong has DRM transmissions 24 hours per day at 1386 kHz. The HF transmitter at Brandon also transmits DRM signals part of the day.

The DRM system can use three different types of audio coding, depending on broadcasters' preferences. MPEG4 AAC audio coding, augmented by SBR bandwidth extension, is used as a general-purpose audio coder and provides the highest quality. Spectral Band Replication (SBR) is an audio coding enhancement tool that allows the full audio bandwidth to be achieved at low bit rates. It can be applied to AAC, CELP and HVXC. The sampling rates are 12 KHz and 24 kHz. For AAC coding with SBR 22.8 kbps will give a good quality mono signal. 1.2 kHz is required for the stereo (L-R) information, giving a total bit rate of 24 kbps. That fits inside a 10 kHz bandwidth under normal conditions. MPEG4 CELP speech coding is used for high quality speech coding where there is no musical content. HVXC speech coding can be used to provide a very low bit-rate speech coder.

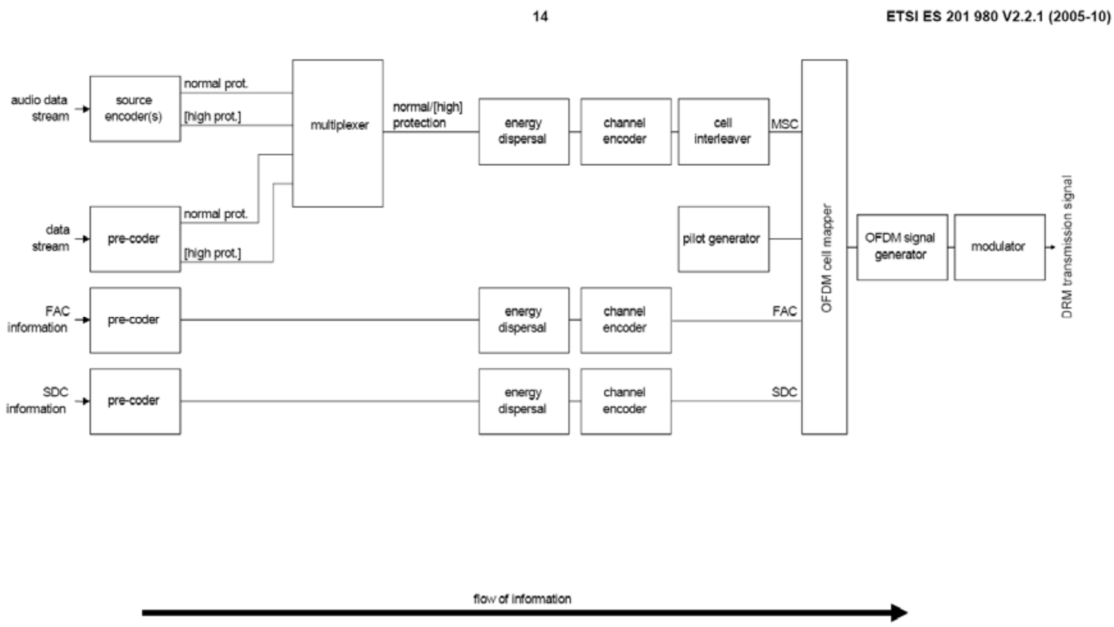

Figure 8. Block diagram of a DRM radio transmitter. [ETSI ES 201 980 V2.2.1 (2005-10)]

The DRM system uses COFDM (Coded Orthogonal Frequency Division Multiplex). The DRM system is designed so that the number of carriers can be varied, depending on factors such as the allotted channel bandwidth and degree of robustness required. The robustness of the DRM signal can be chosen to match different propagation conditions. The block diagram of the DRM transmitter is shown in figure 8.

Robustness mode	Typical propagation conditions
A	Gaussian channels, with minor fading
B	Time and frequency selective channels, with longer delay spread
C	As robustness mode B, but with higher Doppler spread
D	As robustness mode B, but with severe delay and Doppler spread

Table 9 Transmission Modes for DRM. [ETSI ES 201 980 V2.2.1 (2005-10)]

There are different transmission modes depending on the frequency and propagation conditions. For the AM broadcast band mode A would be suitable but for the HF band mode D may be required. The Doppler spread may purely be due to the Ionosphere changing.

The symbol length is 26.6667 ms, for modes A and B, and There are a number of variables in the DRM system to be considered. Transmission mode (number of carriers and pilots), modulation (64QAM, 16QAM or 4QAM), code rate (e.g. 0.5, 0.6 etc) and interleaver length (0.4 or 2sec) can all be altered. For a typical MF daytime service, the determinant of coverage is mainly SNR and hence the distance from the transmitter, so the bit rate can typically be set between 20 to 28kb/s. A service using MPEG4 AAC with SBR parametric stereo can then be provided. During the night the available bit rate is more likely to be within the range of 16 to 24kb/s, depending on the broadcaster's trade-off between coverage and quality. So if audio quality is considered more important, parametric stereo may be retained. However where coverage retention (or coverage increase in the case of sky-wave service) is wanted the lower available bit rate will force the choice of mono audio.

Robustness mode	Duration T_u	Carrier spacing $1/T_u$	Duration of guard interval T_g	Duration of symbol $T_s = T_u + T_g$	T_g/T_u	Number of symbols per frame N_s
A	24 ms	$41.{2/3}$ Hz	2,66 ms	26,66 ms	1/9	15
B	21,33 ms	$46.{7/8}$ Hz	5,33 ms	26,66 ms	1/4	15
C	14,66 ms	$68.{2/11}$ Hz	5,33 ms	20 ms	4/11	20
D	9,33 ms	$107.{1/7}$ Hz	7,33 ms	16,66 ms	11/14	24

Table 10. Numerical values of the OFDM parameters [ETSI ES 201 980 V2.2.1 (2005-10)]

For modes 0 and 1, a single 4.5 kHz or 5 kHz DRM channel is used as an upper sideband like signal, with the nominal "carrier" at the lower end of the spectrum. For modes 2 and 3, two 4.5 kHz or 5 kHz DRM channels are used, the main data and control channel the spectrum above the carrier, like in mode 0 and 1 and a data only channel below the carrier. In mode 4 and 5, four 4.5 kHz or 5 kHz DRM, the channel location is like that of mode 2 and 3, with an additional 2 channels above the data and control channel of modes 0 and 1. As a result the spectrum is asymmetrical for modes 0, 1 4 and 5 as shown in the table 11.

Robustness Mode	Carriers	Spectrum occupancy and BW					
		0	1	2	3	4	5
		4.5 kHz	5 kHz	9 kHz	10 kHz	18 kHz	20 kHz
A	Kmin	2	2	-102	-114	-98	-110
	Kmax	102	114	102	114	314	350
	total	101	112	202	226	412	460
B	Kmin	1	1	-91	-103	-87	-99
	Kmax	91	103	91	103	279	311
	total	90	102	180	204	366	401
C	Kmin	-	-	-	-69	-	-67
	Kmax	-	-	-	69	-	213
	total				136		280
D	Kmin	-	-	-	-44	-	-43
	Kmax	-	-	-	44	-	135
	total				86		178

Table 11 Number of Carriers for DRM [ETSI ES 201 980 V2.2.1 (2005-10)]

The resulting typical data rates are given in table 12. The transmission can contain up to 4 separate signal sources, which can be either data or audio. It is thus possible to have 3 audio signals and one data signal, or 2 audio signals and 2 data signals etc. A stereo music signal requires 24 kbit/s, so that a 64QAM mode and a 10 kHz bandwidth can readily accommodate a good quality. It should be noted that this data rate does not include the system overhead.

In the table 12 the following are used:

Minimum absolute (R = 0,50, 16-QAM, Mode B, 4,5 kHz) 4,8 kbit/s.

Maximum absolute (R = 0,78, 64-QAM, Mode A, 20 kHz) 72 kbit/s.

For HF transmission in Australia a 10 kHz bandwidth is to be used. Assuming an 82% spectral usage, and a coding data rate of 62%, i.e. having 38% error correcting coding and synchronisation overhead, results in 55 kbit/s data rate for 64 QAM and a 36 kbit/s data rate for 16 QAM. Comparing these figures with those in the table, shows a significant amount of data is used in providing the system overheads, guard period, data rate changes to allow for propagation characteristics etc.

For a 64-QAM modulation, a coding rate of 0,6, for the MSC (EEP SM):

Robustness mode	Spectrum occupancy					
	0	1	2	3	4	5
A	11,3 kbit/s	12,8 kbit/s	23,6 kbit/s	26,6 kbit/s	49,1 kbit/s	55 kbit/s
B	8,7 kbit/s	10 kbit/s	18,4 kbit/s	21 kbit/s	38,2 kbit/s	43 kbit/s
C	-	-	-	16,6 kbit/s	-	34,8 kbit/s
D	-	-	-	11 kbit/s	-	23,4 kbit/s

For a 16-QAM modulation, a coding rate of 0,62, for the MSC (EEP SM):

Robustness mode	Spectrum occupancy					
	0	1	2	3	4	5
A	7,8 kbit/s	8,9 kbit/s	16,4 kbit/s	18,5 kbit/s	34,1 kbit/s	38,2 kbit/s
B	6 kbit/s	6,9 kbit/s	12,8 kbit/s	14,6 kbit/s	26,5 kbit/s	29,8 kbit/s
C	-	-	-	11,5 kbit/s	-	24,1 kbit/s
D	-	-	-	7,6 kbit/s	-	16,3 kbit/s

Table 12 Bit capacity of DRM transmission modes.

Simulcasting trials, where the DRM data is transmitted as an above audio signal, i.e. as high frequency sidebands on an existing transmitter are under way. In those instances, the audio is limited to 4.5 kHz and the RDM signal is located in two 4.5 kHz bands, one being the upper sideband and one the lower sideband. In all the DRM transmissions, the transmitter is modulated with an IQ spectrum where the upper and lower sideband are different. This requires low level modulation, followed by a high power linear amplifier for the transmitter. In many cases the modulation is a magnitude / phase modulation rather than an I / Q modulation as this is more suited to AM transmitters.

DRM has been selected by the India only radio network, All India Radio, as it's preferred digital broadcast system and has been broadcasting DRM from shortware transmitters since 2009. It plans to change its entire network of 149 MW (AM) transmitters, 54 HF transmitters and 171 FM transmitters to DRM by 2013 and turn off analogue transmissions by 2015. This will make low cost DRM receivers available.

Brazil is expected to announce the adoption of DRM for it's digital radio system. For Australia MF transmission is needed to cover the whole country. DRM is a likely candidate once the cost of receivers is reduced. The Radio Australia transmitter at Brandon transmits DRM programmes on a daily basis. However it is very difficult to purchase a DRM receiver in Australia.

Other Audio Broadcast Systems

Other digital radio transmission systems have been developed. For instance in Australia, the DVB-T transmissions for the ABC and SBS include two sound only transmissions each. It is possible to have a single TV channel allocation purely dedicated to audio transmissions. Such a system will give Dolby surround sound quality. Most people do not like to have their TV ON when listening to the radio, as a result the radio services which are part of the DVB-T transmissions have a limited appeal

Other digital radio systems are iBiquity's HD radio which has in 2002 been adopted as the only system for digital AM and FM broadcasting in the USA. This system allows simultaneous transmission of analogue and digital transmissions from the same transmitter, by adding the digital signals as a pair of sidebands just outside the existing RF spectrum of a transmitter as shown in figure 9.

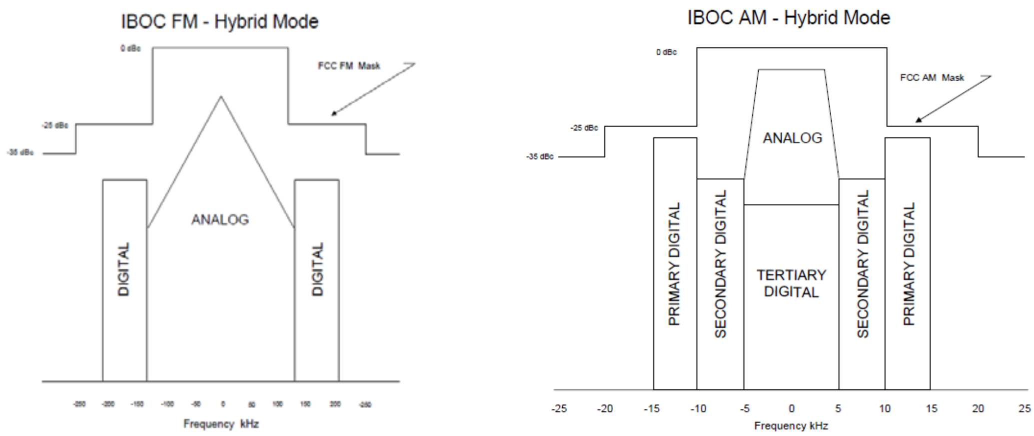

Figure 9. Spectra of HD Radio. [http://www.ibiquity.com/i/pdfs/Conversion_Requirements.pdf]

Once the analogue transmissions are turned off, the analogue signals can be replaced with a digital one.

Computer Communications

ADSL

Asymmetric Digital Subscriber Loop, is a technique where data signals are coded onto copper cable connecting the telephone exchange to the telephone subscriber. The bandwidth from 0- 4 kHz is taken up by the Plain Old Telephone Service (POTS).The frequency band from 25.875 kHz to 138 kHz is used as an upstream band, ie from the subscriber to the exchange. The frequency band from 138 kHz to either 552 kHz or 1104 kHz is used for the reverse link, ie the link from the exchange to the subscriber.

The bandwidth from 10 kHz to 1 MHz is divided up into 256 independent sub-channels, each slightly more than 4.3125 kHz wide. Each channel is QAM modulated with between 2-15 bit of data and trellis coding an option. By measuring the quality of each subchannel on a particular subscriber telephone line, the subchannel capacity can be determined and an appropriate modulation scheme can be assigned to it. The actual number of channels and the frequency of the channel used is thus variable and depends on the line condition. Figure 10 shows the typical data rates that can be achieved on copper cables as a function of the distance between the customer and the exchange. A data rate of 1 Mbps can be achieved for distances up to 6 km from the exchange. The cables have the least attenuation at low frequencies and for this reason the upstream data is allocated the lower frequency region, since that has a lower data rate, but is less tolerant to errors than say video on demand.

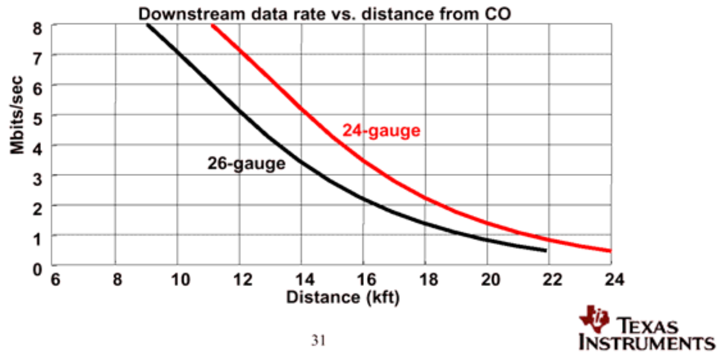

Figure 10. Data rates possible on copper cable. (Texas Instruments[14]).

The first six channels are reserved for analogue telephony. The upstream digital communication link can occupy 24 subchannels, giving an upstream data rate of up to 640kbit/s. The downstream data takes up 248 channels if echo cancellation is used and 222 channels if it is not, giving a downstream data rate up to 6.144 Mbit/s.

A simplified version ADSL-Lite has 512 kbit/s upstream capability and 1.5 Mbit/s downstream capability. The ADSL-Lite hardware does not require any splitter to seperate the POTS, and this reduces installation costs. ADSL lite is also known as G.Lite has 128 subchannels, with a modulation of 8 bits (256QAM) per carrier. ADSL-Lite is very suitable for Internet access, the full ADSL system is required for video on demand.

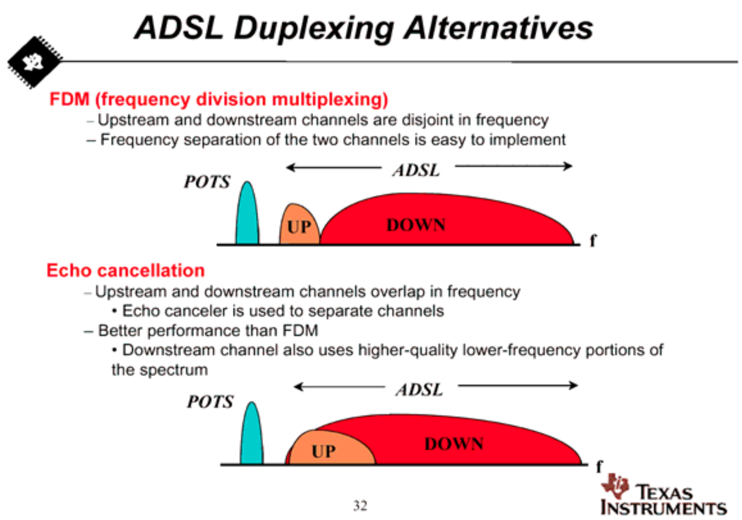

Figure 11. ADSL frequency usage. (Texas Instruments[14]).

The operation of ASDL is very similar to OFDM, except that we have Multitone Channels, the carriers of which are not synchronised and since Multipath problems do not occur on cables, no guard period is used. There are several versions of xDSL available, HDSL, ADSL, VDSL. HSDL was the first version , is symmetrical (same uplink and downlink speed) and is the slowest, VDSL is the fastest and is under development. VSDL has up to 26 Mbps upstream and 56Mbps downstream data speed. Even inside ASDL, there are several versions available the ASDL-Lite version is a popular one.

If no echo cancellation is used, the upstream data will produce a significant amount of crosstalk in the downstream channel. To avoid this, the upstream (ie sent by the user) channel and the downstream (ie received by the user) channel are allocated different frequencies as shown in the top plot of figure 11. If echo cancellation is used, the crosstalk is reduced sufficiently to permit the downstream data to occupy the same frequency region as the upstream data as shown in the bottom plot of figure 11. Since this is a lower frequency region, less attenuation and noise results, giving rise to better communication at the expense of more complex hardware. A good source for information on ADSL is available from the ADSL Forum web site[15].

In Australia ASDL was introduced late in 2000. The ADSL-Lite version available in Australia There are three data rates available depending on how much one pays. The lowers rate is 64 kbps upstream and 256 kbps downstream . The medium speed system is 128 kbps upstream and 512 kbps downstream and the high speed service is 256 kbps upstream and 1500 kbps downstream.

During 2005, ADSL2 was introduced in Australia, allowing a higher data rate services to be introduced. A good web site for information on this is that run by the Australian Communications Industry Forum http://www/commsalliance.com.au [21]. The maximum data rates for ADSL are 1Mb/s upstream (user to exchange) and 6.648 Mb/s downstream. For ADSL2 that will be 1.1 Mb/s upstream and 6.648 Mb/s downstream. ADSL2 uses the same channel frequencies as ADSL but includes smarter channel characterisation to give higher data rates for customers that are close to an exchange. ADSL2+ doubles the used frequencies to 2.2MHz for the maximum downstream channels, thus allowing data rates up to 25 Mbps under ideal conditions.

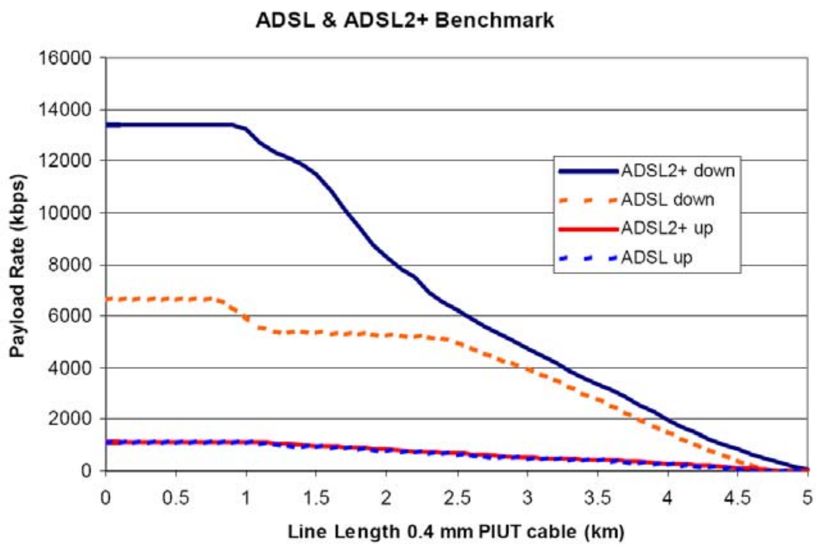

Fig 12 Spectral Compatibility Benchmark I values for Variable Rate Systems, operating on 0.4mm PIUT cable [21]

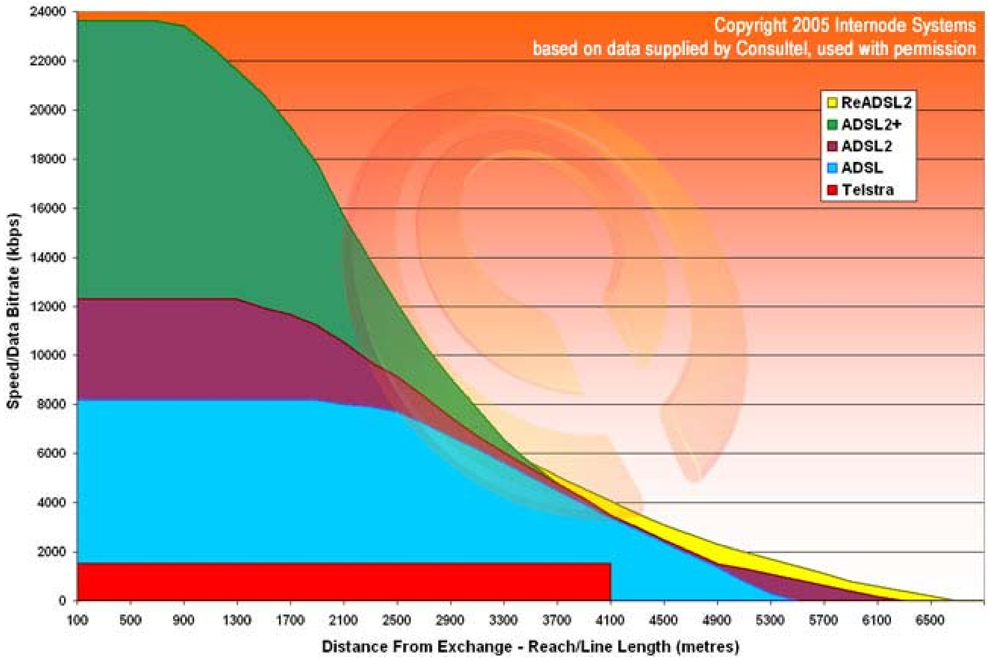

Figure 13. ADSL speed comparisons [www.internode.com.au]

Local Area Networks

Wireless LAN is intended to be used for a radio linked Local Area Network for computers. This will allow portable computers access to the Internet or mass data storage and printing. In addition it will provide flexibility in office layout. Communication distances of up to 800m can be achieved at a reduced data rate. Interfacing with third generation mobile radio systems is being developed.

The IEEE 802.11 is a wireless LAN standard encompassing all the aspects of WLAN specifications. The 802.11 a, b, g, standards relate to global physical layer standards.

IEEE 802.11a/g is capable of data rates of up to 54 Mbps. The signal modulation uses OFDM, with several sub-carrier modulation and forward error correction combinations that allow the system to cope with various channel configurations. The physical layer, i.e. the modulation, parameters of IEEE 802.11a/g is virtually identical as was proposed for the Hyperlan system. The main parameters have the following values:

FFT size: 64.

Number of used sub-carriers: 52, where 48 sub-carriers are used for data and the rest for pilots.

Carrier spacing: 312.5 kHz

Channel Spacing: 20 MHz.

Sampling rate: 20 Msamples/s.

Guard interval: 800 ns default mode corresponding to 16 time samples; 400 ns as an option.

Sub-carrier modulation: BPSK, QPSK, 16QAM and optionally 64QAM.

Sub-carrier demodulation: Coherent.

Mandatory Forward Error Correction: a rate 1/2, constraint length 7 convolutional code.

Supported data rates: 6, 9, 12, 18, 27, 36, 54 Mbit/s.

Interleaving: Block interleaving with the size of one OFDM symbol.

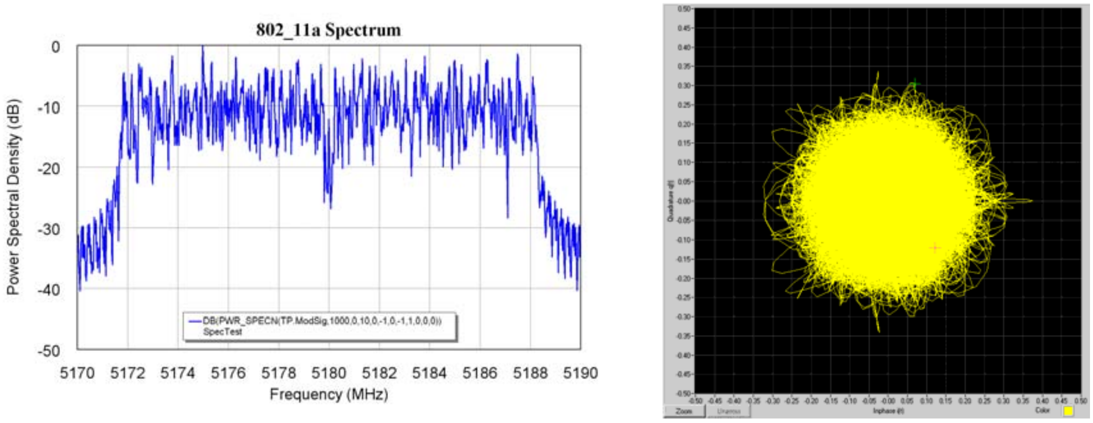

Figure 14. WLAN 802.11a spectrum and IQ vectors

From the above figure it can be seen that the bandwidth for 802.11a is 16.5 MHz.

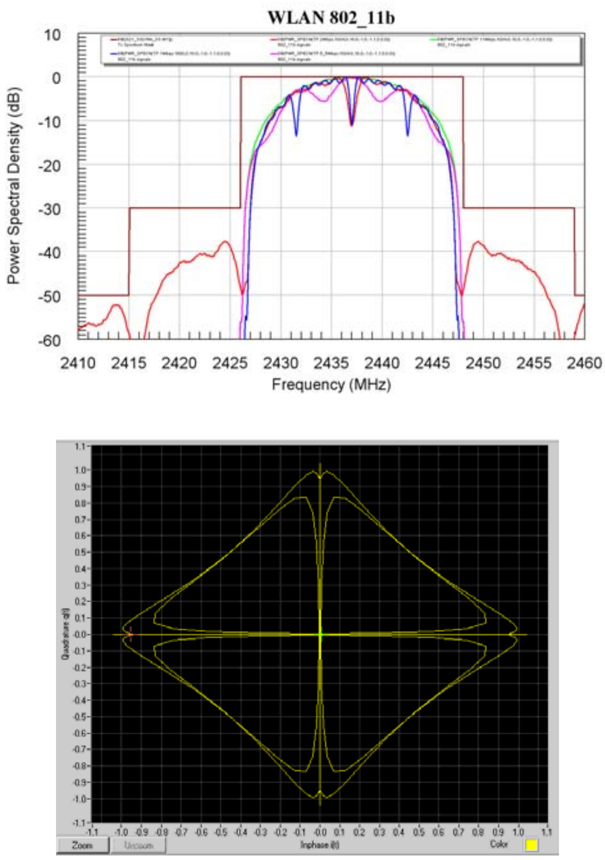

Figure 15. WLAN 802.11b spectrum and IQ vectors.

The IEEE 802.11b wireless LAN system uses Direct Sequence Spread Spectrum Techniques with BPSK for 1 Mbps data transfer, QPSK for 2 Mbps data rates and CCK (*Complementary* ***C****ode* ***K****eying)*, a set of 64 eight-bit code words used to encode data for 5.5 and 11Mbps data rates in the 2.4GHz band of 802.11b wireless networking. The code words have unique mathematical properties that allow them to be correctly distinguished from one another by a receiver even in the presence of substantial noise and multipath interference. The IEEE 802.11b wireless system operates in the 2.4 – 2.4835 GHz frequency ISM band. The IEEE 802.11g standard allows higher data rates in the same frequency band and makes the physical layer backward compatible with IEEE 802.11b, by permitting OFDM for high data rates and CCK for low data rates

The mask for 802.11b is 22MHz wide. The bandwidth for 802.11b is thus slightly wider than that for 801.11a. The maximum data rate for 802.11b is 11 Mbps and that for 802.11a is 54 Mbps. This shows that OFDM is much more efficient in bandwidth usage. That is because each of the carriers can be modulated using up to 64 QAM in 802.11a, while QPSK is used in 802.11b.

The IEEE 802.11b and 802.11g systems operate in the same frequency band as Microwave Ovens and Bluetooth. As a result some interference can be expected. The 802.a system operates in a less used band and is thus a better choice if a faster data rate is desired.

Further wireless LAN systems are proposed, operating in frequency bands up to 66 GHz and data rates to 577 Mbps. Presently available IEEE 802.11g cards are capable of data rates up to 108 Mbps.

Bluetooth

Bluetooth is a global radio frequency standard for connecting small mobile devices in short range ad-hoc networks. Examples are communication between a computer, a printer and a personal organiser (diary) or palmtop. The remote control of Radio, TV, lights, microwave ovens etc are also a big application. In addition Bluetooth can be used by mobile phones to communicate with computers and other mobile phones without going through the normal mobile base station.

Bluetooth is named after the 10th century Danish king Harold Bluetooth, who preferred talking to fighting, united Norway and Denmark and changed the Viking Nation forever by converting them to Christianity. He was particularly fond of blueberries, which caused his teeth to be stained blue.

The development of Bluetooth began at Ericsson Mobile Communications in Sweden in 1994. In February 1998 the Bluetooth Special Interest Group [17] was formed to develop the specifications of Bluetooth. The initial 5 members were Ericsson, Nokia, IBM, Intel and Toshiba. In May 1998 the first standard was produced. In 1999 a promotions group was set up to ensure the world wide adoption of the standard. 3Com, Lucent Technologies, Microsoft, Motorola and the initial 5 SIG members are members of the promotions group. The Bluetooth Special Interest Group now has more than 2000 member companies. The Bluetooth standard is being incorporated in the IEEE standard 802.15, a standard for wireless Personal Area Networks.

Bluetooth uses the 2.40 to 2.5 GHz Industrial-Scientific-Medical (ISM) band. This is a licence free band and as a consequence Bluetooth devices have to be able to operate under high interference levels. To minimise the effect of interference, frequency hopping is used, with 1600 hops per second. An 83.5 MHz band from 2.40 to 2.4835 GHz is available for Bluetooth in the USA, Canada, Latin America and Europe, with the exception of France and Spain, where only the range 2.445-2.4835 is available. In Australia the 45 MHz from 2.40 to 2.450 Ghz is available. In Japan only 26 MHz is available from 2.471 to 2.497 GHz. The Bluetooth transmitter and receiver will work anywhere in the 2.4 to 2.5 GHz band and will frequency hop 79 channels with 1 MHz spacing if more than 80 MHz is available and 23 channels otherwise.

Frequency Shift Keying with 0.5 BT Gaussian Filtering on the baseband data (GFSK) is used for the modulation technique. The advantage of GFSK is that non-coherent detectors can be used thus reducing the receiver cost. The system has a 1 Mbps maximum data rate, due to the protocol overheads, the maximum data rate is however 723.2 kbps in one direction and 57.6 kbps in the other direction (asymmetric) or 433.9 kbps both directions in a symmetrical transmission. In addition up to three 64 kbps synchronous voice channels are supported.

A Bluetooth device that is in communication range of another Bluetooth device and that needs to communicate with that device establishes a Piconet network. A Piconet network can have up to 255 devices only 8 of which can be active at a time. One device is the master controlled in the Piconet and the master controller determines the synchronisation timing and the hopping frequencies according to a pseudo random sequence. A device can be a member of more than one Piconet at the same time and this allows the Piconets to form into larger communication networks called Scatternets. Up to ten Piconets can be part of a Scatternet.

The data is sent in fixed format packets. Each contains a 72 bit access code to ensure the packet is only sent to the correct device. This is followed by a 54 bit Packet Header, which contains retransmission and flow control information as well as error correction bits. The data can be sent in one of tree ways, 1/3 rate forward error correction (FEC) for heavy protection of header data and communications in poor quality links. For better quality links 2/3 FEC coding can be used on the data. For better quality links an ARQ protocol is used, where the receiver acknowledges the correct receipt of a packet in the next data slot. Failure to receive that acknowledgment results in a retransmission of the data. The acknowledgement is contained in the Packet Header.

The success of Bluetooth will depend on the cost of the transceivers. The competing technologies such as the IrDA infrared links available on many computers have limitations in data rate and line of sight requirements. WiFi is much faster but will also cost more. HomeRF is a similar product to Bluetooth.

Mobile Phones

Mobile Radio systems are developing rapidly, from a very small base of around 300 000 users in 1991 to more than 80% of the Australian people having a mobile phone. The same applies to most developing countries. In particular the uptake amongst teenagers has been very high. The predominant use of mobile phones has been speech, however that usage is changing, and the use for data and internet access in expected to grow rapidly.

Vocoders

For voice communication good quality speech at low data rates is obtained using Vocoders. Vocoders attempt to describe speech by modelling the operation of the vocal tract and lips and describing the speech production mechanism in terms of a few independent parameters. Voiced and unvoiced sounds are produced by exciting this model with repetitive pulses or white noise respectively.

The Rectangular Pulse Excitation – Long Term Prediction (RPE-LTP) coder [3, 4] processes speech in 20 ms blocks and then calculates the parameters to represent that block of speech. The RPE-LTP codec operates at a bit rate of 13.2 kbps with a delay of 40 ms and produces good quality speech using a single DSP device. RPE-LPT is used in the European GSM cellular radio system.

Vector Sum Excited Linear Predictive (VSELP) coders are used in the North American Digital Cellular radio (NADC) and the Japanese Digital Cellular radio (JDC). This coder produces good quality speech at 8 kbps. A VSELP coder operating at 5.6 kbps is used for the half rate GSM vocoder, which allows twice as many users in a given bandwidth.

Codebook Excitation Linear Predictive (CELP) coding is used in several more recent mobile phone systems, and provides good quality speech at rates below 8 kbps. RPE coders fail at these low bit rates. There are different versions of CELP coders. The codebook search procedure can be simplified using structured codebooks, sparse excitation codebooks, ternary level codebooks and algebraic codebooks (ACELP). In CELP coders the Vocal tract model is excited with a series of stored waveforms rather than rectangular pulses or white noise. The waveforms are stored in a codebook and the one selected matches the currently produced speech as closely as possible. There are many varieties of CELP coders. The USA Department of Defence uses a CELP type coder to produce speech with a quality comparable that produced by the 32 kbps Continuous Variable Slope Delta Modulation (CVSD or CVSDM) system currently used. CVSDM digitises the speech waveform and does not consider the properties of the vocal tract.

An enhanced full rate GMS (EFR-GSM) coder used by the TDD-CDMA third generation mobile phone is a fixed rate 12.2 kbps ACELP coder. Adaptive Multirate (AMR) ACELP vocoders are also implemented in the TDD-CDMA standard, using bit rates of 6.7, 7.4 and 12.2 kbps. In AMR coders the coding rate changes depending on audio conditions.

Error Correction

In practice error correcting coding is used to provide a better performance during poor Carrier to Noise Ratio conditions. The error correcting coding will increase the gross data rate to up to 2 times the net data rate. The data rate of the GSM transmissions, which uses a 13.2 kbps coder, is 22.8 kbps after the error correcting codes are applied to part of the data. In addition the data stream will have some overheads, such as channel identification, synchronisation bits, a training sequence for equalisation and other control bits. The amount of this overhead depends on the communication system. For the GSM system 34 overhead bits are used together with 114 data bits to make the 148 bit packet used in each data channel. A 8.25 bit guard period is also used, making the effective data rate 33.8541667 kbps [5]. Some Speech Coders like the one used in the IS95 CDMAOne cellular radio system use a variable data rate. During active speech the data rate is 9600 bps and during pauses or when the user listens, the rate drops to 1200 bps. Since normal telephony has an activity factor of 40%, a significant reduction in the overall data rate is made.

Second Generation Systems

Modulation parameters

The Second Generation Mobile Phone Standards are shown in Table 13 below.

	GSM DSC 1800	PDC JDC	D-Amps	CDMAOne IS-95
Freq UL	890-915 GSM 1710-1785 DSC	940-956 1429-1441 1453-1465	824-849	824-849
Freq DL	935-960 GSM 1805-1880 DSC	810-826 1477-1489 1501-1513	869-894	869-894
Multiple Access	TDMA	TDMA	TDMA	CDMA
Duplex	FDD	FDD	FDD	FDD
Carrier Spacing	200 kHz	25 kHz	30 k	1.25MHz
Channels/Carrier	8 or 16/pair	3	3	55-62
Modulation	GMSK	$\pi/4$-DQPSK	$\pi/4$-DQPSK	QPSK/OQPSK
Filter	0.3 Gausian	RRCos 0.35	RRCos 0.35	FIR 615kHz
Modulation Rate	270.833 kbps	42 kbps	48.6 kbps	1229 kbps
Codec	RPE-LTP 13 kpbs	VSELP 6.7 kbps	VSELP 7.95 kbps	CELP 1.2-9.6 kbps
Frame Duration	4.615 ms	40 ms	40 ms	20 ms
Data Rate	22.8 kbps	13 kbps		19.2 kbps
Peak Power Mob	2-20W GSM 0.25-2W DSC	0.3-3W	0.6-3W	0.6-3W
Mean Power Mob	.25-2.5W GSM 0.03-0.25W DSC	0.1-1W	0.6-3W	0.2-1W
Capacity Ch/Cell/MHz	6.7 (Full rate) 13.4 (Half rate)		7	16.5
Other Codecs	Half Rate 5.6 HR+FEC 11.4 EFR 12.2			

Table 13 Second Generation Mobile Radio Standards

Notes: DL- Down Link- from the Base Station to the Mobile Radio

UL- Uplink- from the Mobile Radio to the Base Station

Data Transmission for GSM is 9.6 kbps or 14.4 kbps, corresponding to two standard modem rates.

As the second generation is evolving into the third generation mobile phone standards, the data rates are changed. For GSM the following changes have been made, without changing the channel allocations.

Data Services

GPRS (General Packet Radio Service).

This uses between 1 and 8 GSM channels to carry a user packet with IP or X.25 information from mobiles to external packet data networks, like the Internet. The data rates are between 9.6 kbps (one channel) up to 115 kbps (14.4x8).

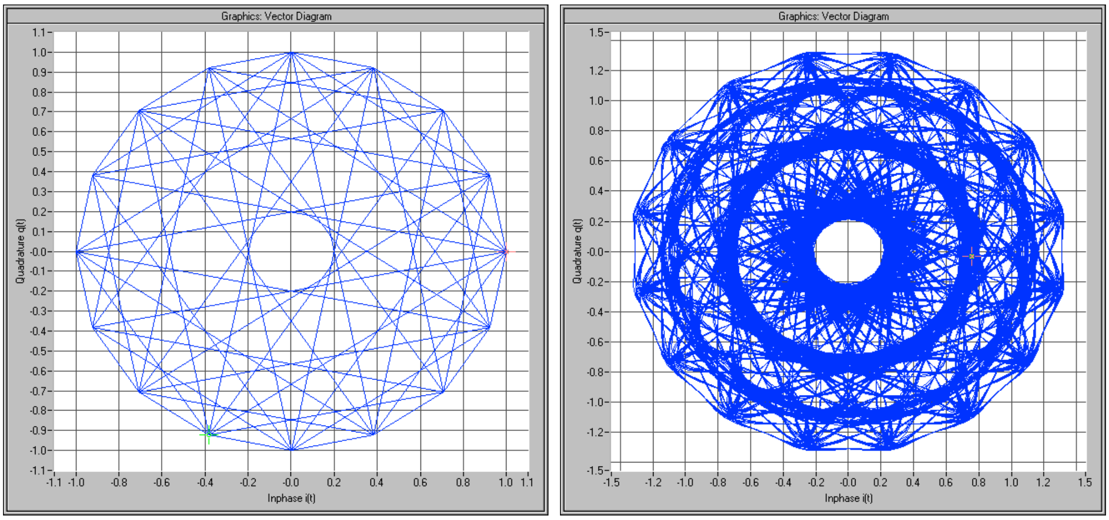

Figure 16. EDGE constellation I-Q diagram. Left No filter, Right Edge filter

EDGE-Enhanced Data rates for GMS Evolution. This system uses a different modulation rate with 8PSK. Like π/4 QPSK, the constellation for adjacent data is shifted by π/8, to produce the constellation shown above, if no filtering is used and like below if the special Edge filtering is used.

The CDMAOne mobile phones also have an enhanced system which allows a higher data rate IS-95B allows up to 12 user slots to be used simultaneously to produce data rates between 9.6 kbps and 115.2 kbps.

iNode is a protocol that allows always ON data services to be implemented. Telstra introduced iNode in November 2004. The user can send and receive email, picture and video messages and do specialised web browsing to iNode sites to order flowers, movie tickets etc.

Third Generation Mobile Phone Systems

Like the second generation systems with GSM produced by the Europeans and CDMA produced by the USA. There are two versions of third generation systems being proposed. The Europeans are proposing the 3GPP standards and the USA are proposing 3GPP2 standards. The current 3^{rd} generation standards are called IMT2000 standards, consisting of W-CDMA by the Europeans and CDMA2000 by the USA. Future standards are already being planned by both the 3GPP group and the 3GPP2 group.

The third generation mobile radio standards are being improved to provide further expansion. By changing the modulation technique for the W-CDMA systems to 16 QAM, a data rate of 14.4 Mbps can be obtained. By combining several CDMA2000 channels a data rate of 2.4 Mbps can be achieved. Both W-CDMA and CDMA2000 allow more than one channel to be transmitted at the same time. This would normally result in I-Q vector diagrams with varying amplitudes, requiring class A amplifiers to be used in the mobile. To ensure that the amplitude variations are minimised, so that class C amplifiers can be used in the mobile, a modulation scheme with complex scrambling of the data called Hybrid Phase Shift Keying (HPSK) is used. The operation of HPSK is outside the scope of these lectures, however a good description can be found in Agilent

Application Note AN 1335 "HPSK spreading for 3G" [20]. The resulting I-Q constellation is very much like an 8PSK system.

3GPP/3GPP2 mobile standards

	W-CDMA 3GPP FDD	W-CDMA 3GPP TDD	TD-SCDMA TDD (China)	CDMA2000
Freq UL	1920-1980 1850-1910 1710-1785	1850-1990 2010-2025	1850-1990 2010-2025	1920-1980 + lower freq
Freq DL	2110-2170 1930-1990 1805-1880	1850-1990 2010-2025	1850-1990 2010-2025	2110-2170 + lower freq
Multiple Access	CDMA	CDMA/TDD	CDMA/TDD	CDMA/FDMA
Modulation	DBPSK UL QPSK DL	QPSK	QPSK, 8PSK	QPSK, OQPSK HPSK
Channel BW MHz	5, 10, 20	5	1.6 MHz	1.25, 5, 10, 15, 20
Data Rate Mbps	2, 14.4	2, 14.4	2, 2.8	0.3077, 2.4
Channels/Carrier	196 (spreading factor 256, AMR 7.95 kbps) 98 (spreading factor 128, AMR 12.2 kbps)		Depends on service	Depends on service
Vocoder	AMR 4.75-12.2kbps, GSM EFR 12.2kbps, SID 1.8kbps			
Filter	RRCos 0.22			
Chip rate Mcps	3.84			1.2288, 3.6864
Frame Length ms	10ms			5, 10, 20, 40, 80
Max Power (Mob)	2W, 0.5W, 0.25W			

Table 14 3rd Generation Mobile Radio Parameters.

The advantage of CDMA TDD systems, are that the Up/Down data rates can be different with an equal time allocation being used for equal transmit and receive data rates. It is however possible for no time being taken one way and full time the other way for one way data transmissions. The up/down times are adjusted to maintain the constant data rate through the channel

In Australia Hutchincon's 3G (http://www.three.com.au/) is in a partnership with Telstra and at present provides coverage in Sydney, Melbourne, Adelaide, Brisbane, Gold Coast and Perth.

During 2006 Telstra introduced the NextG network, which basically uses W-CDMA modulation parameters, modified for HSDPA.

The Next G network is capable of running HSDPA (High Speed Downlink Packet Access) protocol, which supports 1.8 Mbps, 3.6 Mbps, 7.2 Mbps and 14.4 Mbps data rates, as part of the standard. Not all 3G service providers provide all these data rates. The Telstra NextG network at present provides data rates up to 14.4 MBps. Data rates of up to 100 Mbps will be introduced during 2008.

Sine the Next G network now has a larger coverage area than the Telstra CDMA (IS95) network, that network was turned off on the 28th of April 2008, and will allow improved NextG services to be developed in the frequencies formerly used by the CDMA network.

For HSDPA, some of the modulation parameters of W-CDMA are changed. The spreading factor is fixed and modulation parameters are varied. QPSK is used for noisy channels and 16 QAM is used for clearer channels. The Forward Error Correcting rate can effectively be turned off (1/1 rate) on good channels, giving a data rate of 14.4 Mbps and is 1/3 on poorer channels. With QPSK and 1/3 FEC the information bit rate is coding rate is 1.8 Mbps.

Costs for Data

At present the charge for mobile broadband is $29.95 per month for a 400 Mbyte using the next G network at download data rates from 550kbps to 3 Mbps depending on the number of other users using that cell and up to 1.3 Mbps upload speed. Other plans are available with a 2Gbyte download limit at costing $169 per month. Additional usage is charged at typically 25 cents per Mbyte.

In addition Telstra provides data services on mobiles using Telstra's GPRS or 1xEV-DO networks. Other Mobile service providers, provide similar services.

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