REPORT 1065*

THE RF SPECTRUM OF FREQUENCY-MODULATION SOUND-BROADCASTING TRANSMITTERS

(Question 46/10, Study Programme 46L/10)

(1986)

1. Introduction

The RF spectrum of frequency-modulation sound-broadcasting transmitters is infinite in theory. In practice, the need may arise to have a precise knowledge of either the necessary (No. 146 of the Radio Regulations) or the occupied bandwidth (No. 147 of the Radio Regulations). For example, only when the occupied bandwidth is known, is it possible to plan for acceptable service in adjacent bands.

Rules for the calculation of the necessary bandwidth of emission for numerous services are laid down in the Radio Regulations and examples are given in Appendix 6 to these Regulations. According to these rules the necessary bandwidth of frequency-modulation emissions is calculated by using Carson's rule:

$$B_n = 2f_{max} + 2DK$$

where:

B_n : necessary bandwidth,

f_{max} : highest modulation frequency,

D : maximum deviation of the RF carrier,

K : factor which is largely undefined and in the examples set to be equal to 1.

In frequency-modulation sound broadcasting the maximum deviation is $D = 75$ kHz, and the highest modulation frequency $f_{max} = 15$ kHz or $f_{max} = 53$ kHz for monophonic or stereophonic emissions, respectively. When supplementary programme or information signals are transmitted, the corresponding value may be as high as 76 kHz.

With these values and $K = 1$ the necessary bandwidths resulting from the application of Carson's rule would be:

$B_n = 180$ kHz, $B_n = 256$ kHz, or $B_n = 302$ kHz, respectively.

* This Report should be brought to the attention of Study Group 1.

Measurement results, particularly when obtained for stereophonic emissions, differ greatly from the calculated values. In the light of Report 418 it is rather doubtful whether Carson's rule may be used in bandwidth calculations for stereophonic emissions, since the pre-supposition that $D \gg f_{max}$ is not met, and since consequently, a value $K \neq 1$ may have to be used.

Difficulties are also experienced when calculating the occupied bandwidth and also the out-of-band emissions. For example, no reference to out-of-band emissions in FM sound broadcasting is contained in Recommendation 328 "Spectra and bandwidths of emissions", although out-of-band emissions are defined there. Even Reports 275 and 324, which are quoted in the Recommendation and which deal with measurements of bandwidths of emissions, do not include any useful information with respect to this question. Measurements of the frequency spectrum of transmitters which are frequency-modulated with white noise are described in Report 977. However, the results of these measurements do not permit conclusions to be made with regard to the radio-frequency spectrum of frequency modulation sound-broadcasting transmitters. It was with this in mind that the measurements described below were performed [CCIR, 1982-86a].

2. Simulated programme signal

With respect to the time variations, there exists a close interrelation between the RF spectrum of an FM transmitter and the modulating programme signal. Therefore, only statistical information can be given either on the average power-density distribution or on the percentage of time for which certain levels are exceeded.

Because of the close interrelation of the RF spectrum and the modulating AF signal, the first aim was to determine a representative programme signal. For various measurements, the coloured noise described in Recommendation 559 is used to simulate a programme signal. The spectral power density distribution of this coloured noise is in rather good agreement with that of a representative non-compressed broadcasting programme. Because of its low dynamic range it is preferred for certain measurements. In the case of spectrum measurements however, an AF modulating signal should be used which has dynamic characteristics similar to those of an average broadcasting programme. For this purpose, the amplitude distribution of a non-compressed stereophonic broadcasting programme was determined over a period of one week. The continuous line in Fig. 1 shows the cumulative time distribution of programme levels for this AF signal. Moreover, the measurements showed that the day-to-day variations were less than 2 dB.

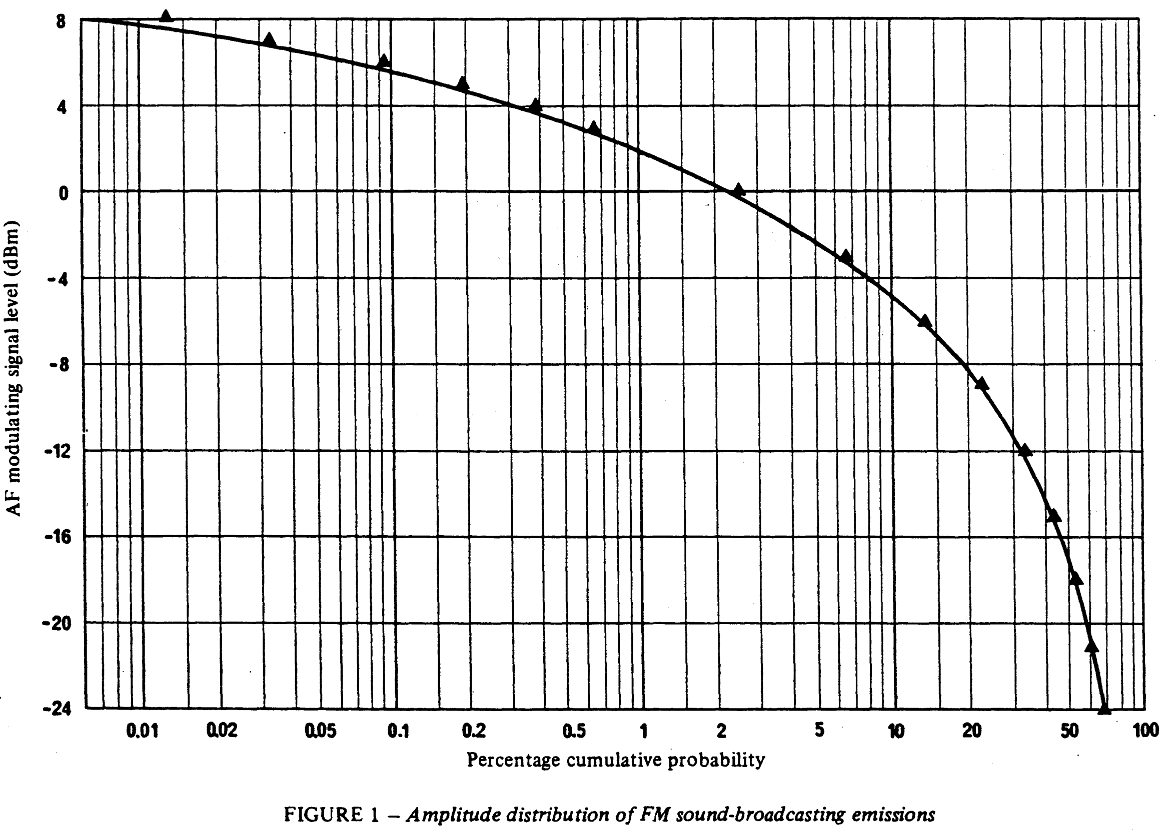

FIGURE 1 – *Amplitude distribution of FM sound-broadcasting emissions*

▲ : Distribution of the test-tape sequence of 60 programme samples (representative of a non-compressed high quality programme)

——— : Distribution of a week's programme

To reduce the time required for the measurements, samples of 1 min duration were taken at equidistant time intervals. In this way a sequence of 60 programme samples was obtained which is representative of a 24 hours stereophonic programme. This can be seen from Fig. 1, where the data points indicate the cumulative distribution of the sequence of samples. The use of this sequence of samples as a representatve substitution for a real programme is justified by the proximity of the data points to the curve in Fig. 1.

3. Measurements of spectra

Under certain assumptions the power-density spectrum of a time function can be measured with a spectrum analyser. As it was intended to determine not only the power-density distribution, but also spectra for different percentages of time, the spectrum analyser was only used as a filter having a noise bandwidth of 1.2 kHz and as a logarithmic demodulator. The analyser was tuned to various frequencies having different frequency separations from the RF carrier. By means of a stochastic counter connected to the output of the analyser, the percentage of time was determined during which various levels were exceeded. For this purpose, an RF signal generator whose output was directly connected to the analyser input, was frequency-modulated via a pre-emphasis network (50 μs) and a stereo coder by either coloured noise or by the AF signal representing a typical stereophonic programme. With coloured noise the frequency deviation was ± 32 kHz as in the method described in Annex I to Recommendation 641, while for AF signals the frequency deviation corresponded to normal operating conditions, i.e. ± 40 kHz when the AF signal is a 500 Hz sinusoidal tone at studio level (+6 dBm). This operating condition (CCITT maximum amplitude indicator (CCIR Report 292)) is obtained with a transmitter adjusted so that the maximum deviation in the stereo mode does not exceed ± 75 kHz.

Stereophonic measurements with coloured noise lead to a further problem. Until now FM transmitters were modulated with coloured noise in the monophonic mode only. If for the A and B channel the same noise source is used, both signals are correlated and thus no difference signal, S, is produced as long as the levels of A and B are equal. As two different noise sources with uncorrelated signals are not representative of broadcasting programmes, it is possible to find a solution based on the amplitude distribution of FM emissions. To be specific, the ratio of the sum signal M and the difference signal S was measured. Several measurements which were in good agreement with one another showed that on average:

$$M \approx S + 10 \text{ dB}$$

In the case of measurements with coloured noise in the stereophonic mode the appropriate levels were obtained by supplying different levels to the A and the B inputs to the stereo coder. The ratio chosen was:

$$A = B - 6 \text{ dB}$$

That means the signal level in the A channel was half that in the B channel. Thus one obtains on a linear scale:

Sum signal: $M = (A + B)/2 = 1.5\ B/2$

Difference signal: $S = (A - B)/2 = 0.5\ B/2$

and, consequently:

$$M = 3\ S$$

i.e. the M signal is roughly 10 dB greater than the S signal.

4. Results of measurements

Initially, the cumulative amplitude distribution with time was determined in various spectral bands, each 1.2 kHz wide, within the FM spectrum of a monophonic or stereophonic transmission. The unmodulated RF carrier served as a reference level (0 dB). Because of the limited dynamic range of the measuring arrangement (typically 85 dB) only in one case could measurements be made at frequency displacements up to 150 kHz. As the RF carrier in the monophonic mode remains unmodulated during programme pauses, the levels tend towards 0 dB at 0 kHz frequency difference and small time percentages. This result is in contrast to that obtained with coloured noise.

From the amplitude distributions measured, the power contained in the corresponding frequency bands can be calculated. The resulting power-density distribution within the frequency spectrum of an FM transmitter depending on the modulation mode and the simulated programme signal is depicted in Figs. 2 and 3. It should be noted that the power density is not related to 1 Hz, but the curve identified by "eff" is the level difference between the unmodulated RF carrier and the power measured within 1.2 kHz noise bandwidth.

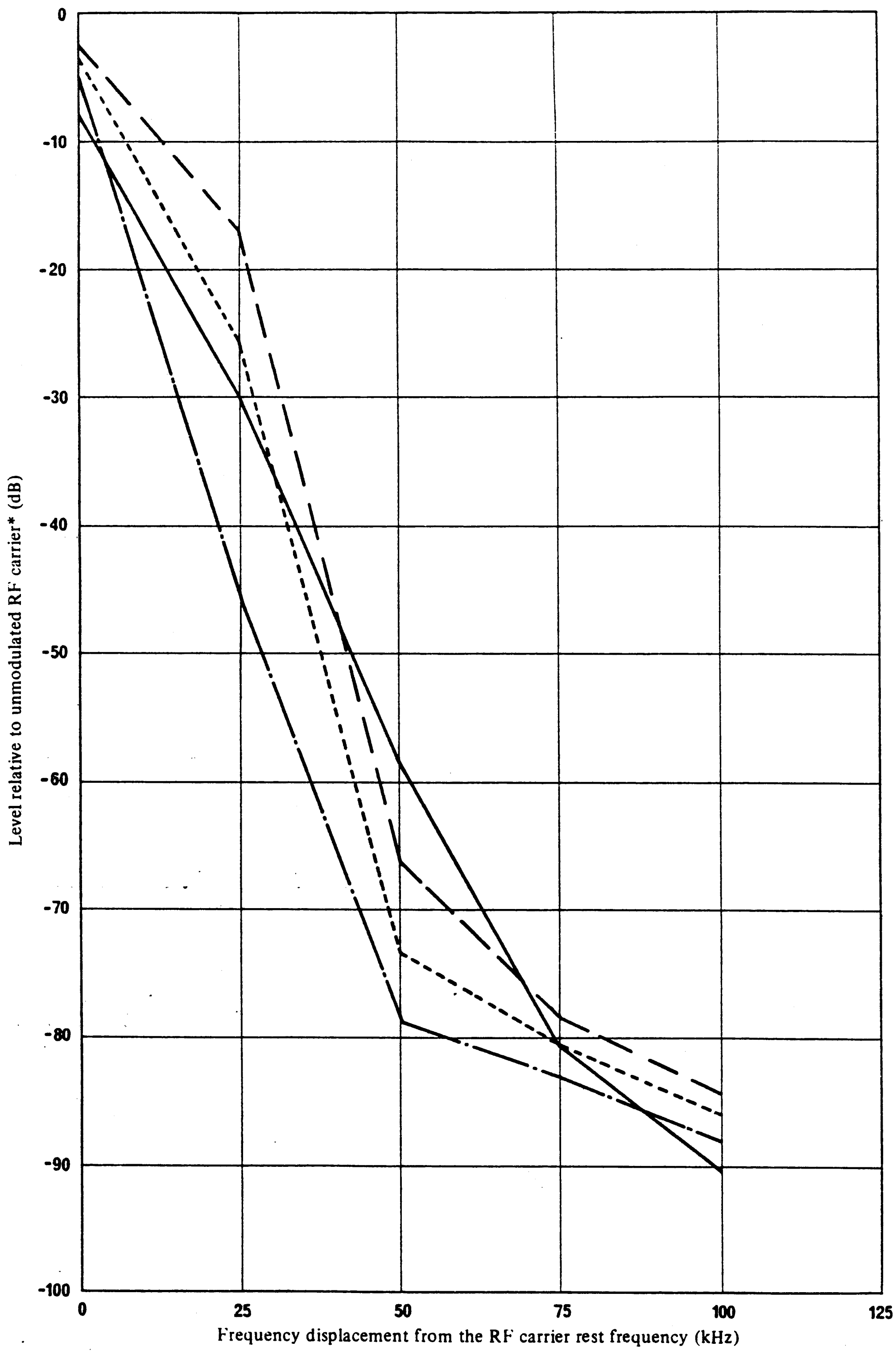

FIGURE 2 – *FM spectrum with programme (mono)*

— —	1%	time for which a level is exceeded
- - - - -	3%	time for which a level is exceeded
— · —	10%	time for which a level is exceeded
———	eff:	r.m.s. level

* Measured within 1.2 kHz noise bandwidth.

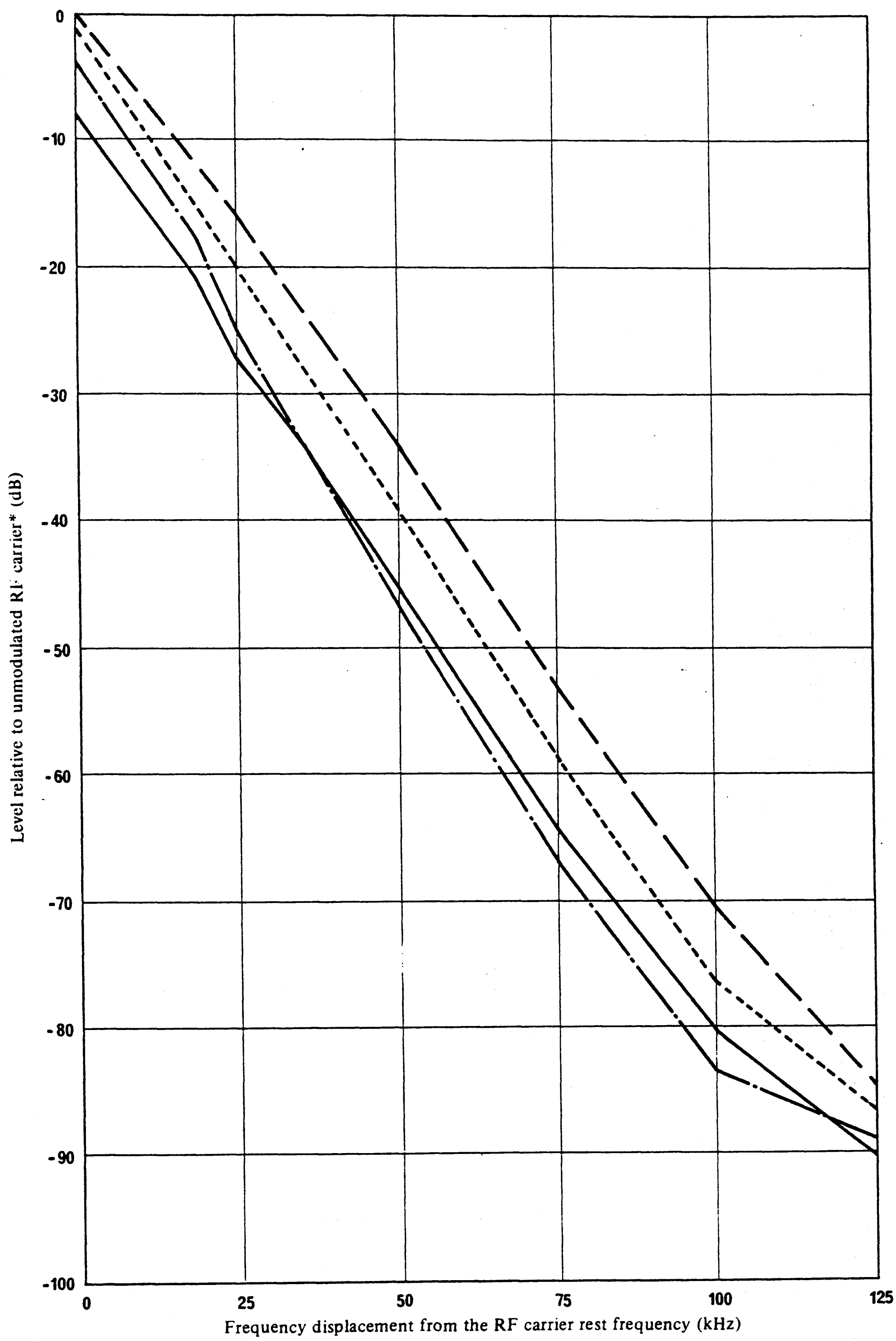

FIGURE 3 – *FM spectrum with programme (stereo)*

— —	1%	time for which a level is exceeded
- - - - - -	3%	time for which a level is exceeded
—·—	10%	time for which a level is exceeded
———	eff:	r.m.s. level

* Measured within 1.2 kHz noise bandwidth.

Frequently, not only the power-density distribution is of interest but also those levels which are exceeded or reached for small percentages of time. Therefore, the values corresponding to 1%, 3% and 10% of the time have been evaluated and depicted as curves in Figs. 2 and 3.

A comparison of those figures clearly shows that for stereophonic modulation the spectrum is wider than for monophonic modulation. It is worth mentioning that the frequency spectrum generated by the representative broadcasting programme is considerably smaller than that generated by coloured noise.

For the purpose of this study it was assumed that 99%* (99.9%) of the power of the FM signal is contained within the occupied bandwidth. Calculating the occupied bandwidth from the spectral power-density distributions, one obtains the following values:

- coloured noise, mono: B_n = 80 kHz (100 kHz)
- coloured noise, stereo: B_n = 74 kHz (112 kHz)
- programme, mono: B_n = 44 kHz (62 kHz)
- programme, stereo: B_n = 50 kHz (80 kHz)

In general, the spectra for stereophonic modulation are somewhat wider than for monophonic modulation. However, with coloured noise the occupied bandwidth calculated for 99% of the power is 6 kHz wider for monophony than for stereophony. This can be explained by the way the energy is distributed in the vicinity of the carrier.

However, when considering the necessary bandwidth, i.e. the bandwidth necessary to obtain a defined quality standard (e.g. small signal distortions) other values are obtained. If one accepts for instance, that outside the necessary bandwidth levels may exist for only 1% of the time which exceed -60 dB relative to the unmodulated RF carrier, a condition which corresponds to non-linear distortions $\leqslant$ 0.1%, one obtains the following bandwidths:

- coloured noise, mono: B_n = 147 kHz
- coloured noise, stereo: B_n = 211 kHz
- programme, mono: B_n = 94 kHz
- programme, stereo: B_n = 170 kHz

The values of occupied and necessary bandwidth both seem to be relatively small and the values for the occupied bandwidth differ from the values given elsewhere. The necessary bandwidth, however, depends on the quality requirements. A requirement for lower distortion or smaller percentages of time would lead to an increase in necessary bandwidth.

The results obtained may contain small errors due to the limited measuring accuracy. However, it can clearly be seen that modulation with coloured noise will lead to larger occupied and necessary bandwidths than a representative programme signal, for monophony as well as for stereophony.

5. Conclusions

On the basis of the measurement results presented, the RF bandwidths of FM sound-broadcast emissions are obviously smaller than one would expect from calculations using Carson's rule. The results obtained so far have not, however, suggested a more reliable formula to replace Carson's rule. Supplementary measurements and theoretical studies are needed to develop a reliable model describing the relationship between typical modulating signals and the associated values of the occupied or the necessary bandwidth in FM sound broadcasting.

It should be stressed that the measurement results presented are still insufficient to permit conclusions to be drawn with respect to the specification of passband characteristics of FM receivers.

REFERENCES

CCIR Documents

[1982-86]: a. 10/53 (Germany (Federal Republic of)).

BIBLIOGRAPHY

[1982-86]: 10/47 (Netherlands).

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* Unless otherwise specified by the CCIR (which is not the case as yet) the value of 99% is in agreement with No. 147 of the Radio Regulations.