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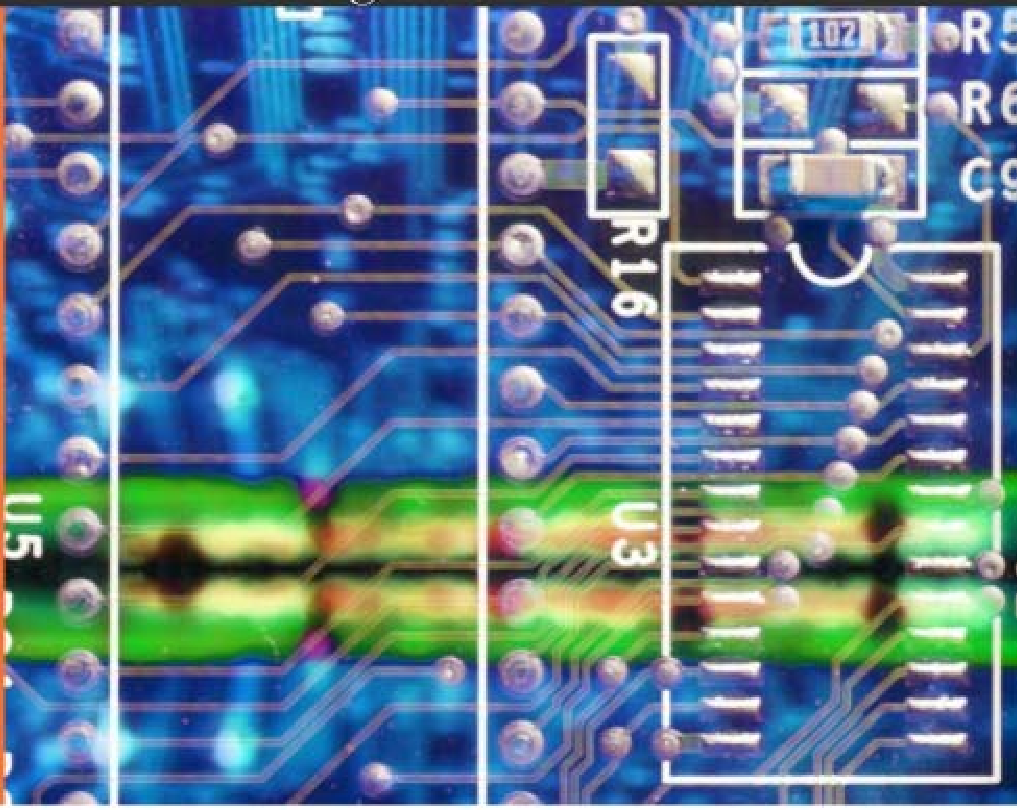

DVB-T Digital Terrestrial Broadcasting

(Explanatory and Tecnical Handbook)

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DVB-T Digital Terrestrial Broadcasting
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Introduction

The introduction of digital television in terrestrial broadcasting represents a considerable technological opportunity, that has to be fully understood to best exploit these innovative and really powerful tools. They enable TV Broadcasters to provide services meeting -- or even exceeding -- the expectations of more and more demanding and advanced users, such as the ones of the Twenty-first century.

The field is extremely wide and complex; these technical notes will focus, in particular, on the DVB-T standard for terrestrial television broadcasting. For a better understanding of the various subjects covered, we suggest that you preliminarily read the "DIGITAL TV BROADCASTING HANDBOOK," that can be downloaded from ABE Elettronica web site (www.abe.it) at the address http://www.abe.it/PDF_Tech/DTVB_Handbook.pdf this handbook covers subjects like MPEG Encoding, Transport Stream and Multiplexing, Digital Modulation, Digital Microwave Links and some other aspects of digital terrestrial broadcasting, necessary to fully understand those subjects that are treated more in depth in these notes.

In summary, the fundamental points are:

- Digital television, compared to analog, has the following advantages:
  - A greater number of programs in the same occupied RF bandwidth (typically four times or more)
  - A lower RF power required to cover the same distance (i.e. a greater immunity to noise and disturbances)
  - A better picture quality
  - The possibility of building isofrequency terrestrial broadcasting networks (SFN)
  - The possibility of mobile reception without the typical problems affecting analog systems
  - The possibility of transmitting data and auxiliary services (for example, Multimedia Home Platform (MHP), the multimedia platform for domestic users)
- TV digital broadcasting requires digital video/audio signals, which can be generated either digitally (with all-digital TV cameras and studio equipment) or, as it currently happens in most cases converting available analog signals into digital ones. Digital video/audio signals must be compressed to form a data flow (stream) of reasonable size to be carried through the distribution link chain and broadcast to users; if these data are transmitted uncompressed they would occupy an RF bandwidth greater than that of an analog signal. However the encoding/compression should not negatively affect in any significant way, the quality of video/audio signals; for this purpose, the

international standard chosen is the Motion Picture Expert Group version 2 (MPEG-2). This standard allows digital systems to compress a TV program from over 200Mbit/s (before compression) to just 5-6Mbit/s while ensuring a very good quality; if required, compression could be lower than 4 Mbit/s but quality will be compromised.

- The Transport Stream is both the data flow containing video/audio program(s) (MPEG compressed) and data that have to be carried from the generating/transmitting equipment to the users/viewers. These data have a constant bit rate and are organized in a continuous sequence of fixed length "packets" (188 or 204 bytes each).

  For the Transport Stream the following interfaces are commonly used:

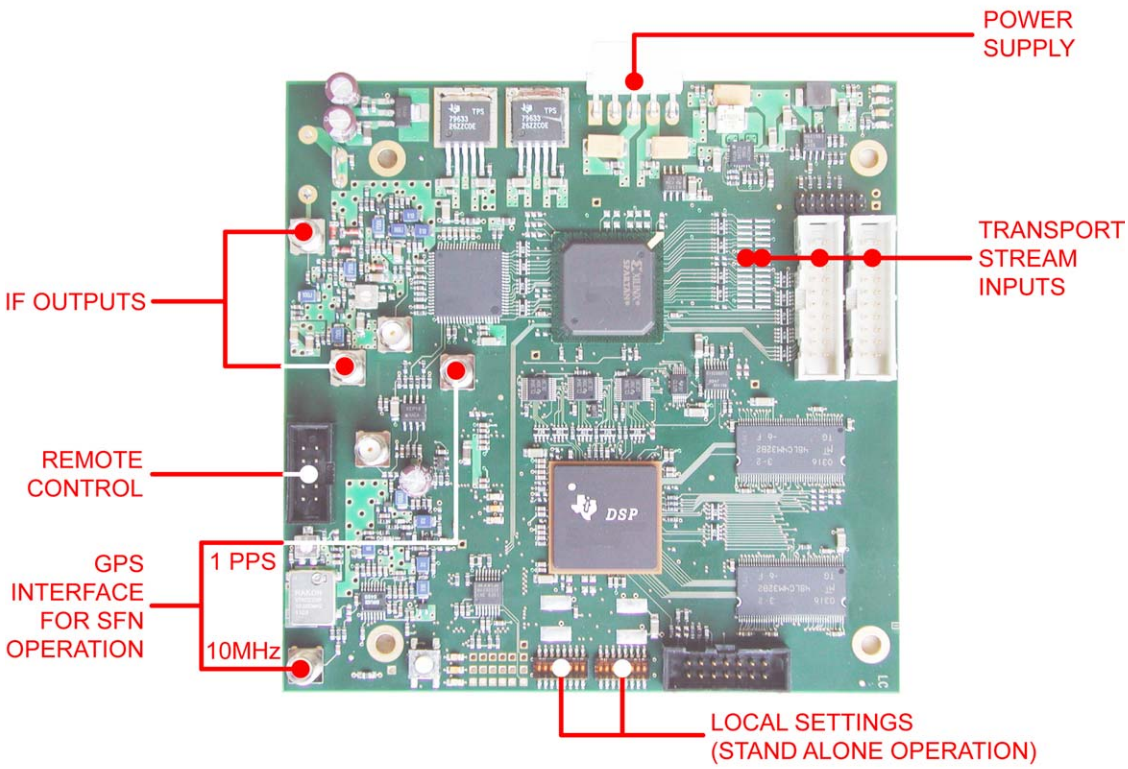
  - Synchronous Parallel Interface (SPI) with electrical levels LVDS (Low Voltage Differential Signal – balanced) or LVTTL (Low Voltage TTL – unbalanced)
  - Asynchronous Serial Interface (ASI), the most commonly used, with a constant bit rate of 270 Mbit/s, working on a single unbalanced coaxial line (75 Ohm).

- The Multiplexer is a device that aggregates various Transport Streams (coming, for example, from different MPEG encoders) to form a single Transport Stream which includes them all. Furthermore, the Multiplexer (in its Re-multiplexing function) can also modify the Transport Streams, adding data and tables, like the Network Information Table (NIT) in which it is possible to edit the names of the programs transmitted, which then will be shown to users.

- In digital modulations the carrier moves continuously through a number of predefined positions of phase and/or amplitude (called "Symbols"), each representing a bit sequence of the Transport Stream being transmitted. The representation of the possible positions of the carrier in the phase (angle)/amplitude (distance from the center) diagram of a modulation is called "Constellation Mapping." The most used modulations are:
  - Quadrature Phase Shift Keying (QPSK): Phase Modulation with 4 constellation positions. It is an extremely robust modulation, used in the DVB-S (uses: terrestrial microwave links, satellite broadcasting or contribution)
  - Quadrature Amplitude Modulation (QAM). Phase Modulation + Amplitude with 16, 64 or more positions in the constellation. It is used in the DVB-C (uses: MMDS broadcasting, cable distribution and terrestrial microwave links).

- The Ortogonal Frequency Division Multiplexing modulation (OFDM) is a complex digital modulation, composed of several carriers (IFFT 2K = 1705 carriers; IFFT 8K = 6717 carriers), equally frequency spaced, each one modulated QPSK or 16-QAM or 64-QAM. It is used in the DVB-T standard for digital terrestrial broadcasting, as well as in microwave links/ENG. The bandwidth occupation (channel) is exactly the same of the analog terrestrial emission, i.e., 6, 7 or 8MHz. The Transport Stream bit rate at the input of the modulator depends on the bandwidth settings (6, 7 or 8MHz), the modulation scheme (QPSK, 16 or 64-QAM), the error correction code employed (Code Rate – from 1/2 to 7/8) and the guard interval (from 1/4 to 1/32). Depending on these parameters, the bit rate can vary from around 4 Mb/s up to almost 32 Mb/s.

OFDM (DVB-T) 2K / 8K ABE DIGITAL MODULATOR BOARD



Isofrequency Broadcasting Networks (Single Frequency Network - SFN)

A significant advantage offered by the digital OFDM modulation used in the DVB-T standard is the possibility of making isofrequency terrestrial broadcasting networks. By this, we mean to have a number of transmitters, which cover adjacent areas, working on the same frequency, broadcasting the same programs. It enables us to use the same emission channel for wide areas, covered by a number of transmitters, without mutual interference (SFN - Single Frequency Network).

In analog broadcasting this is practically impossible. In analog systems, using the offset technique (line, or, better, precision) it is possible to reduce interference at the limits of the service area of each transmitter with reference to the transmitters covering the adjacent areas. However, in practice, an analog isofrequency network cannot be implemented without substantial interference areas, in which signal quality degrades significantly, even in the case of extremely well planned networks and directional antenna systems capable of avoiding much radiation outside the planned service area.

Digital Single Frequency broadcasting Networks (SFN) are constructed as follows.

First of all, the frequency precision/stability, that normally is required to be 500 Hz, must be by far greater than the one of the transmitters used in Multi Frequency Networks (MFN).

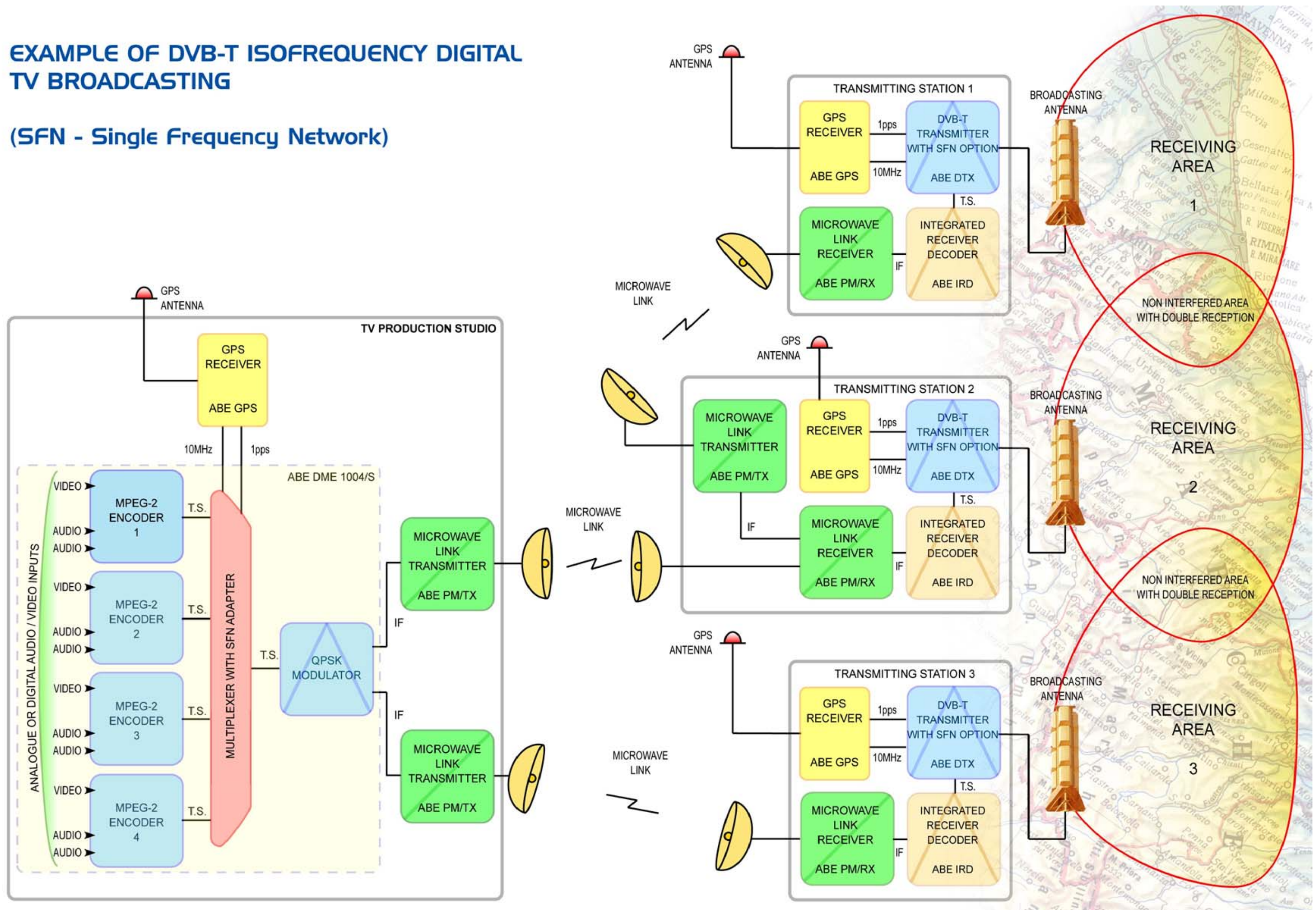
In SFN networks all transmitters must be synchronized on the same frequency reference, which is normally provided by the Global Positioning System (GPS), the satellite navigation system realized and maintained by U.S. Department of Defense.

The signal coming from GPS satellites can be received almost everywhere in the world and contains a very precise time information to which SFN transmitters must be locked; hence frequency precision/stability will have an order of magnitude of 1 Hz.

Each SFN transmitter must transmit exactly the same Transport Stream (TS - the digital data flow containing the programs) and emit it in a way to be synchronized with the other transmitters. During Transport Stream generation, normally in the Multiplexer that shall be duly configured for this purpose, the digital data flow is divided into “Megaframes” and some data are added (Megaframe Initialization Packet - MIP) in order to synchronize the emission of each transmitter in the network.

EXAMPLE OF DVB-T ISOFREQUENCY DIGITAL TV BROADCASTING

(SFN - Single Frequency Network)



Synchronization is achieved thanks to the 1 Hz frequency signal (1pps – 1 pulse per second) coming from GPS receivers.

Up to this point, absolutely identical signals have been generated, from each transmitter of the network. But the *guard interval* is the main reason enabling an SFN network to avoid interference in the overlapping zones where signals from more than one transmitter are received.

The guard interval is the time interval, after the transmission of each symbol, during which the transmitter does not emit any essential signal. This will allow echoes (reflections of the emitted signal, or, as in our case, signals from other isofrequency emissions of the same network reaching the receiver with a certain delay) to extinguish themselves before transmitting the next symbol. So, receivers are not disturbed by a possible "overlap" of symbols that could make the received signal impossible to demodulate, even if its level is sufficient or good.

The longer the guard interval, the greater the time allowed to extinguish unwanted echoes, but the lower the quantity of data that can be transmitted (bit-rate – number and/or quality of programs). The guard interval can be set from few microseconds to over 200 microseconds, which means that it can be set so that the system can tolerate reflections/signals coming from other transmitters located a few kilometers, up to about 70 km away. (Remember that electromagnetic waves propagate at the speed of light; i.e. they travel about 300 m in 1 microsecond.)

When choosing 2 K IFFT (OFDM modulation with 1705 carriers), being the symbol rate higher than 8 K (6817 carriers), the possible guard intervals have a shorter duration, being always expressed as a fraction of the duration of the symbol time (1/4; 1/8; 1/16; 1/32). For this reason, guard intervals in SFN networks is normally used an IFFT = 8 K.

Proportion between the length of the guard interval and the symbol duration	Length of the guard interval with 8K IFFT	Equivalent distance with 8K IFFT	Length of the guard interval with 2K IFFT	Equivalent distance with 2K IFFT
1/4	**224 µs**	**67.2 Km**	**56 µs**	**16.8 Km**
1/8	**112 µs**	**33.6 Km**	**28 µs**	**8.4 Km**
1/16	**56 µs**	**16.8 Km**	**14 µs**	**4.2 Km**
1/32	**28 µs**	**8.4 Km**	**7 µs**	**2.1 Km**

Furthermore, it is also possible to set the transmitter's emission delay of the Transport Stream, in order to have the transmitters' signals reaching the interference zone at the same time and thereby to reduce the length of the guard interval necessary to avoid reception disturbances.

In summary, to implement a SFN network:

- The Transport Stream must be generated by a suitable Multiplexer which, beside being locked to a GPS receiver in order to ensure the precision of the frequency of generated data, inserts the Megaframe Initialization Packet (MIP)
- All transmitters must be set up and locked to GPS receivers
- Network planning (choice of power and location of transmitters, radiation patterns of antenna systems, etc.) must be performed to reduce to the minimum possible the interference areas
- The network must be “optimized,” by adjusting the delay of the Transport Stream emission time of each transmitter, in order to keep differences in the interference zones to a minimum.

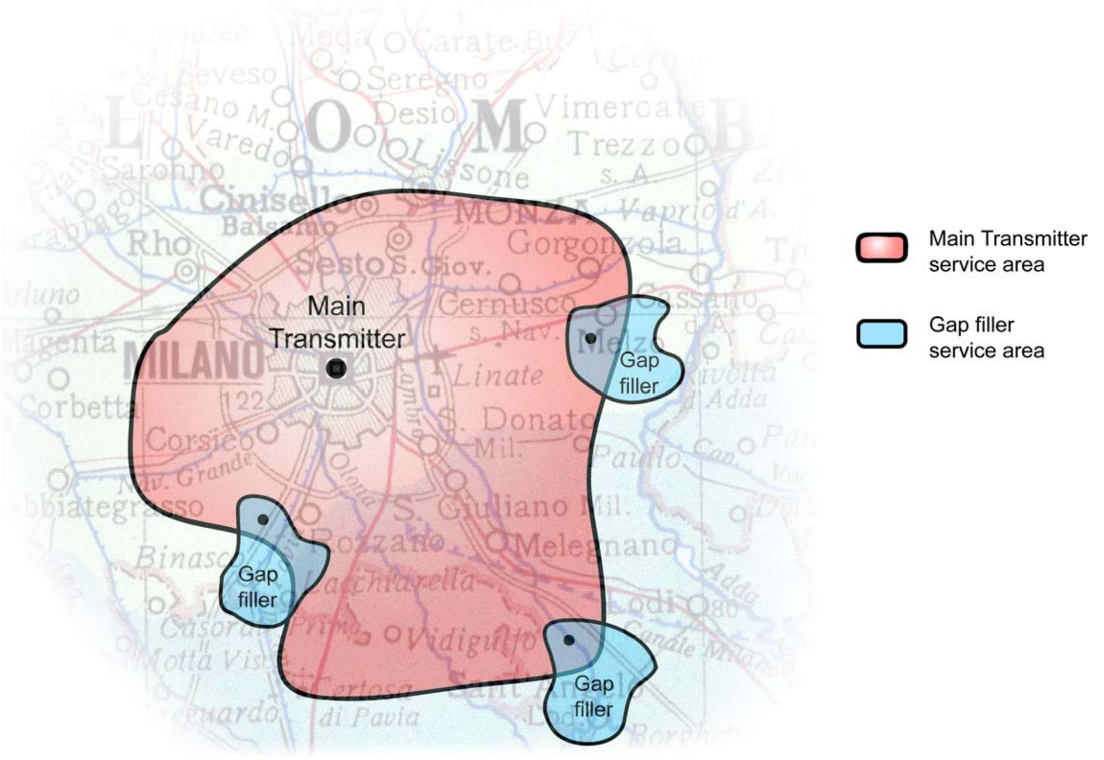
The Gap Fillers

Another very important technical opportunity made available by digital OFDM DVB-T broadcasting is the possibility of covering, in the receiving area or at its border, zones in which signal reception is difficult or impossible (for example, small valleys, the shadow cone of a small hill or a building, in tunnels or even inside a building).

Gap Fillers are, in practice, low power, small and extremely simplified transposers, that receive and transmit on the same channel, hence without occupying different or additional frequencies with regard to the main transmitting channel.

Technically, their emission can be compared to that of another transmitter in an isofrequency network (SFN), without all the costs and the related troubles. As a matter of fact, they exploit the advantage of the robustness to reflected signals, conferred to OFDM by the guard interval.

The technical limit of Gap Fillers -- repeaters working on the same channel -- is represented by the isolation achievable between the transmitting and the receiving antennas. In case the transmitting power is too high, the Gap Filler will auto-oscillate, hence particular attention must be given to properly space out and locate the transmitting and receiving antennas in order to ensure the maximum isolation possible, and, for this reason, to be able to transmit with sufficient power.



Service area of the main transmitter and of the Gap Fillers which cover border areas and/or areas in which reception is difficult

As an example based on real data, assuming to have 80 dB isolation between the transmitting and receiving antennas, using a good directive receiving antenna with a good gain (for example, 15 dBi), and receiving a –40 dBm signal (corresponding to 67 dBµV), the output power of the Gap Filler can be reasonably set to about 1W. Depending on set parameters 1 W power of a digital DVB-T transmitter, can be compared with 100 W of an analog transmitter.
Technically, ABE Elettronica S.p.A. realizes Gap Fillers in different ways, depending on power level and application:

- “Professional” Gap Fillers, double conversion type, with a SAW IF filter and various output power levels, up to 10 W
- “Simplified” Gap Fillers, with an input filter or broadband, without conversion, and with output power up to few hundreds of a milliwatt

Please note that a SAW filter introduces a delay (normally about 1.5 µs) that however is not significant in regard to what is tolerated by the guard interval, especially if it is adopted the IFFT 8 K.

Hierarchical Modulations

The use of hierarchical modulations enables a system to transmit concurrently, with the same transmitter and on the same channel, two Transport Streams with different programs. The first, called “primary” or “high priority,” normally with a low bit rate, is easier to receive; actually it is receivable also in conditions of low and/or disturbed signal – for instance in mobile reception or at the boundaries of a service area. The second, called “secondary” or “low priority,” normally with a higher bit rate, can be received only in good conditions; for instance, with an adequate fixed receiving antenna and a good signal level.

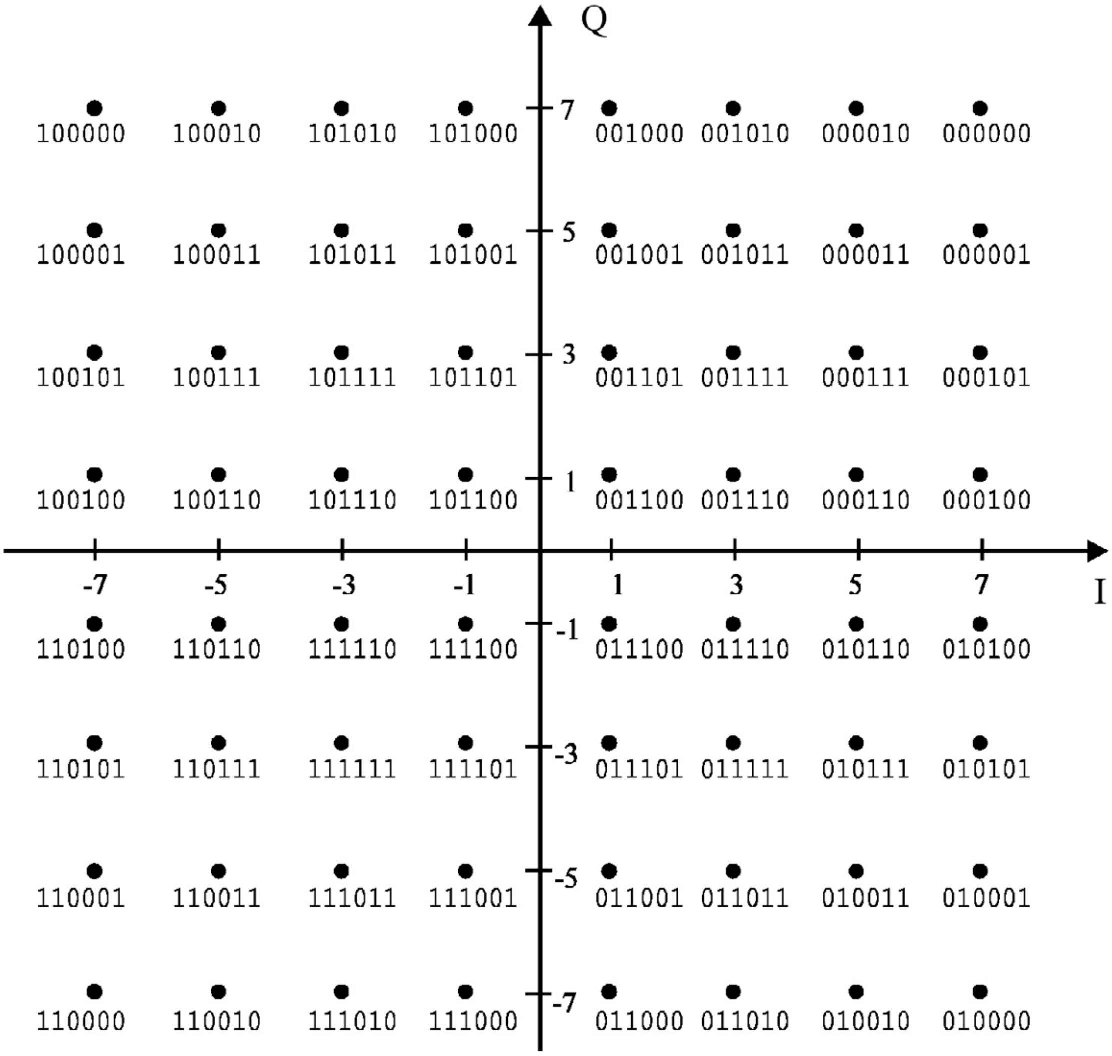
According to the DVB-T standard, explained above, an OFDM modulation is formed by various carriers (1705 or 6817, all equally spaced, from less than 1 kHz to over 4 kHz, depending on the width of the occupied channel), each one modulated according to the QPSK, 16-QAM, or 64-QAM scheme.

With hierarchical modulation (that can be only 16-QAM or 64-QAM) the primary Transport Stream defines only the quadrant of the modulation symbol (as if it is a QPSK modulation scheme). The secondary Transport Stream defines, within the quadrant set by the primary Stream, the exact position of phase and amplitude taken by the symbol.

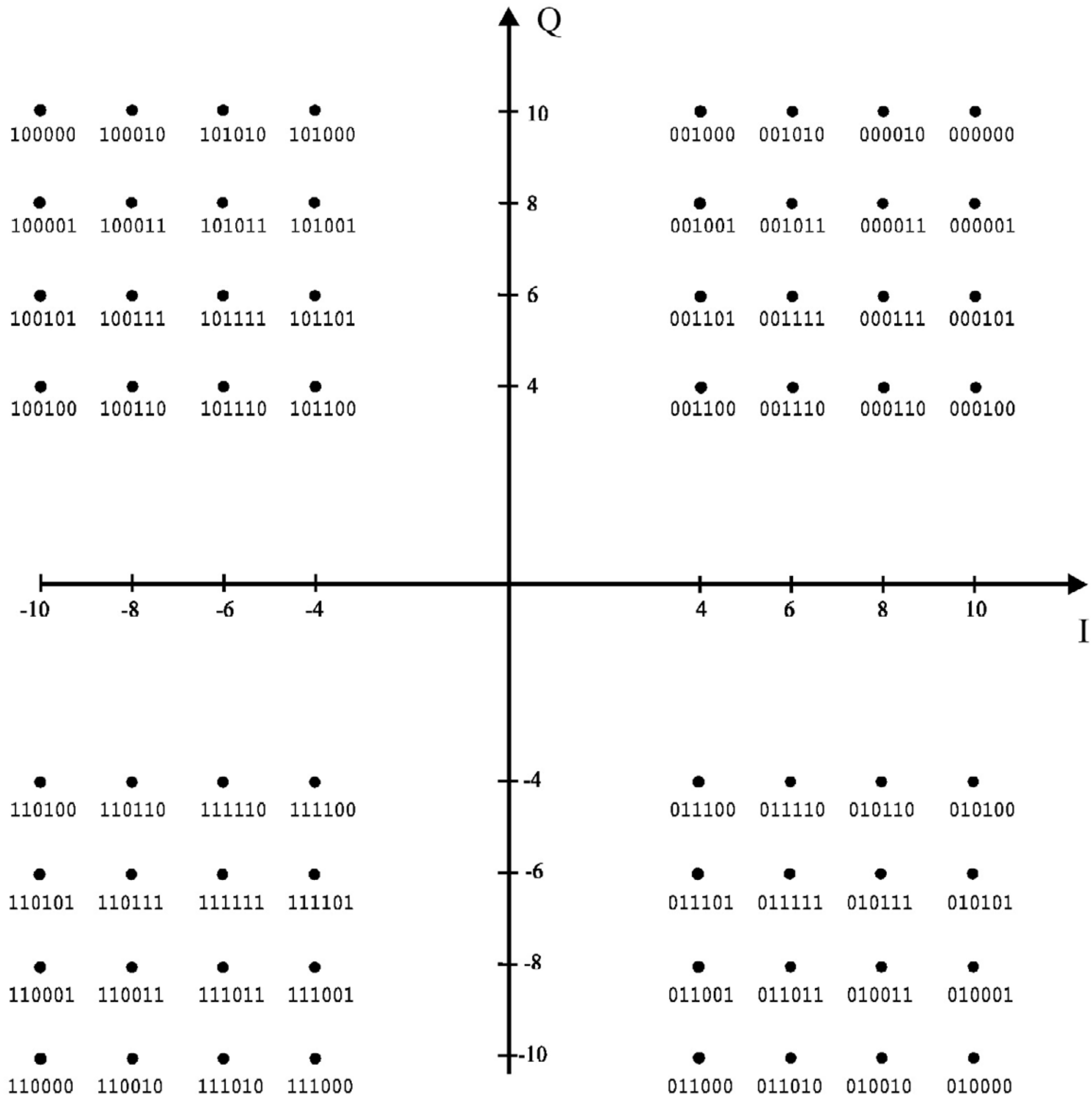
In this way, in spite of using a 16-QAM or 64-QAM modulation, the primary Transport Stream has a modulation robustness almost similar to that of a QPSK. Furthermore, it is possible to chose different error correction codes (code rates) for each Transport Stream, in order to find the best compromise between the available bit rate and the “robustness” (i.e. immunity to noise, disturbances etc.).

In hierarchical modulations it is also possible to define the uniformity degree of the modulation constellation; such a degree is called “α” and can take the values 1, 2 and 4. It is possible, in practice, to decide to adequately space the symbols from the axis of the constellation, in order to further facilitate, in the receivers, the decoding of the primary Stream (but to the detriment of the secondary Stream).

To get a concrete idea of the differences between the primary and the secondary Stream, please consider that, depending on parameters chosen, the minimum reception levels can reach a difference up to about 20 dB (that is like the primary Stream transmitted with a power 100 times higher compared to the one of the secondary Stream).



Constellation diagram for 64-QAM modulation scheme, α=1



Constellation diagram for 64-QAM modulation scheme, hierarchical, non uniform, α=4

"Digital ready" Broadcasting Transmitters: their digital implementation and double use

Especially over the last period, broadcasters have required, whenever reasonable, to convert their own analog transmitters into digital. This opens the possibility for double use of the same equipment, alternatively in analog operational mode, during part of the day, and in digital operational mode in the rest of day. This request generally comes from the need (given the impossibility of occupying additional broadcasting channels) to carry on analog broadcasting in order not to lose audience and, at the same time (generally during night hours), to experiment with digital technology in order to verify its results.

Broadcasters will eventually move to digital broadcasting as the only operational mode as soon as most users have installed the appropriate receivers (digital decoders).

Differences between analog and digital transmitters and possible changes for implementing digital operational mode in existing analog transmitters are treated in the "DIGITAL TV BROADCASTING HANDBOOK." Please refer to this documentation, which can be downloaded from ABE Elettronica's web site (www.abe.it) at the address http://www.abe.it/PDF_Tech/DTVB_Handbook.pdf.

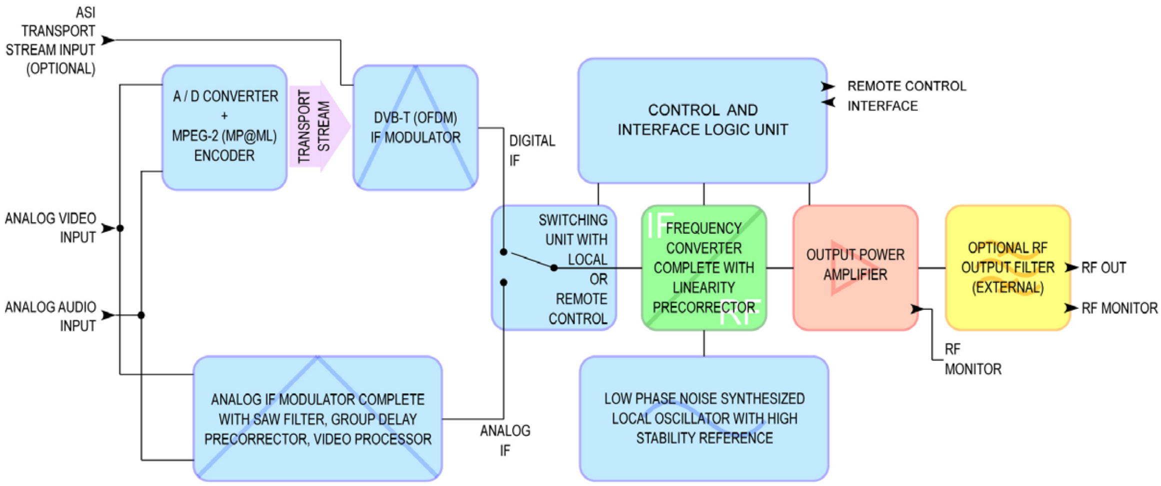
These are necessary considerations for Double Use:

- The driver of the transmitter must have both modulators (analog and digital), with a switching system preferably remote controlled.
- The frequency converter must use a low phase noise local oscillator, capable of the better performance required for the conversion of digital signals.
- When switching the operational mode, it must be possible (hopefully automatically) to set/adjust the output power of the transmitter and the linearity pre-correction, since parameters used for the analog operational mode are seldom likely to be the same for the digital one.
- The power amplifier must be sufficiently linear to be suitable for both modulation types; hence, even using different parameters of output power and linearity pre-correction, both the analog specifications (for example: inter-modulation) and the digital ones (for example: MER) must be met. It has to be pointed out that the nominal "analog" power of the amplifiers (peak video power with combined amplification of both video and audio carriers) must be reduced for digital operational mode of a percentage that normally is between 50 % and 75 % (-3/-6 dB).
- If the output filter used is the one normally employed in digital transmitters (namely a pass-band filter with 6 cavities for the "non critical" RF output mask), it introduces a significant group delay that can be accepted in digital

operation, but requires a pre-correction in the analog mode. In the latter case it is necessary to provide adequately in the IF analog modulator.

- If the output filter employed is the one normally used in analog transmitters (3 or 4 cavities band-pass filter with 2 notches), it is generally not sufficient to comply with the “non-critical” mask of the ETSI EN 300 744 standard. However, it has to be pointed out that the specified mask is applicable only in cases of digital transmitters co-sited with analog transmitters working on adjacent channels and having the video peak power equal to the thermal output power of the digital transmitter. This is a really unusual situation, because the power normally used in digital broadcasting is lower than the analog power, and the case of transmitters on adjacent channels in the same site is not frequent. In other situations, the ETSI standard foresees milder or even no specification. Hence, in many cases, the band-pass filter with 3 or 4 cavities and 2 notches, can also be used for digital operation.
- For transmitting in double operational mode (analog and digital), in the transmitter site it is necessary to have both the analog audio/video signals and the digital Transport Stream. This implies the use of digital microwave links with the receiver/decoder having both analog and digital outputs, or to have the MPEG-2 encoder in the transmitter site or embedded in the transmitter.

In order to ease the transition of TV broadcasting from analog to digital (and facilitate experimentation) all ABE terrestrial broadcasting transmitters can be implemented with an automatic switching of the operational mode and simultaneous change of output power and linearity pre-correction parameters. Furthermore, ABE manufactures MPEG-2 encoders, multiplexers and digital microwave links in order to make available complete and compatible solutions.



Block diagram of the ABE "DTX-DX" transmitter, with dual operating mode (analog and digital DVB-T), complete with MPEG-2 encoder

TV Transmitter VHF – UHF Analogue + Digital DVB-T mod. DTX-DX

A specific solution of great interest is the ABE **DTX-DX** series.

The series is ultra-compact equipment aimed at keeping to a minimum both the technologic and the economic impact in the transition to digital terrestrial broadcasting. The transmitter (low power, contained in a single 19" 3U rack chassis) can be used both as a driver for existing systems (transformation and double use of analog transmitters) or as a small transmitter in its own right.

It is a single piece of equipment with analog audio and video inputs and analog or digital RF output. The operating mode can be switched either on-site or remotely. The system includes a built-in analog-to-digital audio/video signal converter, the MPEG-2 (MP@ML) Encoder and the Digital (DVB-T) COFDM Modulator; also the analog version. When switching the operating mode, the equipment automatically recalls different settings for output power and linearity pre-correction.

Signal levels needed for digital reception: comparison with analog reception

For receiving analog television signals the International Radio Consultative Committee (CCIR) has defined, in its Recommendation 417, the minimum signal levels for television services. Such levels are relatively low: for example in UHF band 5 the minimum field strength level is 70dBµV/m that corresponds, using a 10dBi gain antenna at 700MHz frequency, to a received signal level of about 500 µV (0.5 mV, that is 54dBµV). Actually, this level is not high, but just sufficient to get, with a good receiver, a picture not particularly noisy.

In normal cases, the received signal levels are definitely higher.

Anyway, if an analog signal has a smaller level, it will be still received even if degraded (noisy – with “snow” on the screen).

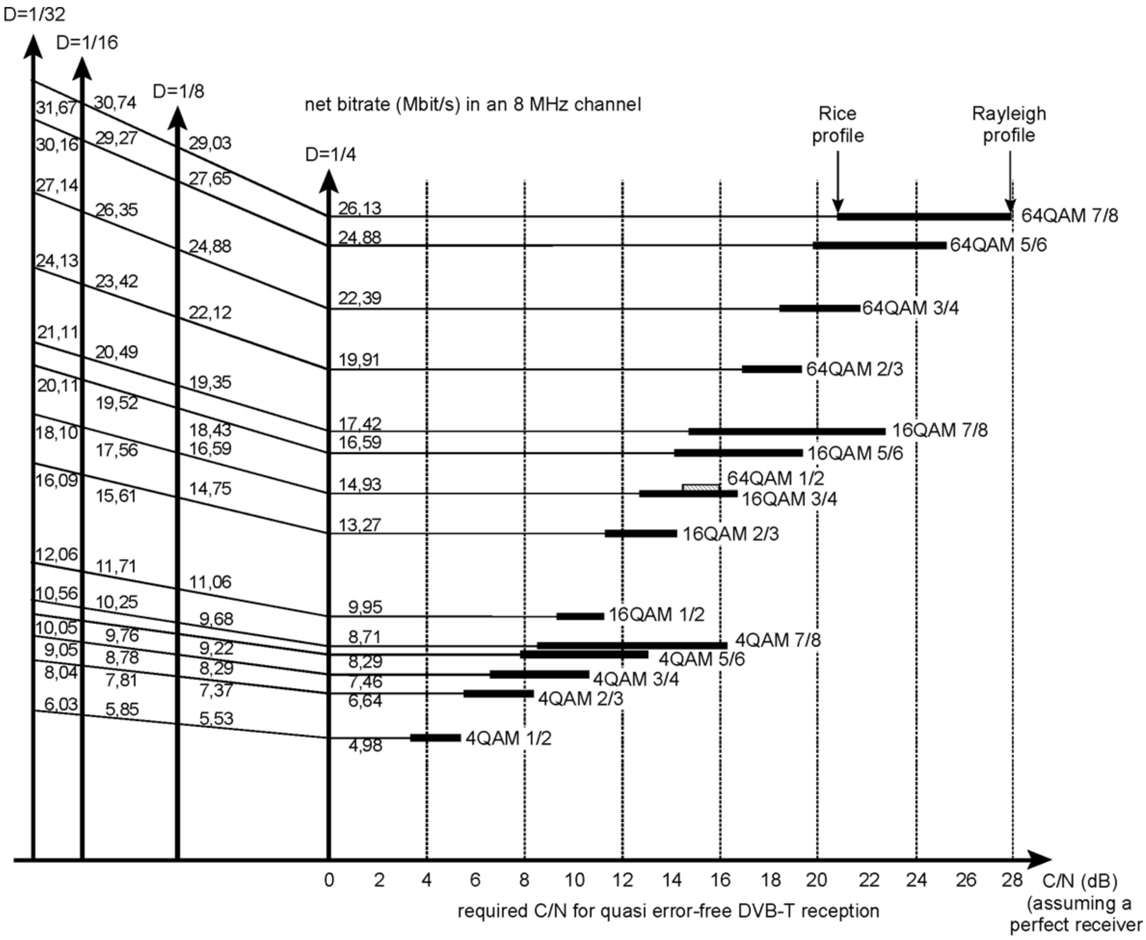
Reception of digital signals remains perfect up to a minimum limit (threshold), below which the signal cannot be demodulated any longer; it “disappears.”

The minimum level of an OFDM (DVB-T) digital signal necessary to be received depends on the type of modulation selected (QPSK, 16-QAM or 64-QAM), and on the error correction code used (code rate – 1/2, 2/3, 3/4, 5/6, or 7/8). As usual, the choice of modulation schemes and of correction codes that enable to transmit higher bit rates (hence more programs, of better quality), requires, in reception, higher signal levels.

In order to give some limit examples, it is enough to remember that using QPSK modulation with code rate 1/2 the receiving level can be about 20 dB lower than using 64-QAM modulation with a code rate 7/8; unfortunately the bit rate of the input Transport Stream, in the first case, will result lower for about 80%!

To carry on the comparison with the analog example, let’s assume that we intend to receive, on the same frequency, an OFDM emission (8MHz bandwidth), 64-QAM modulated with 2/3 code rate and a 1/32 guard interval (hence with a transmitted bit rate over 24MBit/s, capable of carrying, for example, 4 high quality television programs). This requires a received signal strength of about 51dBµV/m, that is 19dB lower than what is requested for the analog reception!

Therefore, in equal conditions, digital transmitters could have considerably reduced power. In digital experimentation, in the case of dual use of the same transmitter in analog mode and in digital mode, even if the power available in digital mode is 6 dB lower (1/4) then in analog mode, the coverage area certainly will not be reduced, but in theory strongly incremented. It is then to be evaluated if the transmitted power in digital mode should have to be furthermore reduced.



C/N and net bit-rate as a function of the constellation, code rate, guard interval length and channel profile for all DVB-T modes

Minimum signal-to-noise ratio necessary for error-free reception (assuming use of a perfect receiver), depending on transmission parameters chosen (modulation scheme, code rate, guard interval, bit rate of the transmitted Transport Stream). Please note that the guard interval affects only the transmitted bit rate, not the signal-to-noise ratio.

If we would like to receive the same digital signal while moving (for example in a car), the 64-QAM modulation scheme certainly isn't the best modulation scheme; we should reasonably use the QPSK one (thereby transmitting a lower bit rate), and even if the lowest necessary signal for the demodulation of the QPSK constellation is lower, the antenna for the mobile reception will usually have low gain. The reception will be disturbed as the vehicle will not always be in line of sight with the transmitting antenna, and therefore the transmitted power should not necessary be lower.

This subject is treated with a wealth of data in the Technical Report TR 101-190 of the European Telecommunications Standards Institute (ETSI), that can be downloaded from its site at www.etsi.org.

Notes:

Notes:

A D V A N C E D
B R O A D C A S T I N G
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