REPORT 463-5

TRANSMISSION OF SEVERAL SOUND PROGRAMMES OR OTHER SIGNALS WITH A SINGLE TRANSMITTER IN FREQUENCY-MODULATION SOUND BROADCASTING

(Question 46/10, Study Programme 46G/10 and 46H/10)

(1970-1974-1978-1982-1986-1990)

1. Introduction

The growing need for more programmes in almost all parts of the world makes it desirable to examine the present broadcasting standards to determine what changes are possible to provide a better utilization of the available frequency bands. The frequency-modulation service uses a large bandwidth to provide a programme service of exceptional quality. However, it has been found that some additional broadcasting services can be added without significant deterioration of the programme quality. This is an important consideration when the need for additional broadcasting services might make a reconsideration of the standards a necessity.

The transmission of data information as an alternative to the main sound programme, is described in Reports 802, 1207 and 1208.

2. Requirements for monitoring and test instruments

The basic purpose of the supplementary sub-carrier monitoring instruments is:

- to provide equipment for use in the routine operation and adjustment of the broadcasting station in its day-to-day operations;
- to provide the instrumentation necessary to test and prove the integrity of the transmitting system.

In keeping with the above requirements, the following parameters become subjects of interest:

- the degree of modulation of the main carrier by the sub-carrier;
- centre frequency of the sub-carrier;
- spectrum of the modulated sub-carrier;
- cross-talk and noise;
- distortion, frequency response, or error rate, as applicable.

3. Systems using one or more sub-carriers for supplementary sound programmes

The analysis of supplementary sub-carrier operation in [CCIR, 1966-69a], shows that the use of a frequency-modulated sub-carrier provides the best signal-to-noise ratio for a given sub-carrier amplitude. Although the theoretical analysis of cross-talk is omitted, qualitative analysis, borne out by experience with sub-carrier operation, indicates that the system of modulation with the best signal-to-noise ratio also has the least cross-talk when other system parameters are the same.

Although the choice of the lowest possible sub-carrier frequency will provide the best signal-to-noise ratio in the supplementary sub-carrier channel, the sub-carrier frequency should be high enough to prevent audible beats. The use of a still higher sub-carrier frequency reduces the probability of cross-talk but unnecessarily reduces the signal-to-noise ratio.

3.1 An FM-FM system using a compressor/expander in the *S* channel is described in Report 300.

Note - The system did not conform to Recommendation 450.

3.2 An FM-FM system is described in [CCIR, 1966-69b]. In this instance, the frequency of the sub-carrier was 67 kHz with a maximum deviation of the main carrier by the sub-carrier of ± 7.5 kHz during stereophonic broadcasting and a maximum deviation of the main carrier by the sub-carrier of ± 11.25 kHz during monophonic broadcasting. The maximum audio frequency of the supplementary channel is restricted to 6 kHz.

3.3 [CCIR, 1966-69c] gives the results of tests showing that it is possible to transmit simultaneously a main channel programme and a second programme using a supplementary sub-carrier. The frequency response is as good and the distortion as low, for the supplementary sub-channel as for the main channel. A sub-carrier frequency of 58 kHz was used. The deviation of the main carrier by the sub-carrier was ± 15 kHz and the deviation of the sub-carrier ± 12 kHz. The cross-talk figures were −70 dB or better, for the main channel and about −50 dB for the sub-channel.

3.4 A system for the transmission of four supplementary sound programmes in frequency-modulation broadcasting is described in [CCIR, 1966-69d]. In this instance four sub-carriers with frequencies of 70.75 kHz, 55.25 kHz, 39.75 kHz and 24.25 kHz are used. The maximum deviation of the main carrier by all four sub-carriers simultaneously, is 22.5 kHz. The maximum audio frequency of each sub-carrier is 3 kHz.

3.5 A similar FM-FM system providing two supplementary programmes is described in [CCIR, 1966-69e]. The first sub-carrier has a frequency of 33.3 kHz and carries the second programme as described in Report 300. A third programme is carried on a second sub-carrier having a frequency of 66.6 kHz. This second sub-carrier, which has a deviation of ± 8 kHz, determines the deviation of the main carrier which is ± 3 kHz. The audio-frequency range is 40 to 5000 Hz. The system includes a compressor/expander with the same characteristics as mentioned in § 3.1. The cross-talk figures are better than −70 dB for the first and second channels and better than −60 dB for the third channel (when modulated at 100% in the third channel, and at 30% in the others, the cross-talk figure was better than −45 dB).

Note - This system does not conform to Recommendation 450.

3.6 [CCIR, 1970-74a] describes a two sound programme system, the supplementary channel intended to be received with high-grade receivers for feeding wired distribution systems. The maximum deviation of the main carrier caused by the first channel programme is ± 40 kHz (80% of the maximum system deviation). The sub-carrier frequency is 62.5 kHz and is frequency modulated with a maximum deviation of ± 30 kHz. The sub-carrier level is varied, deviating the main carrier ± 15 kHz during periods of no modulation and is reduced to a minimum value of ± 6 kHz (8 dB) at 100% modulation. The cross-talk figure for the first channel from the second channel is better than 55 dB and better than 50 dB for the second channel from the first channel. The difference in immunity to interference between the two channels is calculated to be 18 dB. This value can be reduced to 5 dB if the audio bandwidth of the second channel is reduced from 15 kHz to 6 kHz and highly directional antennas are used. More details are given in the bibliography.

3.7 [CCIR, 1970-74b] describes a system providing for a maximum of eight supplementary low-quality channels, in each of which suppressed carrier single-sideband modulation is employed. The corresponding eight frequencies are chosen within the band 64 kHz to 100 kHz, so as to avoid interference with the stereophonic signal within the frequency band up to 53 kHz.

3.8 Tests in the UK [Whythe, 1977] have shown that a subsidiary programme using a 41 kHz sub-carrier at any worthwhile level of injection caused unacceptable impairment to reception of a monophonic main programme. When a 67 kHz sub-carrier was used, at 15% or less injection, the subsidiary programme was found to be acceptably compatible with reception of a monophonic main programme. The quality of reproduction of the subsidiary programme was found to be markedly inferior to that of the main programme.

3.9 [CCIR, 1982-86a] shows that a supplementary monophonic broadcasting programme can be effectively transmitted to relay-distribution networks in FM stereophonic broadcasting of pilot-tone systems by employing a 67 kHz (± 4 kHz deviation) supplementary channel with a compandor. By using antennas with moderate directivity, the coverage area of the supplementary programme can approximate that of stereophonic broadcasting with conventional receiving antennas.

3.10 [CCIR, 1982-86b] shows that a subsidiary music programme using a 67 kHz (± 6 kHz deviation) sub-carrier transmitted with a data channel using a 92 kHz (± 4 kHz deviation) sub-carrier, exhibited some impairment in multipath reception areas. Reception of the stereophonic main programme was unaffected except in the area of the most extreme multipath conditions, Generally, in modern receivers fitted with sub-carrier trap filters and/or phase locked loop demodulators, the impairment of the main stereophonic programme was minimal or negligible. Where impairment of the subsidiary programme was evident (due to multipath) the reception could always be improved by relocating the receiver or by using a directional antenna.

Note. – The frequency of the 92 kHz sub-carrier did not conform to Recommendation 450.

3.11 An FM multiplex broadcasting transmission system that has a 76-kHz subcarrier, ±1.875-kHz deviation and 48-kbps transmission capacity has been developed and a digital sound broadcasting system using 32-kbps ADPCM has been put into service for fixed receivers [CCIR, 1986-1990a].

4. Systems using one or more sub-carriers for supplementary information

A number of applications are foreseen for the transmission of various types of information in addition to the main programme and which may, or may not, be related to that programme. Such applications include the control of receivers, operation of display devices built into the receiver or operation of a separate display device such as a television receiver. Additionally, the broadcaster may make use of the system for monitoring purposes.

Recommendation 643 (Annex I) provides details of a Radio Data System (RDS) for applications of this type.

Earlier work has shown that the transmission of sound is best accomplished through the use of frequency-modulation of a sub-carrier. Whilst this method may also be used for other types of information, more recent work [CCIR, 1974-78a] has shown that if the information can be digitally coded, other forms of modulation may be preferred. Further studies should be undertaken in order to examine any possibility for the use of a common transmission standard for different applications.

4.1 [CCIR, 1970-74c] describes the ARI traffic broadcast identification system, which is used in several countries in broadcasting networks. Results of field trials are given. The traffic information is broadcast in the normal way. Those listeners wishing to operate their receiver automatically, have three different control signals available. A sub-carrier at 57 kHz (see § 5.3) is used as an identification signal for networks transmitting traffic information. This sub-carrier is amplitude modulated. One of six possible modulation frequencies in the range 23 Hz to 54 Hz indicates the traffic area. A modulation frequency of 125 Hz is used for receiver muting and is present only during traffic announcements. The frequency deviation of the main carrier due to the unmodulated 57 kHz sub-carrier should not exceed ± 3.8 kHz [CCIR, 1982-86c]. Operational practice has shown that even under difficult receiving conditions a high degree of reliability was obtained, of both the control functions and the sound reception. No mutual interference was observed between the identification signals and either monophonic or stereophonic channels.

4.2 [CCIR, 1970-74d] describes the use of a supplementary sub-carrier for the simultaneous transmission of voice and a graphic display. The graphic display portion of the system is designed for the transmission of handwritten messages, diagrams, maps, and sketches at the time when written. The co-ordinates are frequency determined in ranges from 1310 to 1490 Hz and 2060 to 2340 Hz for vertical and horizontal travel respectively. Actual writing causes one of the co-ordinate signals to become modulated in amplitude with double the power line frequency. Frequency modulation on a carrier of 5100 Hz makes it possible to achieve frequency division multiplex of an audio-frequency channel from 200 to 2000 Hz from the writing channel. The sum signal is used for modulating a frequency-modulation sub-carrier as mentioned in Recommendation 450. The voice transmission can be related to the graphic display or not, as the user wishes. The system is especially useful for educational purposes. The entire information can be stored on audio quality magnetic tape.

4.3 [CCIR, 1970-74e] describes the transmission of television picture signals using a frequency-modulation sub-carrier with sampling scan conversion techniques to reduce the video bandwidth to the audio-frequency range. The transmission system consists of a source of composite video from a Vidicon camera, a scan converter, a sub-carrier generator, and a frequency-modulated transmitter. The receiver consists of a sub-carrier demodulator, a scan converter and a video monitor. The bandwidth of the output signal will correspond to one half of the line rate of the wide-band input signal. A line rate of 15 750 Hz will give a bandwidth of approximately 8 kHz. The picture period for a bandwidth of 8 kHz is 7 s. If the picture period is increased to 14 s, a bandwidth of only 4 kHz will be required.

4.4 Since an ideographic character has more information than an alphabetic character, an error-correction technique is essential for its reliable transmission. In [CCIR, 1982-86d], a comparison of error-correcting codes for FM data broadcasting under noise limiting conditions is made.

The error-correcting codes compared were:

(a) the (8 : 4) extended Hamming code;

(b) the (26 : 16) shortened cyclic code;

(c) the (24 : 12) extended Golay code; and

(d) the (272 : 190) code.

Packet structures which included 190 or 192 information bits were assumed.

The results were that in comparison with (a) at a bit error ratio of 10^{-3}, (b) has 10^2, (c) has 10^4 and (d) has 10^{12} times improvement of error-correction capability. It was also shown that in the case of error detection, error patterns of 1 out of 2^{82} were undetected and extensive error detection capability is obtained with (d) in comparison with (a) or (b) or (c). By adopting a powerful error correcting and detecting code such as the (272 : 190) code it would be possible to decrease the deviation of the main carrier by the data sub-carrier in order to increase the cross-talk margin to the main programme channel.

4.5 [CCIR, 1982-86b] shows that data transmissions at 1200 Bd were possible using a 92 kHz (±4 kHz deviation) sub-carrier together with a subsidiary programme using a 67 kHz sub-carrier (±6 kHz deviation). In multipath reception conditions, impairment to the data did occur but this was eliminated with the use of a linearly polarized directional antenna.

Note. — The frequency of the 92 kHz sub-carrier did not conform to Recommendation 450.

4.6 [CCIR, 1986-1990 (b)] describes the feasibility for the supplementary transmission of three sub-channels simultaneously with the main stereo program: the RDS (Radio Data System) or a Paging service, an audio service and a data service. The RDS or Paging service sub-channel, both having their sub-carrier set at 57 kHz, were tested separately during this test program. The injection level was set at 3% of 75 kHz for the RDS system and between 3% and 7% for the Paging service. Amplitude modulation double sideband suppressed carrier was used.

For the audio sub-channel, the carrier frequency was set at 72 kHz for a 10 kHz audio frequency bandwidth (between 61 and 73 kHz). The injection level of the main carrier was set at 5% of 75 kHz and amplitude modulation, single sideband (lower sideband) suppressed carrier was used.

For the data service sub-channel, the carrier frequency was set at 92 kHz for an occupied bandwidth between 80.5 to 90 kHz. The injection level was set at 6% of 75 kHz for a 9.6 kbps data rate. Amplitude modulation, vestigial sideband suppressed carrier was used.

Field and laboratory tests were used for the feasibility study.

5. Cross-talk into the stereophonic channels caused by supplementary sound programmes or other signals

5.1 [CCIR, 1974-78b] gives typical test results of measurements of supplementary sub-carrier cross-talk into the *M*-channel and the *S*-channel in the transmission chain. It suggests that the deviation of the 67 kHz sub-carrier should be limited to ±4 kHz when used with stereophonic transmissions.

5.2 [CCIR, 1970-74f] underlines the difficulty in avoiding cross-talk caused by sub-carrier channels similar to the specifications given in Recommendation 450. Receivers with insufficient filtering between the stereophonic multiplex-signal and the supplementary signals will incur cross-talk in the stereophonic programme. Those administrations not at present using supplementary broadcasts should be alert to this interference possibility before commencing such services.

5.3 [CCIR, 1970-74f] indicates that a supplementary carrier could be tolerated having a frequency of three times the pilot tone frequency and being phase-locked to it. In this case, only the deviation of the main carrier by the sub-carrier may be quite high (±7.5 kHz). This sub-carrier, for example, can be used as a means of identification for a particular transmitter programme (e.g. a road traffic information programme).

5.4 [CCIR, 1974-78c] and [CCIR, 1974-78a] show results from tests with various sub-carrier frequencies and types of modulation. The Documents indicate that a supplementary sub-carrier having a frequency of three times the pilot-tone frequency and being phase-locked to it, causes minimum interference in existing stereophonic receivers. The Documents also indicate that with that choice of sub-carrier frequency there can be interference in receivers utilizing the phase-lock loop technique for the 38 kHz carrier regeneration. The phase of this carrier is altered by the modulated supplementary sub-carrier unless the spectrum of the modulating signal lies above the loop-bandwidth of the filter in the phase-lock loop. Such phase changes cause a change in amplitude of the demodulated *S*-signal resulting in an increase in *A* to *B* cross-talk and an intermodulation between the demodulated *S*-signal and the modulating signal of the supplementary sub-carrier.

5.5 Tests in the U.K. [Whythe, 1977] have shown that a subsidiary programme using a 67 kHz sub-carrier at any worthwhile level of injection caused unacceptable impairment to reception of a stereophonic main programme on at least 50% of existing stereo receivers. The use of a highly compressed main programme signal could, to some extent, conceal the interference from the subsidiary programme. The quality of reproduction of the subsidiary programme was found to be markedly inferior to that of the main programme.

5.6 [CCIR,1982-86a] shows that the cross-talk from the supplementary channel with a compandor into the stereophonic channel can be attenuated by more than 60 dB by a correct choice of the supplementary carrier frequency (67 kHz), its maximum frequency deviation (+/- 4 kHz) and maximum audio frequency (6 kHz).

5.7 [CCIR, 1982-86b] shows that with a subsidiary programme using a 67 kHz sub-carrier (± 6 kHz deviation) and a data channel using a 92 kHz sub-carrier (± 4 kHz deviation), there was no noticeable cross-talk from either of the two sub-carriers into the main stereophonic channel (± 75 kHz deviation) in multipath reception areas. However, cross-talk from the main stereophonic channel into the sub-channels was noted. The reduction of this cross-talk was always possible with the use of a linearly polarized directional antenna or by relocating the receivers. The deviation of the main carrier by each sub-carrier was ± 7.5 kHz.

5.8 [CCIR, 1986-90a] shows results from tests with a 76 kHz sub-carrier frequency. In both laboratory and field tests, using fixed receivers, a 48 kbps digital signal transmitting system which can transmit a narrow-band sound signal and data signals simultaneously, had very little influence on the level of interference to stereo reception at 2.5% (± 1.875 kHz) multiplexing level. The two sub-carrier system which uses a 76 kHz frequency-modulated sub-carrier for the sound signal and a 57 kHz sub-carrier for the data signal, affected about twice the number of receivers compared with that of the digital system.

5.9 Tests in Australia [CCIR, 1986-90d] have shown that for a 67 kHz sub-carrier injected at a level not exceeding 10% (± 7.5 kHz deviation), beat frequency interference in the main programme will be subjectively insignificant if sub-carrier deviation and percentage injection level conform to the following relationships,

(a) For direct FSK of the sub-carrier:

$$I = [20/(F+2)] + \sqrt[3]{0.83F}$$

where F is the sub-carrier deviation in kHz, and
I is the sub-carrier injection level in percentage of ± 75 kHz.

(b) For analogue modulation of the sub-carrier, a sub-carrier deviation greater than 8 kHz is not permissible as this would produce crosstalk into the 57 kHz portion of the baseband used for other services.

(i) for music and speech, and a sub-carrier deviation up to 4 kHz, the maximum permissible modulating frequency is 8 kHz. For a deviation in excess of 4 kHz, the maximum modulating frequency must be progressively reduced until it does not exceed 3 kHz at a sub-carrier deviation of 8 kHz.

(ii) for audio frequency shift keying, the permissible sub-carrier deviation is related to the audio modulating frequency. For a modulating frequency up to 2.6 kHz, the sub-carrier deviation should not exceed 6 kHz. High modulating frequencies in the range of 6 to 8 kHz require the sub-carrier deviation to be reduced to between 4 and 2 kHz respectively.

It has been found that interference due to the sidebands associated with the modulated 67 kHz sub-carrier overlapping the S signal was inaudible provided that the sideband products below 53 kHz averaged in a 3 kHz bandwidth, were less than 60 dB below the level of the unmodulated sub-carrier.

5.10 Tests in India [CCIR, 1986-90e] show that a data channel using a sub-carrier at 57 kHz with a deviation of $\pm$2.4 kHz, and a subsidiary speech quality programme using a 67 kHz sub-carrier with $\pm$5 kHz deviation intended for auxiliary services, along with a main stereo programme, exhibited no impairment in reception to any of the services. The data channel used Group 5A (CCIR Recommendation 643) for text transmission for educational and public utility services.

5.11 [CCIR, 1986-90b] shows the impact of transmitting, simultaneously with the main stereo programme, three sub-channels: the RDS or Paging service, an audio service and a data service. Interference into the main channel was measured as an increase in background noise (weighted) and evaluated subjectively by using the CCIR 5-Grade impairment scale. Based on results from 13 receivers (field and laboratory results), crosstalk into the main programme by the different combinations of sub-channel arrangements was detectable on four of the receivers and only when the Paging service was transmitted at the 7% injection level.

Interference into the RDS, the Paging and data service sub-channels was evaluated by observing errors in messages received while interference into the audio sub-channel was measured as increase in background noise (weighted). Errors in the messages were easily corrected by bit error correcting circuits. The increase in noise background depended on the tone used as the modulating signal for the main programme. Improvements to the prototype equipment can reduce this increase in noise.

6. Radio frequency problems

When additional signals are multiplexed onto the main monophonic or stereophonic programme, account must be taken of certain radio-frequency effects. These effects include a possible change in the required protection ratio and a possible increase in susceptibility to the deleterious effects of multipath. Administrations proposing systems requiring the use of additional sub-carriers are, therefore, urged to include this information.

Investigations into possible protection ratio changes should explore the case where the wanted transmission is stereophonic and the unwanted transmission includes additional sub-carriers, also the case where both transmissions include additional sub-carriers. Results are needed for co-channel and for adjacent channel protection ratios, noting that in different parts of the world channel spacings of 100 kHz and 200 kHz are used.

Note - A complete list of CCIR documents on supplementary sub-carriers in frequency modulation sound broadcasting from the period between 1966 and 1986 can be found in Volume X, Part I, of the XVIth Plenary Assembly, Dubrovnik, 1986, pages 243-248.

REFERENCES

WHYTHE, D. J. [February, 1977] The transmission of two programmes from Band-II transmitters: an assessment of "store-casting". *EBU Rev. Tech.*, **161**, 20-28.

CCIR Documents

[1966-69]: a. X/43 (USA); b. X/44 (USA); c. X/158 (USA); d. X/37 (USA); e. X/154 (Sweden).

[1970-74]: a. 10/81 (USSR); b. 10/52 (Netherlands); c. 10/198 (Germany (Federal Republic of)); d. 10/13 (United States); e. 10/40 (United States); f. 10/30 (Germany (Federal Republic of)).

[1974-78]: a. 10/342 (Sweden); b. 10/40 (United States); c. 10/129 (Sweden).

[1982-86]: a. 10/263 (China (People's Republic of)); b. 10/247 (Australia); c. 10/236 (Germany (Federal Republic of)); d. 10/271 (Japan).

[1986-90]: a. 10/204 (Japan); b. 10/317 (Canada); c. 10/49 (Japan); d. 10/76 (Australia); e: 10/331 (India).

BIBLIOGRAPHY

CHINA (People's Republic of) [March, 1984] FM broadcasting – stereophonic with a supplementary channel. National Standard GB 4311.

DOC [May, 1985] An assessment of multipath propagation effects on VHF-FM transmissions with supplementary carriers. Lab. Rep. 109. Dept. of Communications (DOC), Belconnen ACT 2616, Australia.

GIELIS, G. C. M., PEEK, J. B. H. and SCHMIDT, J. M. [1980] Station and programme identification in FM sound broadcasting. *Philips Tech. Rev.* Vol. 39, 8, 216-225.

KOTIKOVA, R. A. and SAVITSKY, V. I. [1968] Peredacha nezavisimykh programm v odnom UKV ChM kanale (Transmission of independent programmes over a single VHF FM channel). *Trudy NIIR*, 2.

PEEK, J. B. H. and SCHMIDT, J. M. [September, 1978] A station programme identification (SPI) system for FM sound broadcasting. Proc. International Broadcasting Convention (IBC 78) London. IEE Conf. Publ. 166, 321-323.

SAVITSKY, V. I. [1966] O pomekhoustoichivosti priema uplotnennogo UKV ChM kanala (Immunity to interference in reception of a multiplexed VHF FM channel). *Sb. trudov Gos. NIIR Min sviazi U.S.S.R.*, 3, 48.

YAMAMOTO, T., MASUKO, Y. and YAMANE, H. [December, 1983] An experimental system of FM data-broadcasting. NHK Lab. Note 293.

Department of Communications (DOC Australia) [December,1986] 'VHF-FM Ancillary Communications Service with 67 kHz sub-carrier - Technical Report No.7'