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The development of the EBU VHF/FM radio-data system (RDS)

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In order to enable users of suitably-equiped radio receivers to be provided with information about the programmes to which they are tuned, a system permitting digital signals to be superimposed inaudibly on VHF/FM broadcasts has been developed by an EBU Working Party. The basis for the design of this system and the considerations taken into account in determining the optimum values of the various parameters are described. Details are given, in particular, of the organisation of the data and of the protection provided in order to ensure that satisfactory reception may be obtained even under difficult conditions, such as in the case of receivers installed in moving vehicles.

The development of the EBU VHF/FM radio-data system (RDS)

C. Odmalm*

1. Introduction

For many years, the number of radio programme services and radio broadcasting stations has been increasing rapidly all over the world, and it seems very likely that this trend will continue in the future. The problems experienced by listeners trying to find the programme they want and in trying to continue to receive it while travelling are thus becoming more and more difficult. These problems are already well known, both to broadcasting companies and radio manufacturers, and many different solutions have been presented in recent years.

These proposals, which involve the provision of tuning aids such as direct frequency display, presetting of frequencies, or storage of a frequency table with automatic retuning of the best-received transmissions within a network of stations broadcasting the same programme, are good solutions, but they require the listener to know, to a greater or lesser extent, how to make use of this information.

One way to simplify the listener's task is to add a data channel permitting tuning and programme information to be inserted inaudibly into a monophonic or stereophonic VHF/FM broadcast [1]. Techniques for doing this have therefore been studied by broadcasting organisations in different countries in Europe with coordination by the European Broadcasting Union (EBU). The studies have resulted in the definition of specifications for such a radio-data transmission system, which are in the course of publication [2]. This new EBU system has received the name "RDS", the abbreviation for "radio-data system".

The following text consists of a description of the various main characteristics of the system and accounts of how the corresponding values were determined. This description is subdivided into three main parts :

- Modulation characteristics
- Baseband coding
- Message structure.

2. Modulation characteristics

There are three main requirements to take into consideration when developing a system involving the insertion of digital signals into the stereophonic multiplex signal at the VHF/FM sound broadcast transmitter :

a) The signal in the data channel must not impair the quality of the main programme, whether monophonic or stereophonic, and every effort should be made to prevent them from causing interference to signals of other existing subsidiary systems.

b) No additional interference should be caused to transmissions from any other broadcasting transmitter. (*Fig. 1* shows the protection ratio curve for the new radio-data system, together with the protection ratio curves for monophony and stereophony given in CCIR Rec. 412-3.)

c) The coverage area of the data signals should be somewhat larger than that of the monophonic sound transmission.

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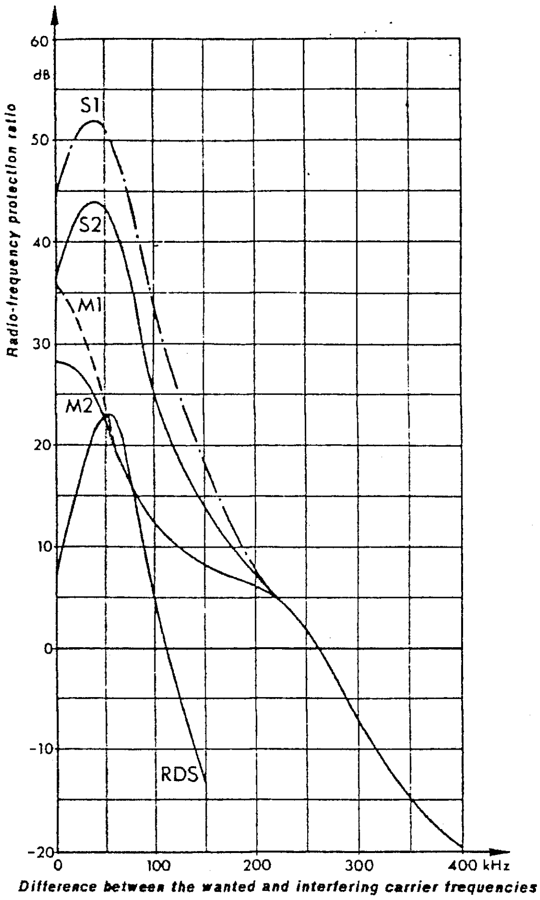


Fig. 1. - Protection ratios for VHF/FM radio

Curve M1 : monophonic broadcasting; steady interference.
Curve M2 : monophonic broadcasting; tropospheric interference (protection for 99% of the time).
Curve S1 : stereophonic broadcasting; steady interference.
Curve S2 : stereophonic broadcasting; tropospheric interference (protection for 99% of the time).
Curve RDS : radio-data transmission; steady interference; bit-error ratio : 1.10^{-3}; deviation : 3 kHz.

2.1. Compatibility with the main programme

The choice of the modulation method is very important. The available frequency space for transmission of supplementary information is between 15 kHz and 23 kHz and above 53 kHz.

The frequency and the level of the subcarrier and the modulation method have to be chosen in such a way as not to cause harmful interference. The frequency band between 15 kHz and 23 kHz is not so useful, because intermodulation can cause interference both in monophonic and stereophonic reception. Interference may be caused by non-linearities before the decoder producing *intermodulation* products occurring within the M- or S-channel. Another reason is the possible existence of deficiencies in the *decoder* making it sensitive to signals outside the M- and S-channels.

a) *Intermodulation in the transmitter and receiver*

The composite signal of the pilot-tone stereophonic system can be written as (*Fig. 2*) :

$$\mathrm{C}(t) = \underset{(M\ \text{signal})}{\frac{A+B}{2}} + \underset{(S\ \text{signal})}{\frac{A-B}{2}} \sin \omega t + \underset{(\text{pilot tone})}{K \sin \frac{\omega t}{2}}$$

where A is the left-hand signal
B is the right-hand signal
ω is the angular frequency of the stereophonic subcarrier at 38 kHz.

The supplementary information signal can be written as

$$T(t) = D(t) \sin \Omega t$$

where Ω is the angular frequency of the subcarrier modulated with the supplementary information.

Because of non-linearities, a number of distortion and intermodulation products will be generated. By calculation, one can see that the product most likely to cause audible interference is $D(t) \cos(\Omega - \omega/2)t$, since it exists even during programme pauses. Selecting 57 kHz as the subcarrier for the data transmission, i.e. the third harmonic of the pilot-tone, makes $\Omega = 3\omega/2$, and that component is equal to $D(t) \cos \omega t$. Such a choice of Ω minimises the interference because this component is in quadrature with the S-channel subcarrier.

b) *Interference caused by deficiencies in the decoder*

Because of shortcomings in the process used to regenerate the 38 kHz carrier, not only 38 kHz and its harmonics, but also components at the frequencies 19 kHz and 57 kHz are obtained. In the demodulation process, intermodulation products of the different components in the multiplex signal are produced. They may fall into the pass-band of the wanted signal, so that audible interference is generated. The subjective effect can be decreased by using modulation signals having a *noise-like spectrum.*

The type of interference described above is such that it may be audible in programme pauses. In current IC-decoders, in which the stereophonic carrier is generated by a phase-locked loop, another type of interference may be generated when supplementary

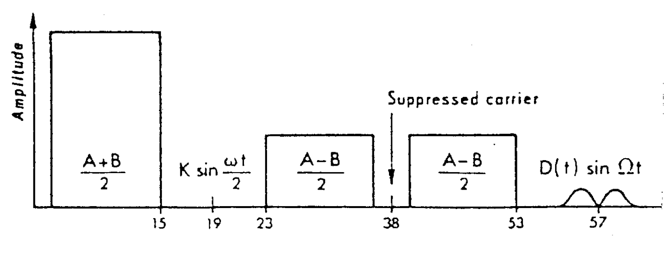


Fig. 2. - Baseband spectrum of the complex signal.

information is transmitted with a subcarrier frequency that is an odd multiple of the pilot tone. If the supplementary information contains frequencies within the bandwidth of the loop, the stereophonic carrier will be phase-modulated and intermodulation between the supplementary information and the stereophonic signal will occur. The use of a modulation method with a suppressed carrier and avoiding modulation frequencies below 300 Hz, is a way to overcome this problem.

On the basis of the foregoing principles it is evident that in order to cause minimum interference, the system for transmitting supplementary information simultaneously with a stereophonic transmission should have the following characteristics :

- 57-kHz subcarrier phase-locked to the 19-kHz pilot-tone;
- amplitude modulation with suppressed carrier;
- reduced amplitude for modulation frequencies below 300 Hz.

These characteristics have therefore been adopted for the new radio-data system. *Fig. 3* depicts the modulation method used. *Fig. 4* represents the spectrum of the modulating data signal.

In order to find out if and how the sound programme quality can be affected by the radio-data signal, especially in multipath conditions, field-tests were undertaken in several European countries [3, 4]. From these tests, it was found that in most areas no impairment of the sound programme was noticeable. In the case of reception in moving vehicles, in areas where extensive multipath reception occurs, audible interference could be heard on some very few occasions, and only in the case of certain receivers. There is a strong correlation between the presence of audible interference and sound programme quality; that is, if the data signal is audible, the sound programme quality would be severely impaired even if the data signal was not present. The overall conclusion, which

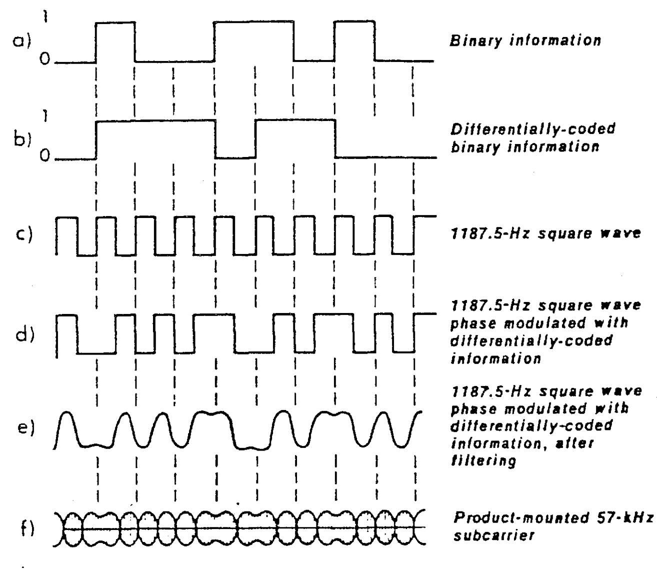


Fig. 3. - Modulation method.

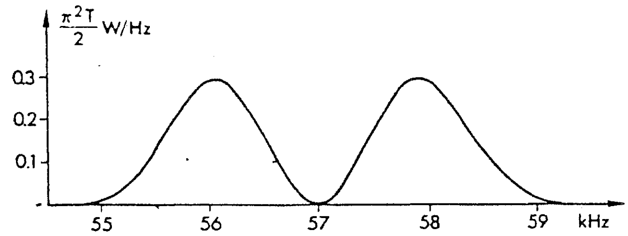


Fig. 4. - Power spectrum of the product-modulated 57-kHz subcarrier.

is also confirmed by the small number of complaints that have been received since 1978 from among the more than 15 million listeners who live within the radio-data test areas, is that the modulation method adopted fulfills the requirement on compatibility.

2.2. Coverage area

The reliability of the system, the degree of compliance with the compatibility requirement and the deviation of the main carrier by the radio-data signal, are strongly inter-related. On the basis of careful tests, it was found that a nominal deviation of ± 2 kHz is the optimum, and this value has therefore been recommended. *Fig. 5* shows some representative results from recent field-tests in which the nominal deviation of the data-signal RDS was ± 2 kHz.

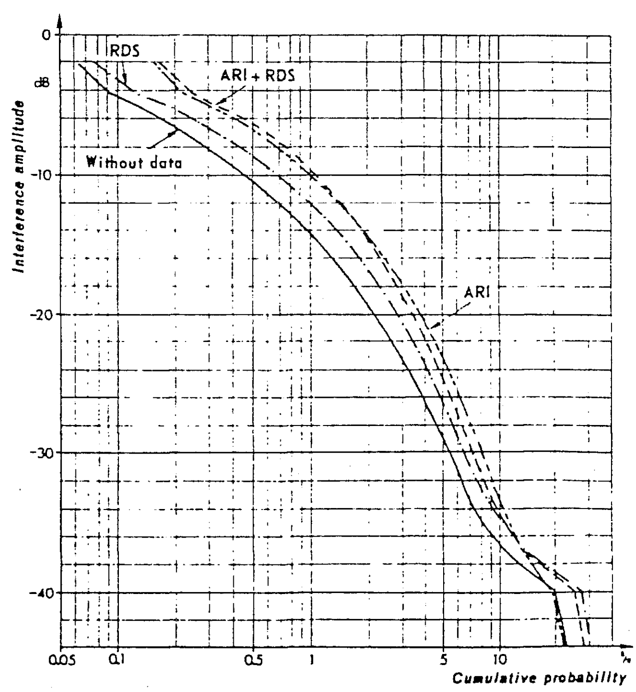


Fig. 5. - Statistical distribution of the interference amplitude on road sections, where the RF levels are high and multipath propagation effects are small (with and without the ARI and RDS systems with a 2-kHz deviation).

3. Baseband coding

In the case of stationary reception of low input-level signals in the absence of interference, such as with domestic receivers, random errors with an error rate P occur. When the input signal level is incresed, P decreases as an exponential function. The improvement in data-reception quality obtainable by the use of error correction is very small for single-error correcting codes and negligible for longer codes.

In the case of mobile reception in the presence of multipath propagation, and even in static reception with interference from electrical equipment, the received signal is sometimes heavily impaired. This means that the signal strength varies very rapidly. When the sensitivity threshold is passed, the error probability increases very rapidly. The length of the burst is inversely proportional to the speed of the vehicle containing the receiver and the mean field-strength. In order to obtain more knowledge about the performance of the data-channel, a field-test was organised in Switzerland in 1980, in which five different modulation methods were tested (*Fig. 6*). It was decided to concentrate mainly on the case of mobile reception, and test-routes which were known to be subject to extensive multipath propagation were used. The average speed of the test-vehicle was 20 km/h.

The computer-analysed measurements gave the following results :

a) Systems with a subcarrier above 53 kHz performed consistently better than systems with a subcarrier in the region around 19 kHz.
b) Errors in the received data occurred in dense bursts.
c) Because of the density of the bursts of errors, it was considered that it would be most appropriate to use an error-detecting code.
d) Data should be grouped into blocks of about 100 bits. Further measurements were then made to find out if these results were also valid for higher speeds, corresponding to driving on a motorway. It was found that most of the bursts of errors are short, which means that error-correction techniques capable of correcting errors of up to 2 or 3 bits in a block will improve the reception quality considerably.
e) Long error-detecting codes are more effective in the case of stationary reception and at low speeds, while shorter error-correcting codes are better at medium and high speeds (*Fig. 7*).
f) Impulsive noise from the ignition system can cause double errors.

On the basis of tests undertaken in Sweden in 1982, where 8 different systems were compared, a shortened cyclic block-code with 16 information bits and 10 check-bits was adopted. This code enables error bursts of up to 5 bits to be corrected.

The code used provides for an optimum burst-error correction and has the generator polynomial :

$$g(x) = x^{10} + x^{8} + x^{7} + x^{5} + x^{4} + x^{3} + 1$$

The 10-bit checkword of the basic shortened cyclic code, which provides for error detection as well, may be formed in the usual way; it is the remainder after multiplication by x^k, were k is the number of check-bits (10 here) and then division by the generator polynomial $g(x)$, of the message vector.

Thus, if the 16-bit message vector is

$$m(x) = m_{15}\,x^{15} + m_{14}\,x^{14} + \ldots + m_1\,x + m_0$$

(where the coefficients m_n are 0 or 1), the basic code vector $v(x)$ is given by

$$v(x) = m(x)\,x^{10} + \frac{m(x)x^{10}}{g(x)} \bmod g(x)$$

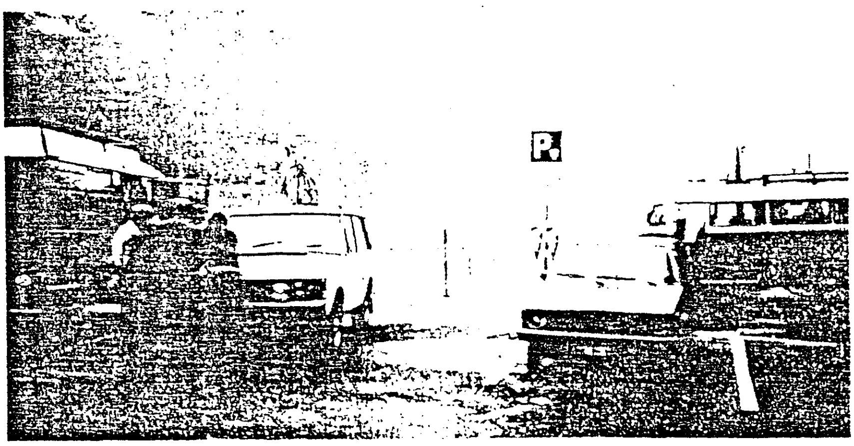
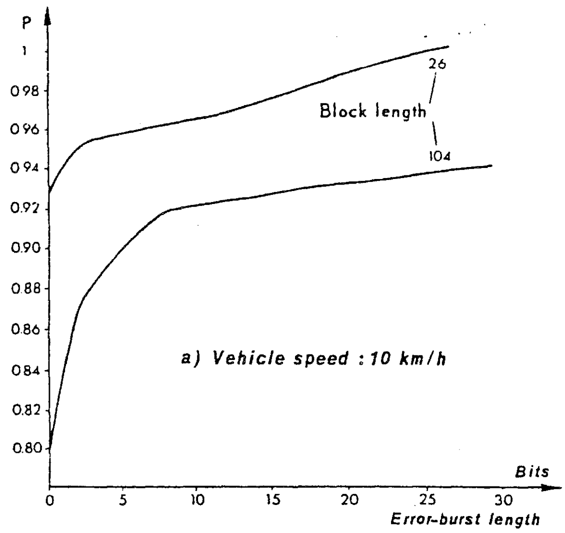


Fig. 6. - The vehicles from the Swiss PTT, the BBC and the IRT used for making measurements in Switzerland in 1980.



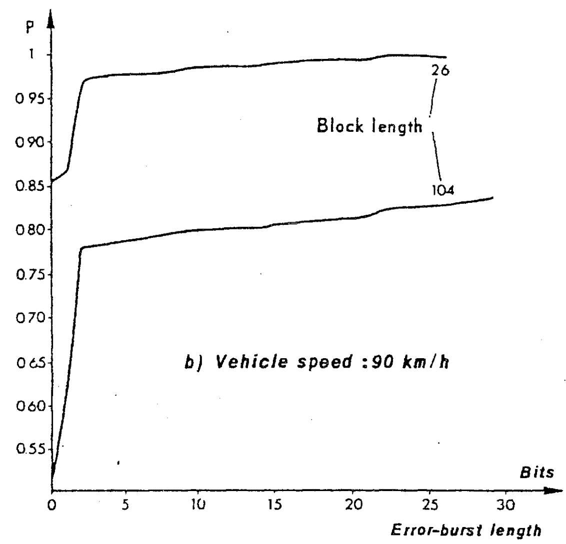


Fig. 7. - Distribution of the probability *P* of successful reception of one block of data in terms of the error-burst length that the error-correction code must correct, for blocks of 26 and 104 bits at vehicle speeds of 10 and 90 km/h.

The disadvantage of using such a code is that the percentage of overhead due to the check-bits and the block- and group-headers increases.

In order to minimise the overhead, a new synchronisation method was developed for the shortened cyclic code used, in which block- and group-(frame) synchronisation are effected at the same time. Instead of using a specific synchronisation word (header) for each group, which would require 10 % of the information rate, in the new method a special synchronisation word (later called " offset word ") is added, " modulo two ", (so that no extra bits are needed) to the particular check-word in each block. This means that the time required for synchronisation, which is also called the lock-in time, can be made very short (i.e. corresponding to about 2.5 blocks) and it will thus be possible to have very high repetition rates for individually-coded information (message) in a given block.

Consequently, the blocks within each group are identified by the offset words A, B, C and D added to the check-words of blocks 1, 2, 3 and 4, respectively, in each group (*Fig. 8*).

The beginnings and ends of the data blocks may be recognised in the receiver decoder by using the fact that the error-checking decoder will, with a high level of confidence, detect faulty block synchronisation as well as burst errors.

The offset words are chosen in such a way that the contents of the syndrome register will not be interpreted as a burst error equal to or shorter than five bits when rotated in the polynomial shift register.

The offset words are added by an " exclusive or " circuit to the check-word $C_9 - C_0$ to generate the modified check-bits $C'_9 - C'_0$.

There are several methods, using either hardware or software, for implementing the synchronisation as well as for implementing the encoding and decoding of the block-code.

For a received binary sequence $\bar{y}$, the syndrome can be calculated as $\bar{s} = \bar{y}H$. If $\bar{x}$ is transmitted and $\bar{y}$ is received, then $\bar{y} \oplus \bar{x}$ is a sequence that contains a 1 in each position in which $\bar{y}$ and $\bar{x}$ differ. This sequence is called the error sequence $\bar{z}$. The definition of the matrix H is such that $\bar{x}H = 0$ if $\bar{x}$ is a code word.

$$\bar{z}H = (\bar{y} \oplus \bar{x})H = \bar{y}H \oplus \bar{x}H = \bar{y}H = \bar{s}$$

$$\bar{s} = \bar{z}H$$

More details about the shortened cyclic code used and the method of synchronisation employed may be found in [5,6].

4. Message structure

4.1. Nature and rate of the information to be broadcast

In order to define the type of information to be sent and also the corresponding repetition rates, the following table was prepared on the basis of the replies received to a questionary sent to the broadcasting organisations, setting out the minimum requirements.

Type of information	Repetitions/second
Programme identification	11
Programme service	1
Programme type	11
Trafic programme	11
Trafic announcement	4
Alternative frequencies	4
Decoder identification	1
Music/speech	4
Programme item number	1
Radio text	0.2

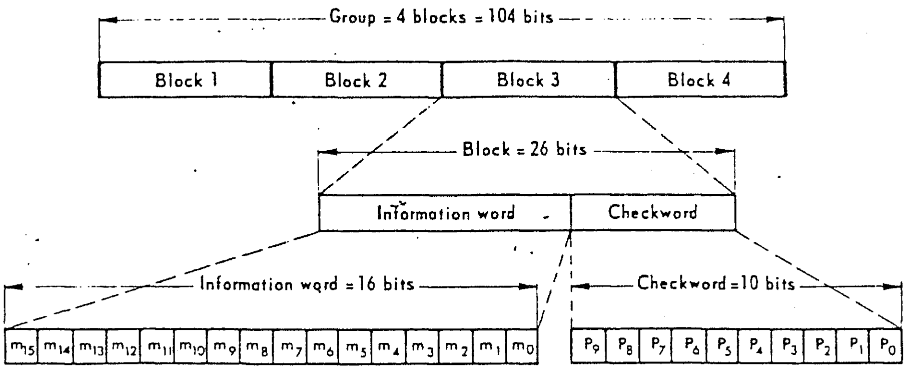


Fig. 8. - Baseband coding structure.

4.2. Baseband grouping of the coded data

The data are grouped together according to the following structure (*Fig. 8*) :

- The largest ensemble in the structure consists of 104 bits, known as a group.
- Each group comprises 4 blocks, of 26 bits each.
- Each block comprises one information word and one check-word.
- Each information word comprises 16 bits.
- Each check-word comprises 10 bits.

4.3. Message format

Each transmitted group is a self-contained packet containing a group type code and an address which indicates how the block should be decoded.

The messages which are to be repeated most frequently, and for which a short acquisition time is required, usually occupy the same fixed positions within every group. They can therefore be decoded without reference to any other block.

5. Conclusions

In this article, the principal characteristics of the EBU radio-data system have been described, and an account has been given of the basis on which the corresponding values were determined. These values are listed in an Appendix. Proposals for the practical application of a radio-data system and a description of its operational aspects have already been published elsewhere [7, 8].

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APPENDIX

Values of the principal characteristics of the EBU radio-data system

Subcarrier frequency : 57 kHz.

Modulation : DSB suppressed carrier AM.

Bit-rate : 1187.5 (57 kHz : 48) bits per second.

Data signal spectrum shaping : the data signal comprises spectrum-shaped biphase-coded symbols.

Recommended nominal deviation of the main FM carrier due to the unmodulated subcarrier is ± 2 kHz. With this level of subcarrier, the level of each sideband of the subcarrier corresponds to half the nominal peak deviation level of ± 2 kHz, i.e. ± 1 kHz for an "all zeros" message data stream (a continuous bit-rate sine-wave after biphase coding).

Structure : groups consisting of 4 blocks with 16 information bits and 10 check-bits each, using a shortened cyclic code permitting error correction or detection. The code can correct error bursts of up to five bits in length.

Block- and group-synchronisation : 10-bit offset words included in the check-bits.

Protection ratios : below those specified for monophony and stereophony in CCIR Recommendation 412-3 [9].