Transmission

Establishing a Digital COFDM Transmission Network

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With the advent of digital terrestrial television broadcasters and equipment manufacturers alike are facing new challenges. Although the ETSI standard defines very precisely the coding and modulation to be employed for the COFDM principle for TV transmission, a number of choices in the design of a transmitter system are still left open. Much interest is gathered around the new possibilities opened by the COFDM transmission method. One interesting aspect in a network layout is the possibility to operate within a Single Frequency networking system. Another interesting aspect is the possibility for mobile reception. This paper deals with typical solution for setting up a COFDM network. Emphasis is placed in systems supporting an easy and flexible interfacing between the distribution network and the TV transmitter. Solutions to both multi and single frequency network operation are presented.

Three systems for digital television are currently being tested in several countries. Two of the systems are based upon the OFDM principles for modulation. At three places the tests have been succeeded by an implementation phase. In Great Britain and Sweden the COFDM system is now in operation in larger scale. All the three digital transmission systems make use of the MPEG-2 system for encoding and multiplexing of video and audio channels (ref.1).

In USA the installation of a system using another modulation system is in progress. The system named ATSC modulates the digital encoded signal on a carrier using an 8 level amplitude modulation principle.

In understanding the background for the systems a few comments might be useful. For all systems the digital encoding of the video and audio signals is based upon the MPEG-2 principle. The choice of modulation system reflects an interesting difference in philosophy.

The driving power behind the European version of the digital system, COFDM, is the need for squeezing more TV programmes into a limited number of free TV channels. By the DVB-T standard 4 to 6 programs per OFDM channel are realistic depending of the type of multiplexer. Compared with the present PAL or SECAM system, the new system will support an advanced quality such as 16:9 format and stereo sound. The number of sound channels is sufficient to support at least a second language. Another matter of importance has been the ability to produce high quality noise free signals even in a mobile application in spite of reflections from building in a city. The system supports high definition Television as well, however; in Europe this aspect has been given a lower priority.

In the frequency planning low and medium power level transmitters are considered. The possibility to use single frequency networking for national programs is considered a very attractive feature.

For ATSC system the main objective has been to provide a wide screen high-resolution service of one or two programs from a broadcast organisation to the viewers. In the frequency planning typically one high power transmitter will serve the area of business. The modulation method used by the ATSC system is based upon the 8 level modulation principles; VSB shaped for 6 MHz Bandwidth (ref.4). This system is considerably simpler than the COFDM system, and the costs of set-top boxes and TV receivers for the system were estimated to be significant lower. However, the break through in chip design for the COFDM receiver system has put a question mark on the statement.

The drawback is that the ATSC system is very sensitive to echoes, and the systems ability to serve large cities with a high density of buildings has been questioned.

The COFDM principle

A simplification of the block diagram of a COFDM modulator is shown in fig.1. The input is the MPEG transport stream carrying not only the data from the encoded programs but also information about the program content, the number of programs and the condition for access. Before the OFDM modulation the signal is subjected to two error protection systems and a heavily interleaving process. The error protection and interleaving makes it possible in many situations to regenerate the signal even if the signal has been lost in certain fractions of time. Interleaving is a process in where the Bytes or even Bits are reordered in such a way that the information originally following each other in time is separated in time in a structured way. A disturbance in the transmission caused by a reflection or an electrical pulse noise could result in quite a number of Bits lost in the transmission. Later in the receiver the Bytes and Bits are re-arranged in the natural order. Thanks to advance level of interleaving used by the COFDM principle the lost bits or wrongly detected Bits are in the reception process so widely spread that it is possible for the error protection circuit to restore the signal (ref.2).

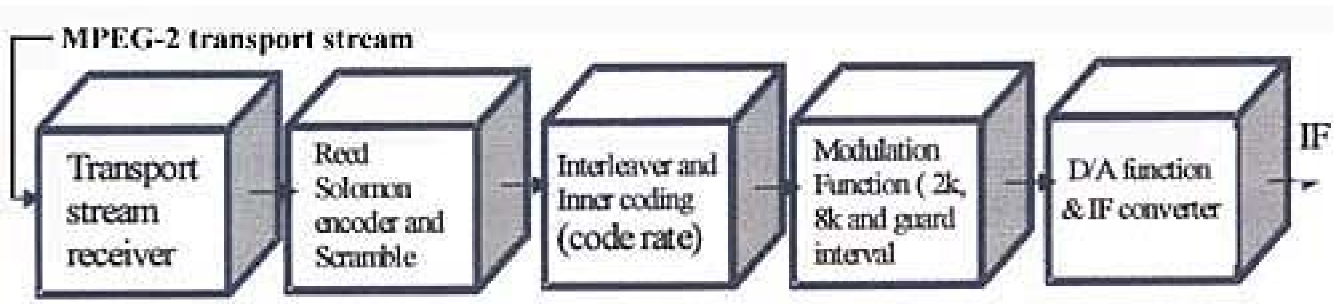

Figure 1 : Simplified block diagram of a COFDM modulator

As in several other digital transmission systems, for energy dispersion a pseudo random binary sequence is multiplied into the digital transport stream. Caused by Intermodulation in local antenna amplifiers or by Co-channel interference the COFDM signal can unwanted be converted into a channel carrying a PAL or NTSC channel. The energy dispersion minimises the visibility of such a disturbance on the TV screen

The modulation stage operates as an OFDM modulator. A number of carriers are modulated with the digital signal. Except for a few carriers used for receiver synchronisation each carrier transports a certain number of the Bits of the 'modified transport stream'. The original transport stream has been modified for transmission by the error protection, scrambling and interleaving. The carriers can be modulated using QPSK techniques, 16 QAM or 64 QAM principle. Two systems are in operation in Europe, one is using approximately 2000 carriers, and the other is using approximately 8000 carriers. The bandwidth is defined by the broadcast system and thereby the frequency steps between the carriers.

There are two strong facilities in the COFDM. One is the number of carriers, where each carrier is only carrying a part of the digital information at a very low bit rate. The other is the guard interval. During the guard interval the modulation rest stages of carriers representing the transmitted Bits are kept constant for a certain time (the guard interval), before the carriers are allowed to change to the new position. The Guard interval steals in a way capacity in Bit-rates, but there are benefits in robustness of the transmission to compensate for the losses.

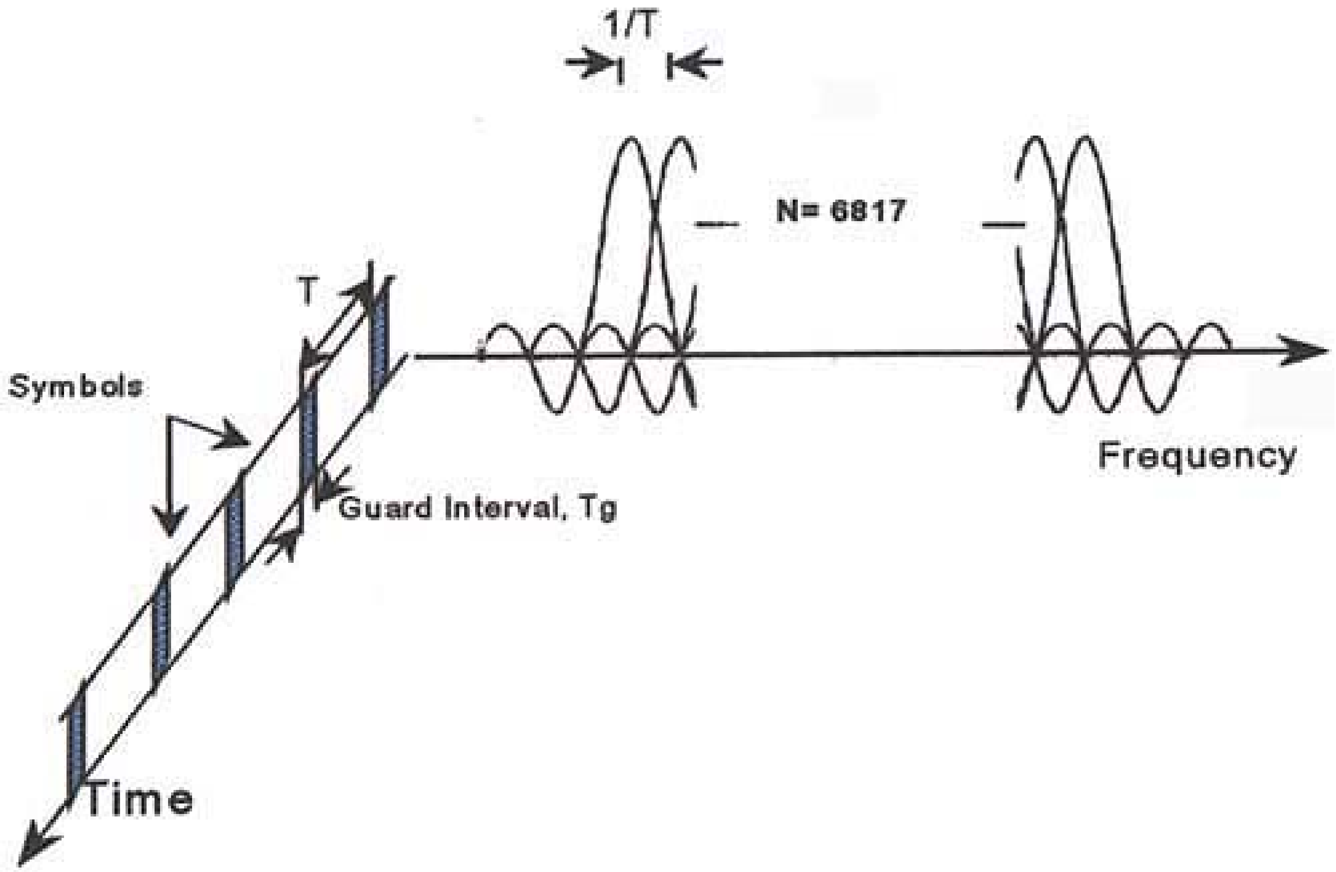

Figure 2 : OFDM signal in the 8 k version

It is easy to understand when the number of carriers is increased with the same Bit Rate in the transport stream that the guard interval can be proportionally increased. Central Europe, being a mountainous area full coverage has always meant installation of many transposers and transmitters together with a restrictive frequency planning. By the COFDM system and a network reference for time and frequency, it is possible for a country to implement full coverage by a network of transmitters operating on the same frequency. The 8-k system is the favourable system for such a network. The long guard interval allows the receiver to delay the decoding by the same time before the signal is decoded back to '0'and '1'. Echoes and even signals from transmitters operating at the same frequency have then in many cases 'died out' before the decoding takes place. As the influence from other transmitters in an SFN network is similar to an echo, the long guard intervals of the 8 k system make it possible to implement a network with relative few transmitters. In principle the 2-k network can obtain the same, however; the smaller guard interval the system will be less robust to echoes and the system will require a shorter distance between the transmitters.

In small-scale OFDM test the carriers could be generated as 'real' carriers and the modulation can be carried for each single frequency. The original description of the system suggests that systems using more than 10 carriers should generate the signal by a Fourier transformation.

This is today the most common method (ref. 3). By an Inverse Fast Fourier Transformation the envelope of the COFDM signal is calculated from the digital information about the carriers. The analogue signal is generated by a Digital to Analogue conversion. The envelope of the analogue signal represents the wanted multicarrier spectrum.

The COFDM transmitter

The OFDM systems presently in operation operate with a bandwidth of 8 MHz, even if new proposals for a 7 MHz and a 6 MHz system are being worked out. For the 8 MHz version, the output from the OFDM modulator part of the COFDM modulator is 32/7 or 64/7 MHz, (9,142857 MHz), the latter equals two times oversampling. For the transmitter the output is converted up to an appropriate IF frequency of e.g. 36.0 MHz.

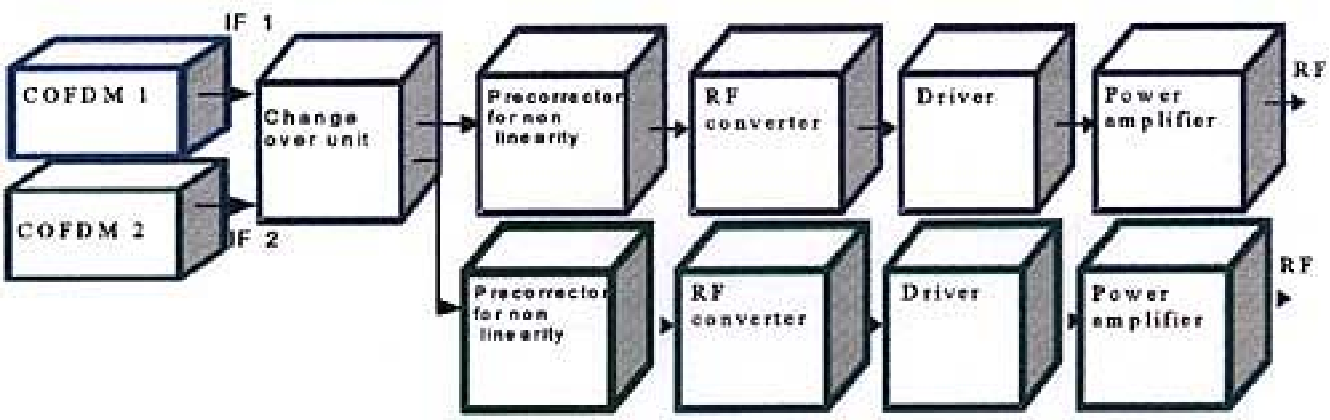

Figure 3 : The transmitter, shown with a redundancy system

However, during the initial phase broadcaster would often prefer to modify one of their analogue transmitters. For such a modification it is important to be aware that COFDM is very sensitive to phase instability and non-linearity. Most easy to modify is transmitters using one of the more linear output devices such as the LDMOS, the Dicroid and the IOT. The IF will typical have to changed to 36.15 MHz. Even if the 36.00 MHz is more in line with the new RF specification from the ETSI standard, the IF of 36.15 MHz will match the transmitter to the correct RF OFDM frequency.

The next modification is adapt the transmitter to the Back-off. In the OFDM processing we operate with the Back-off figure. The Back-off is the level in dB between the average RMS level and the absolute peak level. In a professional COFDM modulators the operator can set the Back-off. For a 64 QAM signal we will recommend 12 dB, QPSK modulation could manage a lower level even down to 6 dB. The transmitter must in its analogue part support the same headroom.

A few times during transmission the COFDM signal will exceed the 12 dB ratio, e.g. the event where all carriers add in time. In the COFDM modulator the limitter function and filter procession must be designed to deal with this situation. If not proper designed the COFDM modulator would generate a lot of the sidebands during such an overload. By the way, events with a level over the 12 dB comes so seldom that the error correction system should be able to handle them as well as 'normal' transmission degradations

To summarise, an analogue transmitter will be able typically to output a COFDM signal at a RMS level at a level 10 dB below the sync level. Please be aware that we talking about the level of the COFDM signal measured by a RMS power meter, as a spectrum analyser would not give the full story. The RMS level depends of the phases of all the carriers. Some COFDM modulators like the one from ProTeleVision Technologies have a test signal consisting of a single carrier. The single carrier signal is generated to have exactly the same rms level as the average COFDM signal. Such a test signal makes it possible to use a spectrum analyser instead of the more troublesome a 'Real RMS power meter'.

To support integration in the transmitter COFDM modulators are now being produced with a digital pre-corrector. Such a corrector together with the present correction found in transmitter will typically improve the IM performance with 3 dB. The IM performance can easily be measured by means of the shoulder level.

A few companies are now following up the success of a digital preconception. From a theoretical point of view, the idea of a full I&Q digital pre-correction instead of a partly digital and a partly analogue (the analogue already existing corrector) is a very attractive item. However, the system requires that the resolution in the digital processing is increased and the bandwidth extended all through the transmitter. The complexity and cost involved in a full digital corrector had put constrains to the solution, alternatively a solution can be designed accepting some limitations in performance.

Another aspect is frequently a subject for the discussion .The COFDM system can transmit up to 6 channels, often we meet concerns on redundancy. Fig. 3 shows a proposal for such a system. Each of the sections of the transmitter is monitored by a COFDM demodulator. Loss of level or bad BER will activate the changeover system.

The COFDM network

In the transmission centre the programs are encoded in the MPEG 4:2:0 format and multiplexed together. The multiplexed signal is send to the various transmitter sites by cable, microwave link or satellite or a mixture of all methods. On the transmitter station the transport stream is COFDM modulated on an IF carrier in the OFDM modulator and fed to the high power part of transmitter. In the high power part the signal is converted to the RF frequency and amplified in the Power stages before it is fed to the antenna. In a multi frequency network the transmitters are operated on different channels to prevent interference.

>Defined by the modes, protection/constellation/guard interval, the OFDM signal carries a fixed Bit Rate, e.g. 64 QAM code rate 2/3 and guard interval 1/32 equals a rate of 24.13 Mbits/s.

In the basic network system, when the network operator has decided for a certain COFDM configuration, the multiplexer and encoder system must be set for this Bit Rate. Locking the clock frequency of the OFDM modulator to the multiplexer prevents overflow or underflow. The network system must be neutral in respect to transmission between the multiplexer and modulator.

A better system can be obtained by including in the OFDM modulator input circuit a Transport Stream Adapter. First the TSA module removes stuffing bytes from the received transport stream. Secondly it measures the Bit Rate and compares the value with the capacity of the chosen COFDM mode. If required the TSA module will insert new stuffing to adapt the transport stream to BIT rate.

The system benefits by the following:
1. Synchronisation between Encoder/Multiplexer and COFDM modulator is not required. The capacity of the COFDM modulator just has to be equal or higher than the effective transport stream.

2. It is relativly simple to add locally a remultiplexer for insertion of a local program, as the TSA module takes care of the synchronisation between the multiplexer and the OFDM modulation.

The Single Frequency Network

In this network all transmitters in the SFN area are on the same channel with the same program and they output the same signal at the same time by using the same transmission mode.

Timing and frequency accuracy is very important. In the area where the transmitters overlap it is important that the guard interval is able to absorb the differences in time, as one transmitter can be seen as an echo signal into the other transmitter main coverage area.

Timing in the network is most easily being carried out by using the Global Positioning Satellite system. On the market, there are professional GPS receivers, which output a 10 MHz reference - and a 1 pulse per second signal, both signals are locked to the same source and are controlled by the GPS system.

For the overall control an SFN adapter unit (see fig. 6) is introduced at the broadcast centre most convenient near the Multiplexer site, as SFN adapter and multiplexer can then be locked to the same GPS receiver. The SFN adapter inserts general time information and local information to each transmitter in the network. The SFN adapter groups the transport packets in a Megaframe and inserts a Megaframe Information Packet. This MIP data packet carries information to transmitters on OFDM modes, timing information and it can also be used to include individual information to the transmitters, e.g. timing and frequency offsets. (ref.5).

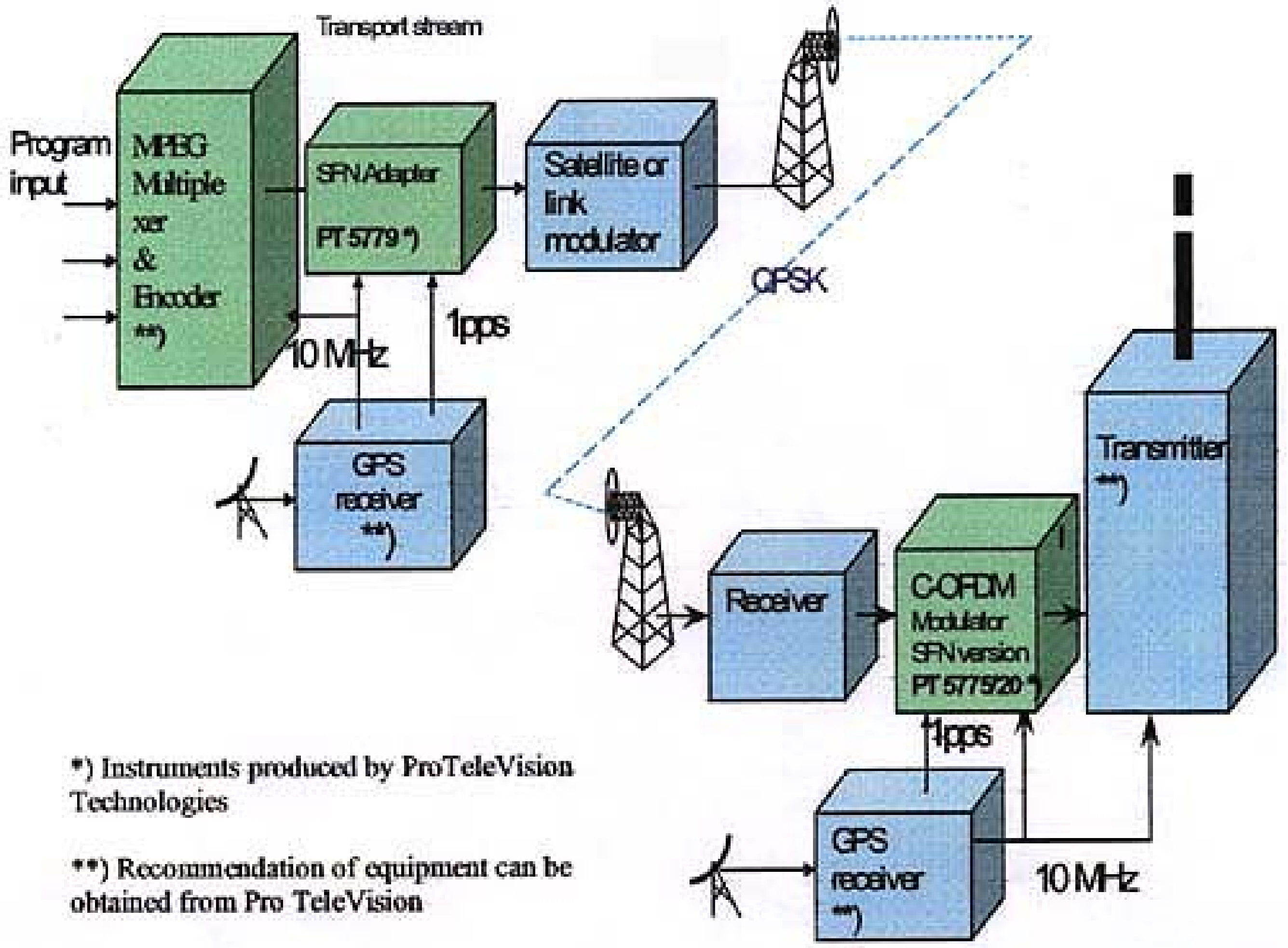

Figure 4 : The SFN networking system

Fig. 4 illustrates the SFN network. At the centre the MPEG transport stream is fed the SFN adapter. The SFN adapter from ProTeleVision includes the same input module as the one used in the MFN version of the COFDM modulator. This module allows the same degree of flexibility between the multiplexers and the SFN adapter as discussed in the paragraphs dealing with the MFN networking.

In each of the COFDM modulators in the SFN network an input SFN card is installed (see fig. 7). The card reads the information in the MIP packets and generates the control signals for setting the modes of the modulator. By means of the 10 MHz signal and the 1 pps the input card is able to generate an accurate clock reference. The timing module controls the time for the transmitter to output the signals. For this function the module receives information from the MIP packet, the clock system and the master control system ODFM. The latter information represents the own delay of the instrument.

The SFN input card allows the operator to insert a delay offset in up to +/- 100 microseconds. With the equipment from ProTeleVision Technologies the operator can either insert a local delay at the transmitter station by means of the front panel of the instrument or remotely via the SFN adapter. The latter requires that the operator has activated an ID function in the COFDM modulator and hereby named the transmitter When using the SFN adapter, the local delay information is conveyed to the transmitter by a specific data-slot in the MIP packet. This data slot is reserved for local transmitter information and includes an ID information for the transmitter.

In fig. 4 a digital microwave link network is used to distribute the signal to the various transmitters. Other methods are satellite feeding or high-speed SDH network via e.g. optical cables. For SDH network, it is important that the operator is aware of the constraints in such a network. SDH networks makes use of an interface system defined by the G703 standard. SFN operation requires in general that the SDH interfaces are designed to respect the ATM protocol. As the ATM cell structure takes up capacity, some networks have been designed without the ATM. ATM will make sure that the time relations between a data packet entering the network and the output is kept constant. An ATM structure will support SFN operation.

Setting up an SFN network

In spite of the excellent idea of the SFN operation, the system can be difficult to set up properly. The main objectives are frequency and timing accuracy.

An SFN adapter is inserted at the broadcast centre together with equipment for servicing the network with a common reference for timing and frequency locking. As mentioned earlier the Global Positioning System comes in very handy for such a function. From setting up the system we experienced following:

> 1. For the operator it is a great help, if the modulator automatically includes its own delay in the calculation of the time to transmit the signal. Some modulators on the market seem not to include this function and it can cause some confusing in setting up a network, if different equipment is used at different location.
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> 2. A network delay can easily be from 20 microseconds and up to several milliseconds. if satellite distribution takes part of the network. A capacity in modulator for a max. delay of up to 1 sec. delay is recommended. As in an SFN network most modulators can add a local plus or minus delay, the best setting for the adapter seems always to set for a delay longer than the total network delay. 3. Local delay on the transmitter site must be adjusted for best performance in areas, where one can receive signal of equal strength from more than one transmitter.

Point 3 represents some difficulty. The idea is that the receiver should synchronise to the strongest signal and the other signal should then fall as an echo within the guard interval. In the areas where there is equal field strength the situation can change within a short distance.

The delay between the transmitters can be fine adjusted by observing the received signal with a spectrum analyser. A heavy ripple on the top of the spectrum would indicate a time difference; e.g. a ripple of 100 kHz equals a delay difference of 10 microseconds.

Lately professional receivers offering a test mode for SFN have been introduced. The receiver has a channel impulse response output which can be fed to an oscilloscope and displayed versus time. Other transmitters in an SFN network and reflections, which is received by the receiver, will show up on the display with a certain delay.

Systems for mobile reception

A very interesting application for COFDM is the ability of the system to support mobile reception. Reception of TV signals in buses and trains could have an important commercial interest as frequent travellers appreciate information related to traffic and news during their journey. Combining this information together with some kind of entertainment and commercials might please the passengers.

Mobile reception represents other technical problems than the fixed reception. The first compromise is to accept a lower capacity of the transport stream for getting a higher degree of protection. For instant the modulation types should be limited to 16 QAM or QPSK and the Code Rate should be adjusted for better protection. The Code rate refers to the 'depth' of the Viterby/Trellis protection, COFDM operates with 1/2, 2/3, 5/6 and 7/8. 1/2 represents the highest degree of protection.

Mobile reception over a larger area or at a difficult area in a city with high building will phase problems with reflections and signals from other transmitters. A high level of the Guard interval is preferable. The '8k' IFFT mode offers 4 times the guard interval than the 2 k.

However, as experienced by the author during tests in Singapore, it is possible by a careful control and adjustment of timing to operate a system with a guard interval of just 56 microseconds.

The selected modulation code rate and guard interval equals for mobile reception a capacity as shown in the table below.

Modes (code rate 1/2, guard interval 56 microseconds)	16 QAM	QPSK
2k	Capacity: 9.95 Mbit/s	Capacity: 4.98 Mbit/s
8k	Capacity: 11/71 Mbit/s	Capacity: 5.85 Mbit/s

Compared with maximum capacity of COFDM at 31.67 Mbit/s the mobile reception represents quite a reduction in capacity. It should not represent any problem as only one program is transmitted for a mobile application. However, in Germany, there are tests going on, combining mobile reception with stationary reception. By using a speciality in COFDM, the hierarchical encoding, the two applications can be combined. Hierarchical encoding means that the constellation display is modified in such a way that in principle the system is a QPSK system with a cloud of points representing the remaining of the 64 QAM.

The system depending on the modification of the constellation (called ï•¡ in the ETSI draft) degrades with a certain degree mobile reception and stationary reception.

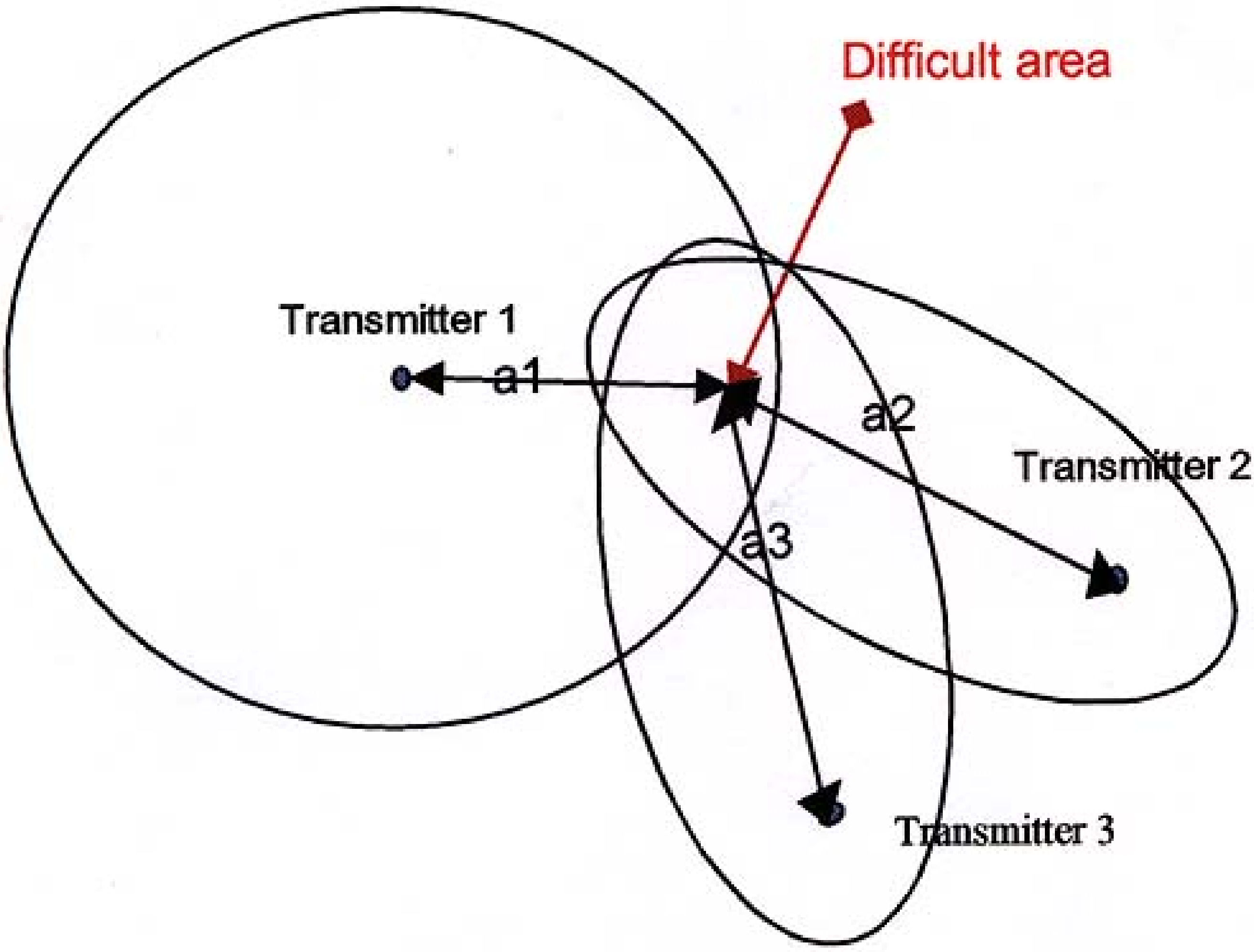

Figure 5 : Transmitter layout for mobile transmission in Singapore

In the Singapore trial we used for the final tests three transmitters. Two were placed at two hills, Bukit Batok and Bukit Bedok, the third transmitter was placed at the World City. The transmitters were at lower power, the main idea was a good coverage at the centre of the city

The transmission mode was IFFT 2k, QPSK mode. Code rate 1/2 and guard interval of 1/4 were used for highest protection. The channel frequency was 603 MHz. The 2k were selected only due to the lack of proper 8 k receiver equipment.

In principle 2 k should be better for mobile reception due to the bigger distance between the carriers, in practice it does not matter very much because the Doppler effect at 60 km is some 30 Hz.

The reduction of the guard interval by the 2 k was a subject for discussion. Two steps helped us. One was an improvement in the modulator systems reflecting a considerable reduction in the time inaccuracy between two transmitters, the other was a measurement carried out in the 'difficult' area in system 10. Local delay was set for best performance in the area. During the tests it was detected that a 'three transmitter system' has its benefit. Two transmitters at the area of equal field strength will generate maxima and minima very locally. In some areas the buildings will act as 'slave' transmitters, but there are some areas which could cause very local effects when the vehicle is moving at very low speed. The third transmitter helped quite a lot in Singapore, where the goal was to cover the bus route 7, which passes through the central part of the city.

The antenna, a flat panel, was placed on the roof of the bus. Six flat panel displays, three at ground level and three at the top, supported viewing of the picture. A stereo audio channel system was been installed. The audio was also transmitted on an FM carrier for those who wanted to use portable FM receivers.

Conclusion

The COFDM system offers an effective, flexible and a high quality solution for a digital TV transmission. By including a transport stream adapter the flexibility of the system can be improved.

The test in Singapore indicated that SFN operation could support mobile reception. Compared with the US system reception of COFDM in all larger cities over the world for mobile transmission to public transportation represents a new opportunity for TV programmes and commercials.

Not only from the Singapore test, but confirmed from several tests in Europe, COFDM can be implemented relatively easy in most of the transmitter types. The best way forward is to select a relative linear transmitter and use only moderate precorrection. However, this means that compared with an analogue transmitter the power has to be reduced by 10 dB. But we should also be aware that the OFDM principle uses the spectrum in a more effective way than any of the analogue systems used today.

References

1. Generic coding of moving pictures and associated audio, ISO/IEC JCT 1/Sc 29
2. ETS 300 744 Specification for Digital Video Broadcasting, 1997
3. J. Salz and S.B. Weinstein: Fourier Transform communication system, Ass. Computer Machinery conference 1969.
4. Robert Hopkins, Digital Terrestrial HDTV for North America, EBU technical review, nr. 260, 1994.
5. TS 101 191, 1997-04, Digital Video Broadcasting; DVB Mega-frame for single frequency network synchronisation.

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