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DIGITAL BROADCASTING SYSTEMS INTENDED FOR AM BANDS

(1995)

1 Introduction

In the last decades, very few innovations have been brought to radiobroadcasting techniques in AM bands (150 kHz - 30 MHz). The simplicity of the receiver has always been a great asset to amplitude modulation, and because of their long range, these AM waves sill stand as best suited to national and international broadcasting.

However, under typical conditions of propagation such as ionospheric instability, a classical analogue system may provide poor quality reception.

The technical developments in the other frequency bands of sound-programme broadcasting and also political changes have resulted in the situation that the AM bands have evidently lost their practical and strategic significance to a large degree.

The poor transmission quality inherent in AM transmission is mainly characteristic of the modulation procedure rather than of the frequency band. If amplitude modulation is replaced by a digital modulation procedure, we can achieve a very good transmission quality and at the same time retain the long range of the transmission. However, The digital transmission has to fit into the existing channel pattern.

Digital transmission is suitable not only for sound-programme broadcasting but also for the transmission of additional information and for data transmission in general (value-added services).

2 AM channel characteristics

AM bands include long waves (LF, 150 to 285 kHz), medium waves (MF, 525 to 1605 kHz), short waves (HF, 3.3 to 26 MHz).

The characteristics of AM channels vary considerably depending on the frequency bands:

LF: 150 - 285 kHz, channel width 9 kHz; ground-wave propagation, little interference by sky-waves.

MF: 525 - 1 605 kHz, channel width 9 kHz or 10 kHz; propagation during daylight hours: as LF, but shorter range. Propagation during night hours : ground- and sky-wave propagation and, as a consequence, strong interference.

HF: 3.3 - 26 MHz, channel width 10 kHz (DSB); 5 kHz (SSB), sky-wave propagation.

The ionosphere is a dispersive propagation medium which is characterized by the presence of multi-modes and multi-paths, each mode (or path) presenting a particular group delay, amplitude, polarization and Doppler frequency shift.

Table 1 gives the typical order of magnitudes of the main parameters of the ionospheric propagation.

TABLE 1

Order of magnitude of the main ionospheric propagation parameters

Parameter	Average channel behaviour	Extreme channel behaviour
Modes and paths number	Depending on the length of the radio link ≤ 8 for sky waves with a 0 to - 40 dB level Ground wave for short distances	
Total delay spread	≤5 ms	≤ 8 ms
Delay spread on each path	A few 10 μs	
Mean Doppler shift for each path	A few 1/10 Hz $fd \leq 2.5$ Hz	A few Hz $fd \leq 10$ Hz
Doppler spread for each path	A few 1/10 Hz $\Delta fd \leq 2$ Hz	A few Hz A $\Delta fd \leq 5$ Hz

Because of these propagation characteristics, severe selective or deep flat fadings often deteriorate ionospherically-propagated signals mid significantly affect the quality of the conventional AM reception).

As far as mobile reception is concerned, the contribution to the Doppler shift from the movement of a mobile reception is smaller than the contribution to Doppler shift due to the movement of the ionospheric layers.

3 Selection criteria for a digital modulation procedure

Theoretically, single-carrier procedures and (orthogonal) multi-carrier procedures are almost equivalent if transmission is performed via time-variable and frequency-selective channels and if coding and/or equalization is used to compensate for the error patterns typical of the modulation procedure.

So both types can be used for Single Frequency Network (SFN) operation.

The number of modulation states is the same in both cases. It depends on the ratio between the needed data rate ad the symbol rate. The symbol rate depends on the existing channel spacing.

Finally, mention must be made of the 9 kHz (or 10 kHz) bandwidth of AM channels which will only afford a few tens of kbit/s data rate.

The different channel spacing of LF and MF (9 or 10 kHz) and HF (10 or 5 kHz) lead to differences in the digital modulation procedures, if we require that the digital procedure be compatible with the existing channel spacing.

From these limitations the digital sound encoder should provide a data rate of approximately 20 kbit/s.

With a usable RF bandwidth of 7 kHz for both the LF and the MF bands, a spectral efficiency of the modulation procedure of approximately 3 bits per Hz of bandwidth is required.

For the HF bands, with a usable RF bandwidth of 4 kHz, a necessary spectral efficiency of 5 bits per Hz of bandwidth is required if the same sound quality as in the LF and MF bands is desired.

Depending upon the parameters selected for the roll-off, code rate, frame structure ratio and guard period, both procedures require 32 to 64 modulation states.

The decision in favour of a multi-carrier or single-carrier procedure is mainly influenced by the length of the channel pulse response, which is specified in terms of the symbol length. In consideration of the technical outlay needed in the receiver the procedure is normally selected according to the following rule:

- Single-carrier procedure: Length of the channel pulse response is less than or equal to the length of 16 symbols.

- Multi-carrier procedure: Length of the channel pulse response is more than or equal to the length of 64 symbols.

If the length of the channel pulse response is less than the length of 64 symbols, the reduction in complexity expected from the multi-carrier procedure is no longer ensured. On the other hand, the efficiency of an equalizer required in the single-carrier procedure declines if the channel pulse responses exceed the length of 16 symbols.

3.1 Transmitter hardware

The decision in favour of a multi-carrier or single-carrier procedure is also influenced by the added complexity on the transmitter side.

If we wish to maintain the coverage zones of AM broadcasting, digital transmission would allow us to reduce the transmitter power by some dB compared with today's analogue transmission. In general, however, the required PF power level will still be large enough to rule out a linear transmitter output stage because of its poor efficiency.

Therefore, it must be possible to continue the operation of existing AM transmitters (class C). For this purpose the transmitter will be complemented by a phase modulator, which is inserted behind the master oscillator. The amplitude modulator should be capable of transmitting a DC component. This requirement is fulfilled by PDM modulators, pulse step modulators etc., i.e. by all modern modulator types.

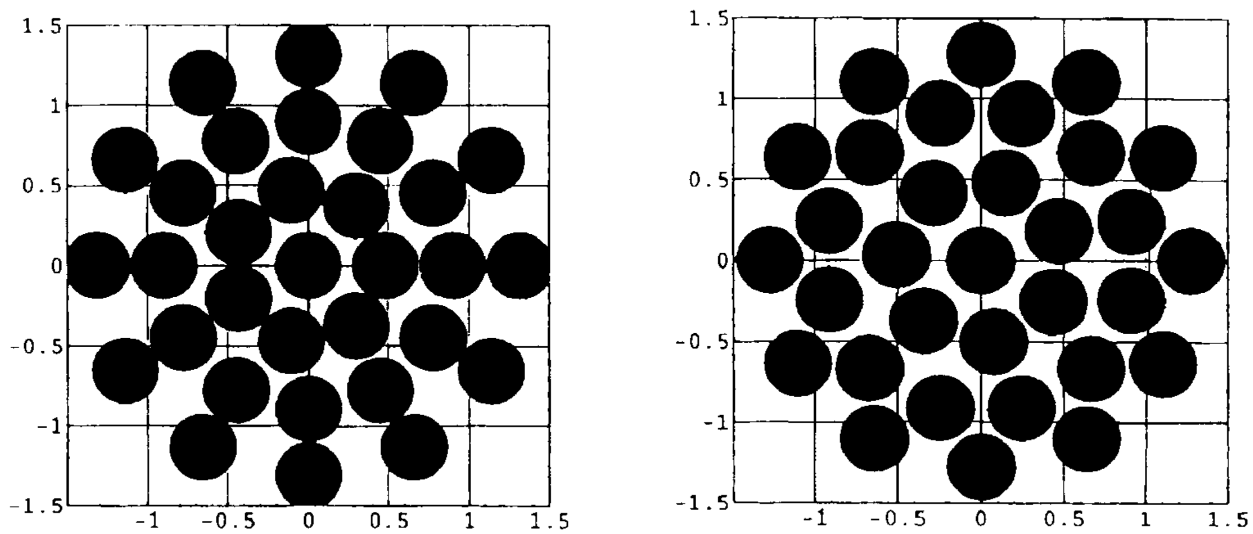
Usually, digital modulation is represented by Cartesian coordinates based on real and imaginary parts (I and Q signals). For this reason modulation procedures with a large number of states, e.g. the 64 QAM procedure, often have square phase stirs (symbol constellations).

For a digital complex modulation of a retrofitted conventional AM transmitter, however, the modulation signal must be converted into an amplitude signal and a phase signal. This is the polar representation by means of A and φ signals.

The amplitude signal is applied to the amplitude modulator, while the phase signal is applied to the phase modulator. Therefore, it is expedient that modulation procedures including a large number of states show a certain rotational symmetry in the phase star. Such procedures should be called APSK (amplitude and phase shift keying) procedures. The state points are arranged on concentric rings. Figure I shows in example of APSK. Other forms of APSK ire possible.

FIGURE 1

1/7/12/12 APSK = 32 APSK of a a) non-compact b) compact form



This modulation procedure, which is adjusted to the characteristics of the transmitter with high efficiency, has the following advantages:

- Non-linearities in the amplitude modulator affect only the diameters of the concentric rings.
- Amplitude-to-phase conversions in the transmitter output stage will result in a slight rotation of the concentric rings only. This may he compensated for by differential coding on the rings.

However, the procedure also has its drawbacks, which must be accepted if transmitter efficiency is emphasized :

- Despite the band limitation applied to I and Q signals, the A and φ signals are normally not bind-limited. In practice, however, the A and (φ signals can be band-limited to about 2.5 times the symbol frequency.

- Due to the delays in the transmitter a time offset occurs between the A and the (φ signals, which must compensated for. In the case of a modulation procedure of 32 states the time offset should not exceed 2% of the symbol length.

These considerations are independent of the modulation system chosen.

4 Multi-carrier modulation intended for AM bands (COFI)M)

Already implemented in the EU 147-DAB (Digital Audio Broadcasting) project, associated with ISO-MPEG audio encoding to meet the requirements of high-quality digital audio broadcasting to mobile, portable and fixed receivers, the COFDM (Coded Orthogonal Frequency Division Multiplex) system could also be the solution to digital broadcasting in AM bands.

The COFDM system could successfully perform despite selective fadings of AM bands, because it has been designed to make use of the presence of multipath rather than he restricted by it.

The COFDM system relies on two principles:

- The first principle consists of splitting the information to be transmitted into a given timber of modulated carriers with individual low bit rates, so that each carrier is affected by a flat or non-selective fading only.

- The second principle systematically exploits multipath between the transmitter and the receiver, by using the fact that signals sufficiently separated in frequency and time cannot be identically affected by the propagation conditions. This is exactly what happens in a 9 kHz channel, in case of delays within a range of a few milliseconds and in the presence of Doppler shift. Therefore, the COFDM system incorporates the linking of elementary signals transmitted at distant locations of the time-frequency domain. This is achieved by convolutional coding associated with soft decision Viterbi decoding, in conjunction with frequency and time interleaving: the more diversity there will be, the more robust the system.

In addition, due to its ability to handle strong multipath, including man-made echos, COFDM provides the opportunity to design more spectrum efficient broadcasting networks.

The capability of COFDM to allow operation with a 0 dB echo would ensure that non-directional antennas could be used to receive a program broadcast, in a cellular fashion - at least on a country scale - from two or more transmitters operating on the same frequency (Single Frequency Network, SFN). Such a network needs multiple frequencies in a conventional analogue [or digital] broadcast. This cannot be overlooked when one considers the lack of spectrum resources.

4.1 A demonstration prototype

After simulation studies, the CCETT (France) has developed a laboratory prototype of a COFDM system dedicated to AM bands.

A major goal of the work was to design a system with a sufficient useful data-rate in a 9 kHz channel, to support services such as audio broadcasting of quite good quality.

For that purpose, the CCETT has implemented advanced digital techniques, such as:

- trellis-coded modulation of high spectra efficiency and also robust against channel distortion,
- continuous channel estimation, by inserting reference carriers among the carriers used by COFDM.

The key parameters of the prototype are listed in Table 2. This prototype is designed for channel delay spread within a value of 2 ins (typically a Single Frequency Network of the size of France) and for a useful data rate of 24 kbit/s.

It is connected to a digital sound codec, adapted from MPEG2 version (ISO/MPEG2 Audio Layer II at reduced sampling frequency), also developed at the CCETT.

The whole system test set-up also includes a hardware channel simulator, which has already verified the advantages of the COFDM technique over classical analogue modulation on typical AM channels.

Further work will now include on-air experiments.

TABLE 2

Performance parameters of the laboratory prototype

Channel bandwidth	9 kHz
Used bandwidth	8.7 kHz
Modulation of each carrier	64-QAM
Coding rate	2/3
FFT size	256 points
Useful symbol duration	21.333 ms
Guard interval	2.666 ms
Total symbol duration	24 ms
Total number of carriers	184
Number of useful carriers	144
Number of reference carriers for continuous channel estimation	24
Number of carriers for automatic frequency control (not used at the moment)	16
Useful data rate	24 kbits
Net spectral efficiency	2.8 bit/s/Hz
C/N for operating on Gaussian channel	17 dB
C/N for operating on Rayleigh channel with a 0 dB echo	25 dB

4.2 Transmitting infrastructures and receiving equipment required

In a COFDM receiver, digital signal processing must be implemented allowing, for automatic, data-aided tuning.

With respect to the transmitting infrastructures, the first tests on new generation solid state AM transmitters have given good results: COFDM on AM bands should operate well on the same amplifier stage as analogue broadcasting (with Single Side Band).

5. Single-carrier modulation intended for AM bands

A single carrier modulation system has been constructed in Germany and is currently under test. Owing to the transmitter characteristics the multi-carrier modulation approach has the following disadvantages compared with the single-carrier approach:

- The time-offset between amplitude and phase signal results in the loss of orthogonality.

- Multi-carrier modulation has a high crest factor so that the requirements with respect to transmitter linearity are far more stringent than in the case of single-carrier modulation. As a consequence, the radiated power of the transmitter is reduced.

There are further aspects mentioned in the following which finally led to the decision in favour of a single-carrier procedure:

- Due to the relatively short length of the channel impulse response the statistical variations of the channel are not sufficient in the frequency direction. Therefore, the averaging effects of the multi-carrier procedure exploited for DAB cannot be achieved to the required extent, where the length of the channel impulse response is some hundred symbols. In the case of LF, MF and HF there are less than 16 symbols.

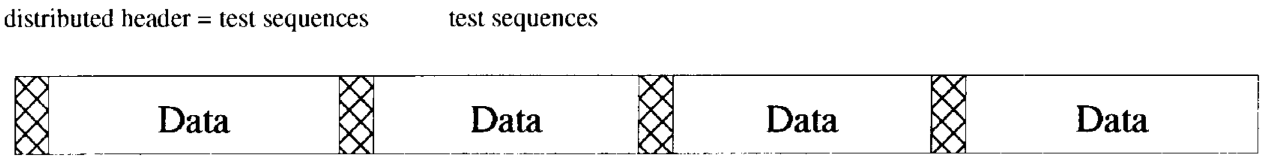
- This requires an extensive and continuous channel estimate in the case of the multi-carrier procedure.
- In the case of a large number of modulation stages it is not easy to apply differential modulation or demodulation to the multi-carrier procedure. For DAB, however, only differential 4 PSK is used.
- The single-carrier modulation allows a simple or a very complex structure of the receiver depending on the requirements. This complies with the need for portable and fixed receivers. Multi-carrier modulation -Wows complex receiver structure only.

5.1 Frame structure

The use of a frame structure has proved successful for various applications, including short waves transmission. The signal consists of the serial line-up of frames (code sequences) of an identical structure, shown in Fig. 2.

FIGURE 2

Framework structure in the case of serial transmission



By means of the headers it is possible:

- to synchronize the receiver with respect to the carrier phase and the symbols;
- to measure the channel for the adjustment of the equalizer.

To conduct a data-independent estimate of the channel impulse response with the help of the headers, these headers must be at least twice as long as the channel impulse response. 2 ms are assumed for the delay spread. With a symbol rate of 6 400 symbol/s these are 12.8 symbols. Therefore, the length of the headers is typically 32 symbols. The ratio between the data length and frame length is assumed to he 9110. Thus, the length of the frame is 320 symbols. With a symbol rate of 6 400 symbol/s there are 20 frames/s.

5.2 System performance parameters

On the basis of simulation studies by German Telekom the following system performance requirements for digital transmission have been worked out:

- Bandwidth 7 kHz
- Usable data rate 20 kbit/s
- Punctured convolutional code with a 2/3 code rate
- Symbol rate 6 400 symbols
- Roll-off factor 0.125
- 3 dB bandwidth 6 400 Hz
- Overall bandwidth 7 200 Hz
- Frame structure ratio 9/10
- Frame structure: test sequence 32, data sequence 288
- Modulation in 1/7/12/12 APSK = 32 APSK

The uncoded symbol error probability of 1/7/12/12 APSK is 10^{-4} for E_b/N_0 = 15 dB.

5.3 Coding and interleaving

A comparison of uncoded and coded error rates is difficult because it depends on the type of coding used. As reference coding a simple convolutional coding method is used which serves to convert the bit error probabilities. A code with constraint length 7 and coding rate 1/2 is used as convolutional code. The received bit stream is decoded by means of the Viterbi algorithm. In this example the hard decision is applied; better results are achieved with the soft decision.

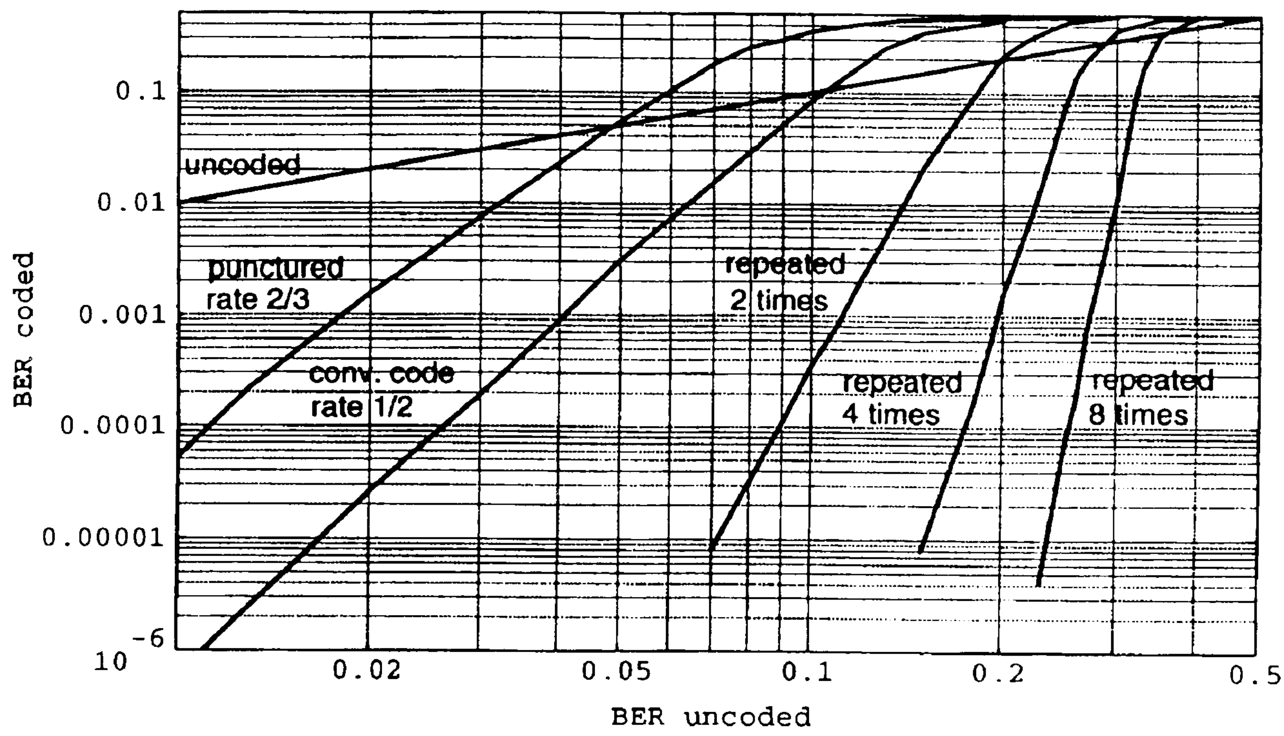
In the case of a specified bit error rate in the bit stream (BER uncoded) with evenly distributed errors, the application of the appropriate code will result in the bit error rate (BER coded) illustrated in Fig. 3.

The various curves show the error probability of systems with a coding derived from the original 1/2 rate code. The error probabilities can only be achieved if the errors at the input of the decoder are evenly distributed. This makes an interleaver necessary. A convolutional interleaver is suited for this purpose because no explicit synchronization is required for the deinterleaver.

FIGURE 3

Performance of a 1/2 rate convolutional code

Rate 1/2 convolutional code, punctured or repeated effective rate (1, 2/3, 1/2, 1/4, 1/8, 1/16) repetition as soft decision.



At the output of the deinterleaver there is a bit stream delay compared to the input of the interleaver. If the objective is to offset a fading frequency of 0.2 Hz corresponding to a fading duration of 5 s, an interleaving period of about 10 s is necessary (flat fading). This time delay may be a problem to listeners (e.g. time signal).

5.4 Field trials

In the course of November 1994 German Telekom will start field trials at the 8 1 0 kHz frequency. A 1 kW transmitter digitally modulated according to the A, φ procedure will be used in these field trials.

The results of the tests will be published.