RESEARCH DEPARTMENT

MULTIPLEX SYSTEMS FOR STEREOPHONIC BROADCASTING

Report No. G-084

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THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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SUMMARY

This report discusses various systems which have been proposed for broadcasting stereophonic programme from a single v.h.f. transmitter. The results of laboratory tests on two systems are summarized. The first is the Zenith-G.E. system, adopted in 1961 by the F.C.C. for stereophonic broadcasting in the U.S.A. and more recently recommended by the European Broadcasting Union. The second is a f.m. subcarrier system with modulation parameters modified as compared with the original proposal of Crosby. The results show that the two systems give comparable performance from the point of view of stereophonic and monophonic reception.

1. INTRODUCTION

The purpose of this report is to review the various proposals for stereophonic broadcasting from a single f.m. transmitter by the use of multiplex techniques. It pays particular attention to the experimental work undertaken by B.B.C. Research Department both in the interests of the Corporation and as part of a programme organized by Working Party S of the European Broadcasting Union. This work, and the work undertaken by other countries, was reviewed by a meeting of the Working Party in Milan in March 1962. Although a decision in favour of the Zenith-G.E. system was taken at that meeting, it is nevertheless considered worth while to give in this report a general discussion of multiplex systems, and to review the position as it appeared immediately prior to that meeting.

2. GENERAL CONSIDERATIONS

Systems for stereophonic sound broadcasting from a single v.h.f. transmitter that have been proposed to date fall into two categories; first, multiplex systems which are capable of providing two complete audio-frequency channels and, second, coded systems in which a narrow-band channel only is required in addition to the main audio-frequency channel. At the present stage of development the latter type of system suffers an appreciable loss or disturbance of stereophonic effects, essentially applying to all listeners, so that little advantage is offered over the "pseudo-stereophonic" systems, i.e. systems employing filter networks to produce arbitrary stereophonic effects from a monophonic programme. In this report, therefore, only the true multiplex systems will be discussed. Moreover, the systems considered will be of the type that transmit the sum of the two stereophonic signals as frequency modulation of the main carrier so that satisfactory monophonic reproduction is obtainable with an ordinary receiver.

Before stereophonic broadcasting, using a multiplex system, can be started two general questions must be considered.

(a) Which is the most advantageous multiplex system?

(b) What limitations of service would arise with transmissions on this system from existing stations using the same carrier frequencies and radiated powers?

Problems arising at the studio, and in feeding the programmes to the transmitters, are outside the scope of this report. It should be added that the above questions assume that what is required is a system which could be started making use of existing transmitters without seriously degrading monophonic reception. An alternative question, which will be considered only briefly, is as follows:

(c) Which is the most advantageous multiplex system for providing a good coverage for both monophonic and stereophonic listeners with a new network of stations, and what would the planning standards be?

In the following section, the theoretical performance of a number of systems is reviewed. Section 4 summarizes the results of laboratory measurements on two of the most promising, one of them being the Zenith-G.E. system, adopted for stereophonic broadcasting in the U.S.A. as from 1st June 1961, and the other a f.m. subcarrier system.

3. THEORETICAL COMPARISON OF SOME MULTIPLEX SYSTEMS

A characteristic of interest which can be obtained theoretically is the signal-to-noise ratio when the noise level is relatively small and arises from continuous sources of noise at the input of the receiver or in the first amplifying stages, rather than from noise developed in the audio-frequency amplifying stages.

Table 1 gives the degradation in signal-to-noise ratio, with respect to monophonic broadcasting, for both the monophonic listener and the stereophonic listener, for the same received r.f. signal level. (See Appendix.) The figures may also be taken to give the increase in input signal level needed to preserve the signal-to-noise ratio at the same value as for a monophonic transmission. In deriving these figures it is assumed that the stereophonic signals *A* and *B* are of equal power but uncorrelated. This is considered to give a fairer comparison between systems than if the assumption that the *A* and *B* signals are identical is made for the purpose of calculation. The degradation for monophonic reception of the Zenith-G.E. system of only 1 dB, as given by the F.C.C.,[1] is an example of the latter type of calculation; in practice the degradation would be expected to be greater, as has been confirmed by a special series of measurements on typical stereophonic programmes.[2] Correction of the theoretical figures of Table 1 to take into account a partial correlation between the *A* and *B* signals, and to allow for statistical effects in dual-channel programme limiters, would be required in a more refined assessment, but these corrections have not been included as they are reasonably small.

From Table 1 it is seen that the Loewe-Opta system, initially attractive because of the very simple adapter required, is poor on stereophonic performance compared with the others. Although some refinements such as the use of a floating

TABLE 1

SYSTEM	SUBCARRIER FREQUENCY	DEVIATION OF MAIN CARRIER AS A PERCENTAGE OF ±75 KC/S			DEVIATION OF SUBCARRIER	S/N RATIO DEGRADATION (dB)	
		by *M* signal:	by subcarrier:			*A*+*B* = *M* signal	*A* or *B* signal
F.M. Subcarrier systems							
1. I (Crosby)	50 kc/s	50%	50%		±25 kc/s	6·0	12·5
2. II (R.A.I.)	50 kc/s	67%	33%		±20 kc/s	3·5	17·6
3. III	50 kc/s	80%	20%		±20 kc/s	1·95	22·0
A.M. Subcarrier systems		by *M* signal when *A* ≡ *B*:	by subcarrier or peak sidebands:	by pilot:			
4. Loewe-Opta (full subcarrier)	35 kc/s	75%	25%	-		3·75	30·25
5. Zenith-G.E. (subcarrier suppressed)	38 kc/s	90%	90%	8–10% (19 kc/s)		3·85	21·5
6. Mullard	32·5 kc/s	52·5%	47·5% (65 kc/s)	5·3% (32·5 kc/s)		8·6	23·3
7. Siemens (lower sideband)	30 kc/s	94%	94%	6% (30 kc/s)		3·5	15·0

carrier have been recently incorporated in the system with a view to reducing certain types of interference, this does not affect the signal-to-noise degradation, and the system as modified requires an adapter comparable in complexity with that for the Zenith-G.E. system.

The Mullard system is seen from Table 1 to allow a relatively small deviation for the monophonic signal and compares unfavourably with the other systems in regard to the performance in monophonic reception. This was confirmed by the B.B.C. Research Department in an earlier series of experimental studies, the results of which were communicated to the European Broadcasting Union in 1960.

The Siemens system, which is attractive from a theoretical point of view, presents difficulties in receiver design. The close proximity in frequency of the subcarrier sidebands and the *M* signal is one contributory factor; there is also difficulty in regenerating a sufficiently stable subcarrier from the small pilot signal in the presence of sidebands, and the more successful experimental receivers in other respects introduced considerable cross-talk at the lower audio frequencies. It was reported at the Milan meeting of E.B.U. Working Party S that this system had recently been abandoned as a serious competitor by the Siemens Company and the West German Broadcasting Authorities.

The most promising systems left are the f.m. subcarrier systems and the Zenith-G.E. system. It is known that the latter system, adopted by the U.S.A., offers a good compromise between receiver complexity and stereophonic performance, and degrades the service range for monophonic reception by a small amount only. The f.m. subcarrier system II or III in Table 1 appears to offer an alternative with a somewhat similar theoretical performance. As the F.C.C. report[1] has indicated, however, a high-performance stereophonic receiver for a f.m. subcarrier system tends to require a rather more complex circuit than the corresponding Zenith-G.E. receiver.

It was with the above considerations in mind that the 1961/62 test programme of Working Party S of the European Broadcasting Union called for a close study of the performance of systems 2, 3, 5 and 7 in Table 1. As part of their contribution to this programme, B.B.C. Research Department has performed laboratory measurements on systems 3 and 5; these are discussed in Section 4 below.

4. EXPERIMENTAL WORK ON THE ZENITH-G.E. SYSTEM AND A F.M. SUBCARRIER SYSTEM

4.1. Zenith-G.E. System

For the tests in the laboratory a coder unit and two stereophonic adapters were constructed. The coder was used to modulate a f.m. signal generator. Three receivers, representative of low-, medium- and high-priced categories, were used for tests on monophonic reception, the medium- and high-priced models being used also for stereophonic reception. The first adapter for stereophonic reception was a well-engineered design intended to check the coder and investigate the system performance with high-grade equipment. The second adapter was intended to represent a commercial design of medium-priced domestic equipment. Since the second adapter proved to be as good in performance in all important respects as the first, the tests on the Zenith-G.E. system reported here will be confined to those on the second adapter.

Objective measurements of frequency response, cross-talk, intermodulation, distortion, non-linear cross-talk, signal-to-noise ratio and beat frequency interference were made, as specified in the E.B.U. test procedure. The subjective tests on two-station interference effects for various frequency separations also followed this test procedure. Additional tests were, however, made on impulsive interference and multipath distortion. The more interesting results are summarized in Table 2.

4.2. The F.M. Subcarrier System

In the Zenith-G.E. system the relative signal-to-noise ratio for monophonic and stereophonic reception is fixed. With the system considered here, however, the modulation parameters can be chosen to give any desired compromise between monophonic and stereophonic performance. A series of tests similar to those on the Zenith-G.E. system was made on a f.m. subcarrier system (No. 3 in Table 1) in which the parameters were adjusted to give, in theory, a stereophonic performance comparable with that of the Zenith-G.E. system. It was hoped by this means to obtain an experimental comparison which would be more revealing in respect of any fundamental advantage of the f.m. system.

It was not possible in the time available to develop a satisfactory "commercial design" of stereophonic adapter for the f.m. system and the results were obtained using a well-engineered adapter. The more interesting results of the corresponding series of tests for this system are given in Table 2. The same receivers were used for these tests as were used for the Zenith-G.E. system.

TABLE 2

Measured Characteristics

CHARACTERISTIC			ZENITH-G.E. SYSTEM		80%-20% F.M. SYSTEM	
			Monophonic reception	Stereophonic reception	Monophonic reception	Stereophonic reception
Degradation in signal-to-noise ratio (receiver noise) relative to monophonic broadcasting			1 dB*	23 dB (good receiver) 17 dB (medium-grade receiver)	2 dB	22 dB (good receiver) 14 dB (medium-grade receiver)
Degradation† of impulsive noise relative to monophonic broadcasting			very slight*	1 grade	slight (<½ grade)	1½ grades
	kc/s					
Increase of protection ratio above monophonic standards at given frequency separation (kc/s) (wanted and interfering transmissions stereophonic)	0		0 dB	7 dB	0 dB	4 dB
	50		0 dB	28 dB	3-11 dB‡	30 dB
	100		0 dB	19 dB	1-8 dB‡	24 dB
	200		0 dB	3 dB	1-3 dB‡	3 dB
	> 200		0 dB	2 dB	1 dB	4 dB
	miles	km				
Increase (+) or decrease (-) in multipath distortion for given path difference relative to distortion in monophonic broadcasting†	2	3·2	-½ to -1 grade	+3 grades	+½ to -½ grade	+1 grade
	3	4·8	-1 "	+2 "	0 to -1 "	+1 "
	5	8	-½ "	+1 grade	-½ "	+½ "
	8	13	0 to -½ "	+1 "	-½ "	+½ to +1 grade
	10	16	0 to -½ "	-½ "	-½ "	+½ to +1 "
	13	21	0 "	+½ to +1 grade	0 "	+1 grade
	15	24	0 "	+½ grade	0 "	+1 "

*Objective measurement with $A \equiv B$; about 3 dB greater in practice (depending on programme) in the case of monophonic reception of the Zenith-G.E. system.

†In subjective grades: "just perceptible", "perceptible", "slightly disturbing", "disturbing".

‡Depends on class of receiver

4.3. Discussion of Experimental Results

The distortion, audio-frequency bandwidth, intermodulation etc. can be made satisfactory for both monophonic and stereophonic reception with either of the two systems and detailed results for these characteristics have not, therefore, been given. These tests served mainly to check that the equipment was operating correctly, the performance being determined by receiver instrumentalities rather than by the nature of the systems.

This is equally true of cross-talk, but since this aspect of performance is fundamental to stereophony, the results of the tests will be briefly mentioned. With both systems the cross-talk was below the levels quoted by the European Broadcasting Union as the limit of perceptibility* and this was confirmed by listening tests. The f.m. subcarrier system was found to give a slightly better performance at the higher audio frequencies, but the receiver adapter used for this system was more complex than that used for the Zenith-G.E. system and included correction for differential time-delays in the sum and difference channels.

The signal-to-noise ratio measurements with a good receiver accord well with theory. In the case of monophonic reception of the Zenith-G.E. system, but not the f.m. subcarrier system, it must be borne in mind that the measured figure in Table 2 is optimistic because the test procedure employs identical signals in the stereophonic channels; it should be corrected by adding 3 dB in order to correspond to the conditions for which the calculations in Table 1 were made.

*These levels are -26 dB from 100 c/s to 5 kc/s, falling to -20 dB at 10 kc/s and -16 dB at 15 kc/s.

The measured degradation for stereophonic reception was smaller when the medium-grade receiver was used in place of the good receiver, not because the stereophonic signal-to-noise ratio was better with the medium-grade receiver, but because it was poorer for monophonic reception - the reference condition.

It is important in this connexion to consider the absolute signal-to-noise ratio possible with stereophonic reception when limited only by receiver noise. Thus a well-designed receiver with a noise factor of 4 dB would give a signal-to-noise ratio, relative to 40% modulation, of 54 dB with a signal input level of 250 μV (75 ohm). This input voltage would be obtained at the nominal limit of the service area (250 μV/m field strength) with a single half-wave dipole at 30 ft (9 m). This example is calculated on the basis of the Zenith-G.E. system but, as shown in Table 1, both systems considered give substantially identical performance in this respect.

Turning now to the question of impulsive interference, the B.B.C. experimental tests showed the f.m. subcarrier system to be only slightly worse than the Zenith-G.E. Some other workers have obtained results which show the f.m. subcarrier system to give a considerably greater degradation with stereophonic reception, but this is probably due to differences in receiver and adapter design. The adapter used in the B.B.C. tests was designed with particular attention to efficient and symmetrical limiting of the subcarrier, the bandwidth before limiting being restricted specifically in order to obtain the best performance in the presence of interference.

Comparing the two systems for interference to monophonic (compatible) reception due to unwanted co-channel transmissions or adjacent-channel transmissions (up to 200 kc/s separation), the Zenith-G.E. system requires no extra protection at any frequency separation, while the f.m. subcarrier system requires no extra protection for co-channel interference, a slight increase for 200 kc/s separation (1 to 3 dB depending on receiver performance) and more significant increases for 50 and 100 kc/s separations in the case of some receivers.

In the case of stereophonic reception, the results given in Table 2 apply to comparison tests using the same receiver up to the discriminator, first for monophonic reception of a monophonic transmission and then (in conjunction with an adapter) for stereophonic reception of a transmission according to the appropriate system. Significant increases in co-channel protection ratio are required by both systems, the larger increase being required by the Zenith-G.E. system. In the case of 50 kc/s and 100 kc/s frequency separation, relatively large increases are required. It appears that better receiver design would not greatly improve the performance for separations up to 100 kc/s. At 200 kc/s separation the increase in protection ratio is relatively small as indicated by the comparison tests. Moreover, in receivers designed for stereophonic reception, any small increase of protection required against interference from transmissions at carrier separations of 200 kc/s or more could be compensated relatively easily by a careful control of the i.f. response, if necessary with an extra pair of tuned circuits.

The discussion on interference has hitherto been based on interfering transmissions which are stereophonic. Experiments with the unwanted signal monophonic show that in the majority of cases there is little difference in the interference caused. Where there is a significant difference, namely for stereophonic reception with frequency separations of about 100 kc/s, the interference is less severe for a monophonic unwanted signal. For example, the respective increases in protection ratios at 100 kc/s separation become 10 dB and 15 dB for the Zenith-G.E. and f.m. subcarrier systems instead of 19 dB and 24 dB as given in Table 2.

While the performance of the two systems in regard to interference appears comparable in Table 2, the adapter used for the Zenith-G.E. system was much simpler than that used for the f.m. subcarrier system. This is because, as mentioned in Section 4.2, it appeared difficult to design for the latter system a relatively simple adapter which could approach the more complex adapter in performance. With either system, experimental work tended to confirm that adjacent-channel interference is reduced not only by a good i.f. response characteristic in the main receiver but also by using the minimum bandwidth permitted by the system in the subcarrier signal circuits of the adapter. In general, this requirement complicates the adapter not only through the presence of the necessary filters but also by the need for correction in the main $A+B$ channel for the time delay in the subcarrier channel. There is, however, a relatively simple method by which the requirements can be largely fulfilled in the case of the Zenith-G.E. system. This was used in the simple adapter for this system, and is based on the provision of a single tuned circuit, centred on the subcarrier frequency of 38 kc/s in the subcarrier channel prior to the a.m. detector. The bandwidth is adjusted so that the attenuation of the sidebands provides de-emphasis of the detected audio-frequency output signal. With this arrangement the output can be combined with the de-emphasized main-channel signal without delay correction and still provide stereophonic signals with a satisfactory cross-talk performance.

Finally, on the question of multipath distortion, the comparison in Table 2 shows a complex pattern of behaviour, neither system showing a clear-cut advantage for all path-differences. It is encouraging, in the first place, that any effects that occur for monophonic reception are always beneficial, i.e. multipath distortion would be, if anything, reduced for the monophonic listener were either of the two systems to be used. In stereophonic reception, with the Zenith-G.E. system, any increase of distortion tends to be nil or quite small at the longer path differences, but large at the shorter path differences, while with the f.m. subcarrier system a slight increase occurs at all path-differences.

5. CONCLUSIONS

Assuming a requirement that the service to the monophonic listener should be substantially unchanged with the commencement of stereophonic broadcasting from existing transmitters, the B.B.C. Research Department tests show that either the Zenith-G.E. system or a 80%-20% f.m. subcarrier system would satisfy this requirement.

In the case of stereophonic reception the same two systems appear very comparable in overall merit; although differences are apparent, they are not very great and the results favour one system in some characteristics and the other system in other characteristics. Thus the f.m. subcarrier system is slightly inferior for impulsive interference, for interference at 100 kc/s channel separation and under long-path-difference multipath conditions. Also on present experience, it does not lend itself so well to the use of a simple design of adapter. On the other hand the Zenith-G.E. system is slightly inferior for co-channel interference, and is considerably worse for multipath reflexions where short path-differences of only two or three miles are concerned.

With either of these systems, the laboratory tests have confirmed that listeners within the 2 mV/m field-strength contour (previously estimated for the stereophonic service limit) would get a good service, since this corresponds to a limiting field strength 18 dB above the monophonic service limit. A factor qualifying this statement is the increase in multipath distortion in stereophonic reception which, in certain situations, might be serious with the Zenith-G.E. system.

For listeners outside the 2 mV/m contour, but within the present-day service limit of 250 μV/m, monophonic reception would be only slightly degraded with either system. Any effect observed would be roughly equivalent to that caused by reducing the degree of modulation at the transmitter by 3 dB. A possible exception is the case of listeners at present near the limit of protection against a station spaced 50 to 100 kc/s in frequency. Stereophonic reception in the 250 μV/m to 2 mV/m range depends on many factors including the quality of the receiver and the type of aerial. It is apparent from the laboratory tests that increased interference from sources of continuous noise or impulsive noise may occur, and that, where the existing protection is near the limit, there may be interference from stations operating on the same channel or at frequency spacings below 200 kc/s.

These conclusions are based on B.B.C. Research Department tests. At the Milan, 1962, meetings of E.B.U. Working Party S information on tests by other countries became available and in general agreed with the B.B.C. findings. It was against this background, and with the awareness of the choice made in the U.S.A. that a decision to recommend the Zenith-G.E. system was made. In giving their recommendation the E.B.U. reserved the right to reconsider the position if, as a result of field trials in difficult reception conditions, it should appear that the Zenith-G.E. system was unsatisfactory. However, those countries who wish to start a stereophonic service in the near future would be advised to observe the recommendation in order to simplify planning standards in Europe.

Question (c) mentioned in Section 2, concerning the optimum system for a new network, has not been studied experimentally. It might well be that a f.m. subcarrier system with standards close to those of system 1 in Table 1 would be a good choice in this case, since the signal-to-noise ratios for monophonic and stereophonic reception are brought closer together than in any of the other systems. Since the main interest in Europe has been in systems with good compatibility, and a system of this type has been selected, further consideration of this point is not given in this report.

6. REFERENCES

1. Report and Order of the Federal Communications Commission, Docket 13506: "Amendment of Part 3 of the Commission's Rules and Regulations to Permit F.M. Broadcast Stations to Transmit Stereophonic Programs on a Multiplex Basis", April 1961. See Audio, Vol. 45, No. 6, p. 18, June 1961.

2. "Determination of the Effective Modulation Depth of Monophonic Programme Transmitted on the Zenith-G.E. Stereophonic System", Research Department Report No. L-050, Serial No. 1962/13.

7. APPENDIX

This appendix gives the basic formulae for the theoretical signal-to-noise ratios for multiplex systems. They apply on the assumptions that the output noise level arises from a continuous source of noise at the receiver input or first amplifying stages and that the signal-to-noise ratio is high.

7.1. List of Symbols

A, B = audio-frequency signals in left and right stereophonic channels

M, S = sum $(A+B)$ and difference $(A-B)$ audio-frequency signals

$\pm H_0$ = peak frequency-deviation in standard monophonic broadcasts ($\pm$ 75 kc/s)

$\pm H_m$ = peak frequency-deviation of main carrier by M signal (f.m. subcarrier systems)

f_s = frequency of subcarrier

$\pm H_s$ = peak frequency-deviation of main carrier by subcarrier

$\pm h_s$ = peak frequency-deviation of subcarrier by S signal (f.m. subcarrier systems)

$\pm H'_m$ = maximum deviation of main carrier by the M signal possible when $A = B$ (no S signal)

$\pm H''_m$ = maximum deviation of main carrier by the M signal possible with a finite A signal input and zero B signal input

$f_a = \omega_a/2\pi$ = maximum audio frequency

τ = pre-emphasis time constant

a_1 = r.m.s. signal-to-noise ratio improvement factor* for pre-emphasis in a.m.

$$= \left[\frac{\arctan \omega_a\tau}{\omega_a\tau}\right]^{-\frac{1}{2}}$$

a_2 = r.m.s. signal-to-noise ratio improvement factor* for pre-emphasis in f.m.

$$= \frac{\omega_a\tau}{\sqrt{3}}\left[1 - \frac{\arctan \omega_a\tau}{\omega_a\tau}\right]^{-\frac{1}{2}}$$

*These factors do not include correction for reduced modulation at the lower audio frequencies, i.e. they assume that the modulation level at low audio frequencies remains constant when pre-emphasis is applied.

b = factor of reduction of modulation at the lower audio frequencies applied in conjunction with pre-emphasis, compared with the modulation in a system without pre-emphasis. (Expressed as voltage ratio <1.)

N = noise factor of receiver (power ratio)

V_0 = receiver input signal voltage corresponding to an available power of 1 mW

V_r = actual receiver input signal voltage.

7.2. Performance on Monophonic Transmissions

The r.m.s. signal-to-noise ratio for a 100% modulated double-sideband amplitude-modulated transmission, no pre-emphasis being used, is

$$\left(\frac{10^{-3}}{2kT_0}\right)^{\frac{1}{2}} \cdot \frac{V_r}{V_0} \cdot \frac{1}{(N\ f_a)^{\frac{1}{2}}} \tag{1}$$

where $(10^{-3}/2kT_0)^{\frac{1}{2}} = 3{\cdot}55 \cdot 10^8$, taking kT_0 as the available thermal noise power per unit bandwidth at room temperature ($T_0 = 290°$K).

The f.m./a.m. improvement factor for r.m.s. signal-to-noise ratio, for a standard monophonic f.m. transmission, is

$$\frac{\sqrt{3}\ H_0}{f_a} \cdot a_2 b \tag{2}$$

The r.m.s. signal-to-noise ratio for a monophonic f.m. transmission may be derived from the product of expressions (1) and (2). Thus, for the U.K. standards, H_0 = 75 kc/s, τ = 50 μs and b = 0·63 (−4 dB); taking f_a = 15 kc/s and N = 5 (noise factor of 7 dB), a theoretical signal-to-noise ratio of 67·2 dB is obtained with an input carrier level of −80 dB (mW). The reference signal in this case corresponds to a deviation of ± 47 kc/s (0·63 times ± 75 kc/s) at a low audio frequency such as 400 c/s.

7.3. Degradation Factors for Stereophonic Transmission

The theoretical noise performance of multiplex stereophonic systems is summarized in Table 3 in the form of degradation factors for the r.m.s. signal-to-noise ratio relative to monophonic f.m. transmission performance.

The calculations in the case of monophonic reception have been based on the reduction in deviation of the main carrier by the A+B signal as compared with the ± 75 kc/s deviation for a monophonic transmission. In the case of the f.m. subcarrier system there is a definite limit to the amplitude of the $M = A+B$ and of the $S = A-B$ signal that can be transmitted, while in the a.m. subcarrier systems the limit is more complex. However, for an a.m. subcarrier system with 50% deviation allocated to the subcarrier, or when the subcarrier is suppressed leaving the upper and lower sidebands, it turns out that there is a definite limit to the amplitude of the A and B

TABLE 3

Theoretical r.m.s. signal-to-noise ratio degradation factors

	F.M. SUBCARRIER SYSTEM	A.M. SUBCARRIER SYSTEM
Monophonic reception (M signal) (i) for $A = B$ (ii) for uncorrelated A and B signals of equal power	(i) and (ii) $\frac{H_m}{H_0}$	(i) $\frac{H'_m}{H_0}$ (ii) $\frac{(H'_m\ H''_m)^{\frac{1}{2}}}{H_0}$*
Subcarrier channel (S signal) at maximum modulation	$\frac{H_s h_s}{\sqrt{2}\ H_0 f_s}$	$\frac{H_s f_s a_1}{\sqrt{6}\ H_0 f_s a_2}$
Stereophonic channel (A signal) for uncorrelated A and B signals of equal power	$\frac{H_s h_s}{H_0 f_s}$	$\frac{H_s f_s a_1}{\sqrt{6}\ H_0 f_s a_2} \cdot \left(\frac{2H''_m}{H'_m}\right)^{\frac{1}{2}}$

*This is an approximation assuming $1 \leqslant H'_m/H''_m \leqslant 2$.

Notes:

(1) In the f.m. subcarrier system, $H_m + H_s$ normally equals H_0 in order to give a total deviation equal to that used in monophonic transmissions.

(2) In the a.m. subcarrier system employing the full subcarrier component with double-sideband modulation, it may be shown that the conditions for a total deviation of $\pm H_0$ and no overmodulation of the subcarrier are respectively $H'_m = H_0 - H_s$ and $H''_m = (H_0 - H_s)^2/H_0$.

(3) In the a.m. subcarrier system (double sideband) with partial or complete suppression of the subcarrier component, H_s must be taken as the deviation of the main carrier by the subcarrier that would be needed supposing that the subcarrier were fully restored before transmission.

(4) For the Siemens system (single sideband a.m. subcarrier) and Mullard system (two effective subcarriers) the appropriate corrections have been made in Table 1 of the report but the details are not given here.

signals that may be transmitted. Other elements in the chain (audio-frequency amplifiers, recording machines, land lines etc.) do not generally place a very rigid limit in the signal amplitudes in either the M and S or the A and B form. Thus, with the f.m. subcarrier system, it is assumed that the programme level may be adjusted in all cases so that the peaks of the $A+B$ signal give the full deviation of the main carrier allocated to it. Only in very exceptional types of programme would this procedure overload the f.m. subcarrier channel carrying the S signal. In the case of a.m. subcarrier systems a different criterion is necessary in achieving the optimum modulation level. Thus when the A and B signals are subject to a definite limit, the programme level would be adjusted so that these signals take up the permitted peak levels. The $A+B$ modulation provided for the monophonic listener then depends on the degree of correlation between the A and B signal waveforms. The result for uncorrelated A and B signals of equal mean power corresponds most closely with the average result obtained in practice.[2]

When stereophonic reception is considered, the signal-to-noise ratio of the subcarrier channel relative to a monophonic transmission channel is first evaluated. For high signal-to-noise ratios, it may be shown that modulation of a subcarrier which deviates the main carrier by $\pm\sqrt{2}$ radians is equivalent in performance to the same type of modulation applied directly to the main carrier instead. Since monophonic f.m. transmission is used as a reference in Table 3 the expression for the S signal is straightforward for f.m. subcarrier systems but, in the case of a.m. subcarrier systems, the effects of pre-emphasis in a.m. and of losing the f.m./a.m. improvement factor must be included.

Finally, for evaluating the performance of the stereophonic channels, allowance must be made for occupation of both the A and B channels. The results given in Table 3 for the A signal assume that modulation levels are set up as discussed above, and that the A and B signals are of equal mean power but uncorrelated. The noise from the main signal channel has been neglected for simplicity since it is usually small compared with the noise at the output arising from the subcarrier channel.

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