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562-574 Bourke Street, Melbourne

TELEPHONE: 602-0151 CODE ADDRESS: CONBOARD, MELBOURNE

ENGINEERING SERVICES DIVISION

REPORT NO. 39

TITLE: SIGNAL STRENGTH REQUIRED FOR A FREQUENCY MODULATION RECEIVER

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ENGINEERING REPORT NO. 39

TITLE: SIGNAL STRENGTH REQUIRED FOR A FREQUENCY MODULATION RECEIVER.

AUTHOR: G.T. MARTIN - FORWARD PLANNING AND DEVELOPMENT SECTION

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(E. J. Wilkinson)
Director
Engineering Services Division.

SUMMARY

Expressions are derived to compare signal to noise ratios for mono FM and pilot tone stereo FM including the effect of de-emphasis.

A general equation giving the signal strength required for an FM receiver operating in a white gaussian noise field is developed.

Compatabilities of different de-emphasis time constants are investigated, and the effects of Dolby-B processing are discussed.

The minimum signal strength for a perfect receiver under noise free conditions is given. Measured performance of a number of FM receivers is discussed and compared with the theoretical results; agreements showns are reasonably good.

SIGNAL TO NOISE RATIO COMPARISON : MONO FM, PILOT TONE STEREO FM, INCLUDING DE-EMPHASIS.

(based on Ref. 1)

Firstly equations are developed for the signal to noise ratio in a mono FM radio operating above threshold.

Assume that the I.F. amplifier is flat topped and sufficiently wide to transmit the signal given by

$$M(t) = A_c \sin(\omega_c t + \beta \sin \omega_v t)$$

M(t) is the instantaneous signal at the I.F. output, A_c is the peak carrier voltage, ω_c is the carrier frequency and ω_v is the modulating frequency. β is the modulation index, the ratio of the carrier deviation to the modulating frequency.

If the signal is passed through a discriminator with a slope of m volts per radian, then the discriminator output is $e_s = m\omega_f \cos \omega_v t$

ω_f is the deviation.

and the average signal power into a normalised 1 ohm load is

$$S_o = \frac{m^2 \omega_f^2}{2} \quad \text{watts.}$$

The electrical incremental noise output of the discriminator caused by an I.F. noise component of ΔN is:

$$e_n = m \frac{\Delta N}{A_c} \omega_n \cos(\omega_n t + \phi)$$

ω_n is the noise deviation.

Incremental normalised detector noise power is

$$dN_n = \frac{m^2}{2} \left(\frac{\Delta N}{A_c}\right)^2 \omega_n^2$$

If the incremental I.F. noise power in watts per hertz is designated by n,

$$n\,df = \frac{(\Delta N)^2}{2}$$

So

$$dN_n = m^2 \frac{\omega_n^2}{A_c^2} n\,df$$

normalised peak I.F. carrier power is

$$P_c = \frac{A_c^2}{2}$$

then

$$dN_n = \frac{m^2 \omega_n^2}{2 P_c} n \, df$$

$$= \frac{2\pi^2 m^2 n f_n^2}{P_c} df$$

The total noise in the discriminator output is produced by all noise components which can beat with the carrier to produce a signal falling within the rectangular audio passband, -B to +B.

Total noise is

$$N_o = \frac{n m^2}{2 P_c} \int_{-B}^{+B} \omega_n^2 \, df$$

$$= \frac{4\pi^2 m^2 n}{3 P_c} B^3$$

Hence the signal to noise power ratio is

$$\frac{S_o}{N_o} = \left(\frac{m^2}{2} \cdot 4\pi^2 f_f\right) \Big/ \left(\frac{4}{3} \pi^2 m^2 \frac{n}{P_c} B^3\right)$$

$$= \frac{3}{2} \left[\frac{f_f}{B}\right]^2 \frac{1}{B} \cdot \frac{P_c}{n} \quad = \quad \frac{3}{2} \beta^2 \cdot \frac{1}{B} \cdot \frac{P_c}{n}$$

<u>De-emphasis</u>

Using a single pole de-emphasis filter of cut-off frequency fo, audio power is reduced in the ratio $\dfrac{1}{1 + f^2/f_o^2}$

Noise output with the de-emphasis filter is

$$N_d = \int_{-B}^{+B} \frac{dN_n}{1 + f^2/f_o^2} df$$

$$= \frac{4\pi^2 m^2 n}{P_c} \left[B f_o^2 - f_o^3 \arctan\left(B/f_o\right) \right]$$

and the improvement factor due to de-emphasis is :

$$\frac{B^3}{3\left[B f_o^2 - f_o^3 \arctan\left(\frac{B}{f_o}\right)\right]}$$

Subcarrier Multiplex operation

In this section, a single frequency subcarrier frequency modulating the carrier is first considered, then amplitude modulation of the subcarrier, with the subcarrier suppressed, is considered.

If the carrier is modulated by a single subcarrier frequency f_s to a deviation f_f,

$$M(t) = A_c \sin\left(\omega_c t + \frac{f_f}{f_s} \sin \omega_s t\right)$$

discriminator output voltage is

$$e_{sc} = m \omega_f \cos \omega_s t$$

and the normalised power is

$$P_{sc} = \frac{m^2 4\pi^2 f_f^2}{2}$$

If the subcarrier signal is passed through a rectangular bandpass filter with cutoff frequencies B_1 and B_2 the normalised noise power output is

$$N_{BP} = \frac{2m^2\pi^2 n}{P_c}\left[\int_{-B_2}^{-B_1} f^2 df + \int_{B_1}^{B_2} f^2 df\right]$$

$$= \frac{4\pi^2 m^2 n}{3P_c}\left(B_2^3 - B_1^3\right)$$

If f_f is the maximum allowable carrier deviation, and the subcarrier uses a portion p of this deviation, the signal power is reduced by a p^2 factor, and the S/N ratio becomes

$$\frac{P_{sc}}{N_{BP}} = \frac{3p^2 f_f^2 P_c}{2n\left(B_2^3 - B_1^3\right)}$$

If fs is in the centre of the passband, and the filter half bandwidth is Ba,

$$B_2 = f_s + B_a$$
$$B_1 = f_s - B_a$$

then $B_2^3 - B_1^3 = 6 f_s^2 B_a + 2 B_a^3$

So $$\frac{P_{sc}}{N_{BP}} = \frac{3p^2 f_f^2}{4(3f_s^2 B_a + B_a^3)} \cdot \frac{P_c}{n}$$

An approximation to the above equation can be derived by assuming the noise power in the passband is constant with frequency, rather than parabolic.

Taking a value of incremental noise corresponding to the subcarrier frequency, and assuming this holds constant across the passband :

$$dN_n = \frac{2\pi^2 m^2 n f_s^2}{P_c} df$$

$$N'_{BP} = \frac{2\pi m^2 n f_s^2}{P_c}\left[\int_{-B_2}^{-B_1} df + \int_{B_1}^{B_2} df\right]$$

$$= \frac{8\pi^2 m^2 n}{P_c} f_s^2 B_a \qquad (\text{because } B_2 - B_1 = 2B_a)$$

and

$$N_{BP} = \frac{8\pi^2 m^2 n}{3P_c}\left(3f_s^2 B_a + B_a^3\right)$$

Comparing the approximate and the accurate expressions, the Ba^3 term represents the parabolic effect.

For a pilot tone system, $f_s > 2B_a$, and the parabolic term adds less than ½db, so the approximate expression is sufficiently accurate.

When the subcarrier is amplitude modulated by an audio signal $v(t)$ with a modulation factor k, the bandpass filter output voltage is

$$e_f = mpf_f \, 2\pi\left[1 + k\,v(t)\right]\cos(\omega_{sc}t + \phi)$$

If the carrier is suppressed,

$$e_f = mpf_f \, 2\pi k \; v(t) \; \cos(\omega_{sc}t + \phi)$$

for this the peak value is

$$\hat{e}_f = 2\pi mpf_f$$

and the normalised mean power is

$$P_f = 2\pi^2 m^2 p^2 f_f^2$$

Using the approximate expression for noise output from the bandpass filter derived previously, the signal to noise power ratio at the subcarrier demodulator is:

$$\frac{P_f}{N_d} = \frac{p^2 F^2}{4 f_s^2 B_a} \cdot \frac{P_c}{n}$$

De-emphasis of Subcarrier Channel

When the demodulated subcarrier signal is passed through a single pole de-emphasis filter of cutoff frequency Bo, subcarrier audio noise is reduced in the power ratio

$$\frac{P_o}{P_{in}} = \frac{1}{1 + f^2/B_o^2}$$

The subcarrier audio incremental noise becomes

$$dN' = \frac{2\pi^2 m^2 n f_s^2}{P_c} \cdot \frac{1}{1 + \frac{B_a^2}{B_o^2}} \cdot df$$

and the total subcarrier noise is

$$N_d' = \frac{8\pi^2 m^2 n f_s^2}{P_c} \int_0^{B_a} \frac{1}{1 + f^2/B_o^2}\, df$$

$$= \frac{8\pi^2 m^2 n f_s^2}{P_c} B_o \operatorname{artan}\left(\frac{B_a}{B_o}\right)$$

Note that the audio bandwidth has been taken as the half bandwidth of the subcarrier bandpass filter, Ba.

Noise reduction due to de-emphasis is

$$\frac{N_d}{N_d'} = \frac{B_a}{B_o \operatorname{artan}(B_a/B_o)}$$

and signal to noise power in the subcarrier channel with de-emphasis is:

$$\frac{P_f}{N_d'} = \frac{P_c}{n} \cdot \frac{p^2 F^2}{4 f_s^2 B_o \operatorname{artan}(B_a/B_o)}$$

Having obtained expressions for signal to noise ratio for both the main and subcarrier channels (M & S), the combined effect on the stereo signal must be deduced.

If the left and right channel voltages are e_ℓ and e_r respectively, the M channel voltage is $e_\ell + e_r$, and the S channel voltage is $e_\ell - e_r$

To recover the stereo channels, the M and S channels are added and subtracted.

$$2e_\ell = e_m + e_s$$

$$2e_r = e_m - e_s$$

When $e_\ell = e_r$, $e_m = 2e_\ell$ and $e_s = 0$

So the peak voltage in either M or S channels equals $2\hat{e}_\ell$ or $2\hat{e}_r$

If e_t is the voltage corresponding to full deviation, let

$$p_1 \hat{e}_\ell + p_2 \hat{e}_r + p_3 \hat{e}_{pc} = e_t$$

where $p_1 + p_2 + p_3 = 1$

and $\hat{e}_{pc}$ is the peak pilot carrier voltage.

If $p_3 = 0.1$

and $p_1 = p_2 = 0.45$

then $2\hat{e}_\ell = 0.9\, e_t$

and $2\hat{e}_r = 0.9\, e_t$

then the normalised maximum carrier power for left or right stereo channels is

$$P_{c_\ell} = P_{c_r} = 4 p_1^2 P_{o_m}$$

where is the maximum mono carrier power.

Thus the stereo signal to noise ratio (identical for each channel) is

$$\frac{P_s}{N_s} = \frac{P_c}{n} \cdot \frac{4p^2 P_{o_m}}{8\pi^2 m^2 f_s^2 B_o \operatorname{artan}\left(\frac{B_a}{B_o}\right) + 4\pi^2 m^2 \left[B f_o^2 - f_o^3 \operatorname{artan}\left(\frac{B}{f_o}\right)\right]}$$

where p=0.45, and we are adding the noise power contributions from both the M and S channels.

$$\text{now} \quad P_{o_m} = S_o = 2\pi^2 F^2 m^2$$

So the ratio of mono signal to noise to stereo signal to noise is:

$$\frac{P_{o_m}/N_a}{P_s/N_s} = \frac{\dfrac{P_c}{n} \cdot \dfrac{F^2}{2\left[2Bf_o^2 - f_o^3 \text{ artan}(B/f_o)\right]}}{\dfrac{P_c}{n} \cdot \dfrac{2p_2^2F^2}{2\left[f_s^2 B \text{ artan}\left(\dfrac{B_a}{B_o}\right) + Bf_o^2 - f_o^3 \text{ artan}\left(\dfrac{B}{f_o}\right)\right]}}$$

$$= \frac{f_s^2 B_o \text{ artan}\left(B_a/B_o\right)}{2p^2\left[Bf_o^2 - f_o^3 \text{ artan}\left(B/f_o\right)\right]} + \frac{1}{4p^2}$$

$$= \frac{f_s^2 \text{ artan}\left(B_a/f_o\right)}{2p^2 f_o\left[B - f_o \text{ artan}\left(B/f_o\right)\right]}$$

Evaluating the above expression for the pilot tone system, and an audio bandwidth of 15 kHz, gives the following siganl to noise degradation figures when changing from mono to stereo, for various de-emphasis time constants:

DE-EMPHASIS TIME CONSTANT	S/N DEGRADATION FROM MONO TO STEREO (dB)
0	17.7
25 uS	19.4
50 uS	21.6
75 uS	23.1

Ref. 1: "Some notes on the Calculation of the S/N Ratio for a FM System Employing a Double Sideband AM Multiplex Signal".

by N. Parker and D.W. Ruby

IRE Transactions on Broadcasting. April 1962

SIGNAL STRENGTH REQUIRED FOR AN FM RECEIVER OPERATING IN A NOISE FIELD:

GREG MARTIN

Assumptions

(i) receiver is operating above threshold

(ii) monophonic FM

(iii) deemphasis is not incorporated.

Corrections for pilot tone stereo and deemphasis are made by adding constant terms to the final result.

Si signal power into the receiver

Ni total noise power into the receiver

So signal power input to the demodulator

No noise power input to the demodulator

Sa signal power after demodulation

Na noise power after demodulation

F' receiver noise figure

F receiver noise figure in dB.

the antenna receiving area is $\frac{g\lambda^2}{4\pi}$ metre^2

where g is the antenna power gain over an isotropic antenna.

λ metre is the wavelength.

the power density at the receiving antenna

is $\frac{E^2}{120\pi}$ watt/metre where E volt/metre is the incident electric field strength, and 120π is the impedance of free space.

So the signal power delivered to a matched receiver is given by:

$$S_1 = \left(\frac{E\lambda}{2\pi}\right)^2 \frac{g}{120} \quad \text{watt} \qquad (1)$$

the site noise field strength measured in the receiver equivalent noise bandwidth is e_n volts rms/metre, then the site noise power delivered to a matched receiver will be:

$$N_s = \left(\frac{e_n \lambda}{2\pi} \right)^2 \cdot \frac{g}{120} \quad \text{watt} \qquad \text{\_\_\_\_\_\_\_\_\_\_(2)}$$

Thermal noise power input from the matched antenna is:

$$N_t = KT\Delta f \qquad \text{\_\_\_\_\_\_\_\_\_\_(3)}$$

where:

K is Boltzmann's constant, 1.38×10^{-28} joule/degK

T is absolute temperature, degree K.

Δf is the receiver equivalent noise bandwidth, hertz.

total noise power input to the receiver is

$$N_i = N_t + N_s$$

$$= KT\Delta f + \left(\frac{e_n \lambda}{2\pi} \right)^2 \frac{g}{120} \quad \text{watt} \qquad \text{\_\_\_\_\_\_\_\_\_\_(4)}$$

From the definition of receiver noise figure,

$$\frac{So}{No} = \frac{1}{F'} \left(\frac{Si}{Ni} \right) \qquad \text{\_\_\_\_\_\_\_\_ (5)}$$

$$F = 10 \log_{10} F' \qquad \text{\_\_\_\_\_\_\_\_ (6)}$$

$$\frac{Si}{Ni} = \frac{\left(\frac{E\lambda}{2\pi} \right)^2 \frac{g}{120}}{KT\Delta f + \left(\frac{e_n \lambda}{2\pi} \right)^2 \frac{g}{120}}$$

from (5) and (6):

$$\frac{So}{No} = \frac{1}{10^{0.1F}} \cdot \frac{\left(\frac{E\lambda}{2\pi} \right)^2 \cdot \frac{g}{120}}{KT\Delta f + \left(\frac{e_n \lambda}{2\pi} \right)^2 \cdot \frac{g}{120}}$$

If the modulation index is β, the signal to noise improvement obtained from the FM process is:

$$\frac{Sa}{Na} = 3\beta^2 \cdot \frac{So}{No} \qquad \text{\_\_\_\_\_\_\_\_(7)}$$

Hence the demodulated signal to noise ratio is:

$$\frac{Sa}{Na} = 3\beta^2 \cdot \frac{1}{10^{0.1F}} \cdot \frac{\left(\frac{E\lambda}{2\pi} \right)^2 \cdot \frac{g}{120}}{KT\Delta f + \left(\frac{e_n \lambda}{2\pi} \right)^2} \qquad \text{\_\_\_\_\_\_\_\_(8)}$$

taking $\log_{10}$ of (8), and multiplying by 10 throughout:

$$10 \log_{10} \left(\frac{Sa}{Na}\right) = 10 \log 3 + 20 \log \beta - F + 20 \log E$$
$$+ 20 \log \lambda + 10 \log g - 10 \log (480 \pi^2)$$
$$- 10 \log \left(KT\Delta f + \left(\frac{e_n \lambda}{2\pi}\right)^2 \cdot \frac{g}{120} \right)$$

let the demodulated signal to noise ratio in dB be $\left(\frac{Sa}{Na}\right)'$

$$\left(\frac{Sa}{Na}\right)' = 10 \log_{10} \left(\frac{Sa}{Na}\right)$$

Also let E_r dBu be the field strenth in dB with a reference of 1 microvolt/metre.

$$E_r = 10 \log \left(\frac{E}{10^{-6}}\right)^2 \quad \text{dBu}$$

$$= 20 \log E + 120$$

$$20 \log E = E_r - 120$$

Hence:

$$Er = 120 + \left(\frac{Sa}{Na}\right)' + F - 10 \log 3 - 20 \log \beta - 20 \log \lambda$$

$$- 10 \log g + 10 \log (480 \pi^2) + 10 \log \left\{ KT\Delta f + \left(\frac{e_n \lambda}{2\pi}\right)^2 \cdot \frac{g}{120} \right\} \qquad (9)$$

from this expression, the field strength E_r required to obtain a desired audio signal to noise ratio $\left(\frac{Sa}{Na}\right)'$ can be calculated, and the influence of receiver noise figure F, modulation index β, receiver antenna gain g, and site noise strength e_n can be seen.

Taking some likely values:

wavelength , geometric mean in 88→108 MHz FM band is 3.08 metre; $20 \log \lambda = 9.77$

$\beta = 5$, $20 \log \beta = 13.98$

For a halfwave dipole $g = 1.64$, $10 \log g = 2.15$

$10 \log 3 = 4.77$

$10 \log (480 \pi^2) = 36.76$

assume $\left(\frac{Sa}{Na}\right)' = 60$ dB receiver noise figure F = 5dB

then:

$$E = 191.1 + 10 \log \left(KT\Delta f + \left(\frac{e_n \lambda}{2\pi}\right)^2 \frac{g}{120} \right) \quad \text{dBu} \qquad (10)$$

Pilot tone Stereo and Deemphasis

For a 50 microsecond deemphasis time constant, the signal to noise improvement for mono is 10.2 dB, and the degradation in going to pilot tone stereo is 21.6 dB, so the overall correction to be added to equation (9) is 21.6 - 10.2 = 11.4 dB

Hence:

$$Er = 202.5 + 10 \log \left(KT\Delta f + \left(\frac{e_n \lambda}{2\pi}\right)^2 . \frac{g}{120} \right) \qquad (11)$$

the log term in (11) comprises a thermal noise and a site noise component.

if site noise is zero, $e_n = 0$

$$Er = 202.5 + 10 \log (KT\Delta f) \qquad (12)$$

the two noise components contribute equally when:

$$KT\Delta f = \left(\frac{e_n \lambda}{2\pi}\right)^2$$

taking $\Delta f = 240 \times 10^3$ hertz

$$e_n = \frac{2\pi}{\lambda} \sqrt{KT\ \Delta f\ .\ \frac{120}{g}}$$

$$= 0.58 \text{ microvolt/metre.}$$

Site Noise Predominating:

If $\left(\frac{e_n \lambda}{2\pi}\right)^2 . \frac{g}{120} \gg KT\ \Delta f$

equation (9) simplifies to:

$$Er = 120 + \left(\frac{Sa}{Na}\right)' + F - 20 \log \beta - 10 \log 3 + 20 \log e_n \qquad (13)$$

using the same assumed values as previously this becomes:

$$E_r = 166.3 + 20 \log e_n$$

adding the correction term for pilot tone stereo and 50 microsecond deemphasis gives:

$Er = 177.7 + 20 \log e_n$ ________(14)

the above approximation is useful for $e_n \geqslant 5$ microvolt/metre (in which case the error in using the approximation is $\leqslant 0.05$ dB)

RESULTS:

Using the previously listed assumed values,

Viz: wavelength $\lambda = 3.08$ metre

receiver noise figure $F = 5$ dB

receiver antenna gain 2.15 dB (dipole)

FM modulation index $\beta = 5$

required audio signal/noise ratio 60dB

deemphasis time constant 50 μs.

receiver system: pilot tone stereo

values of required incident signal field strenth E_r dBu for various values of site noise e_n μV/metre (over the receiver equivalent noise bandwidth) are tabulated below:

SITE NOISE μV/metre	Er dBu
0	52.5
0.5	55.1
5	71.7
10	77.7
50	91.7
100	97.7

Adjustments for other values of audio signal to noise ratio, receiver noise figure and antenna gain are easily made by direct addition to Er in dB.

Receiver Antenna Voltage:

Signal power input to a matched receiver from a receiving antenna of gain g located in a field of strength E volt/metre and wavelength λ is :

$$S_i = \frac{E^2 \lambda^2}{4 \pi^2} \cdot \frac{g}{120} \quad \text{watt}$$

If the antenna voltage is e_i and the antenna impedance is R_{ant},

$$S_i = \frac{e_i^2}{R_{ant}}$$

so

$$e_i^2 = R_{ant} \cdot \frac{E^2 \lambda^2}{4 \pi^2} \cdot \frac{g}{120}$$

$$e_i = \frac{E \lambda}{2 \pi} \sqrt{\frac{g R_{ant}}{120}} \quad \text{volts}$$

Taking g = 1.64 (dipole antenna) and R_{ant} = 50 ohm, λ = 3.08 metre

$$\frac{\lambda}{2 \pi} \cdot \sqrt{\frac{g R_{ant}}{120}} = 0.405$$

For the previously presented values of field strength, the corresponding receiver antenna voltages (using a 50 ohm dipole) are shown in the right hand column of the table below:

SITE NOISE µV/metre	FIELD STRENGTH FOR AUDIO SNR = 60 dB		ANTENNA VOLTAGE (millivolts)
	Er dBu	E mV/metre	
0	52.5	0.42	0.17
0.5	55.1	0.57	0.23
5	71.7	3.85	1.56
10	77.7	7.67	3.11
50	91.7	38.5	15.6
100	97.9	76.7	31.1

DE-EMPHASIS AND DOLBY-B

De-emphasis Correction with Treble Tone Control:

Figure 1 shows de-emphasis frequency response curves for three different time constants, 25, 50 and 75 uS. Differences between these curves are shown as "error curves", and indicate the magnitude of the frequency response error if, for example, a transmission with a 75 uS pre-emphasis is received on a set with 50 uS de-emphasis.

Figure 2 shows measured response curves for various positions of the treble tone control in a medium quality "hi-fi" amplifier (Kenwood Model 4002A). The tone control is a continuous potentiometer with a clicker plate defining the positions where the response measurements were made; however all intermediate curves are possible.

Figure 3 shows the final frequency response error when the treble tone control is used to correct de-emphasis error. The 75 uS - 50 uS case is not plotted, as it required a treble boost position intermediate between positions 6 and 8. The final response error for this unplotted case would not exceed approximately 2dB. From the plotted curves it can be seen that nowhere does the final response error exceed 2.5 dB. Shifting the reference and adding a further 0.5 dB margin means that the final response error is within ±1.5dB.

In the case of a portable receiver using 75 uS de-emphasis receiving a transmission processed with 25 uS pre-emphasis, and having no treble boost control to provide correction, the response will be - 6dB at 5 kHz. Considering the restricted range of the loudspeakers typically used in such sets, this high frequency roll-off may not be very evident.

SIGNAL TO NOISE RATIOS

De-emphasis is used to improve the signal to noise ratio (SNR), and is effective with FM in particular because of the triangular noise spectrum. When pilot tone multiplexed stereo is used, the effectiveness of de-emphasis is diluted because it produces little improvement for the subcarrier channel.

The table below gives the SNR improvement in mono for various de-emphasis time constants, together with the SNR degradation for stereo relative to mono (as de-emphasis becomes less significant, the degradation going from mono to stereo decreases), and hence the stereo improvement due to de-emphasis.

DE-EMPHASIS TIME CONST. uS.	DE-EMPHASIS -3dB FREQ. kHz.	DE-EMPHASIS MONO IMPROVEMENT	STEREO S/N DEGREDATION RELATIVE TO MONO	STEREO S/N IMPROVEMENT DUE TO DE-EMPHASIS	STEREO S/N IMPROVEMENT WITH DE-EMP. AND DOLBY-B
0		0	17.7 dB	0 dB	10 dB
25	6.36	5.6 dB	19.4 dB	3.9 dB	13.9 dB
50	3.18	10.2 dB	21.6 dB	6.3 dB	
75	2.12	13.2 dB	23.1 dB	7.8 dB	

DOLBY-B SYSTEM

This gives a uniform subjective 10 dB improvement in SNR. Receivers must be specially equipped with a decoder, but because defined demodulated signal levels exist in the receiver, there are no problems of level alignment.

Note that Dolby B even without any de-emphasis improvement, is 2.2 dB superior to 75 uS stereo de-emphasis used alone.

Dolby B transmissions can be considered in practice to be compatable with non-Dolby receivers; this is elaborated in the next section.

CONCLUSIONS

Considering that fairly accurate correction for de-emphasis error can be obtained using a typical treble boost control, and that on sets without such a facility reduced treble response caused by de-emphasis error is likely to pass unnoticed, the system designer can feel free to choose any de-emphasis time constant in the range 75 to 25 uS.

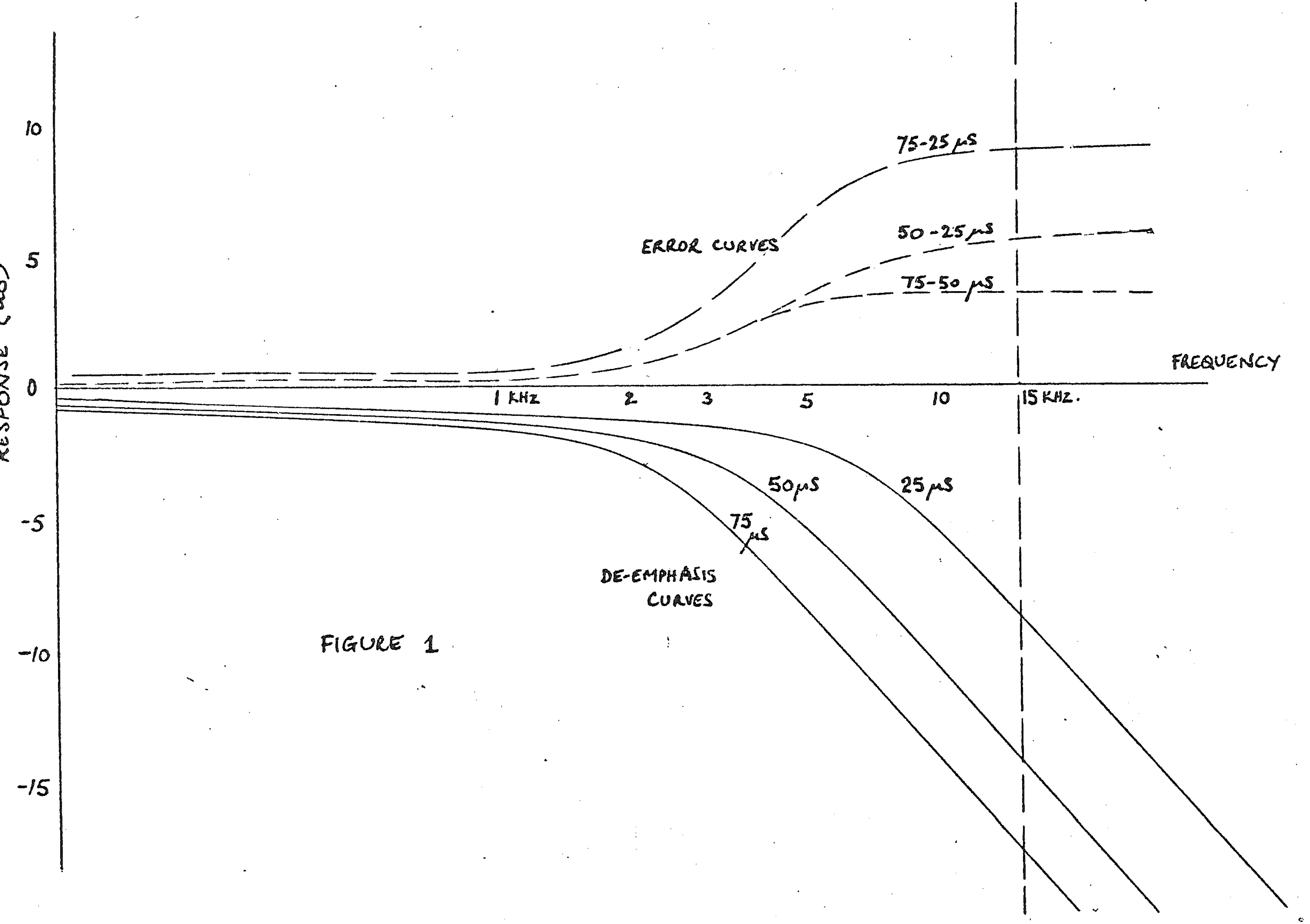
After treble tone control correction, the final, ±1.5 dB error is negligable in comparison with loudspeaker response variations and room acoustic effects. For the purist, the modification involved in altering the receiver time constant is simple and should prove fairly cheap.

In the experience of an experiment conducted by an American FM station (Ref. 2) Dolby B transmissions are compatable with non Dolby receivers, and those with Dolby receivers can of course obtain the benefit of improved SNR.

Combining Dolby B with 25 uS de-emphasis gives a SNR improvement over 75 uS de-emphasis alone of 6.1 dB.

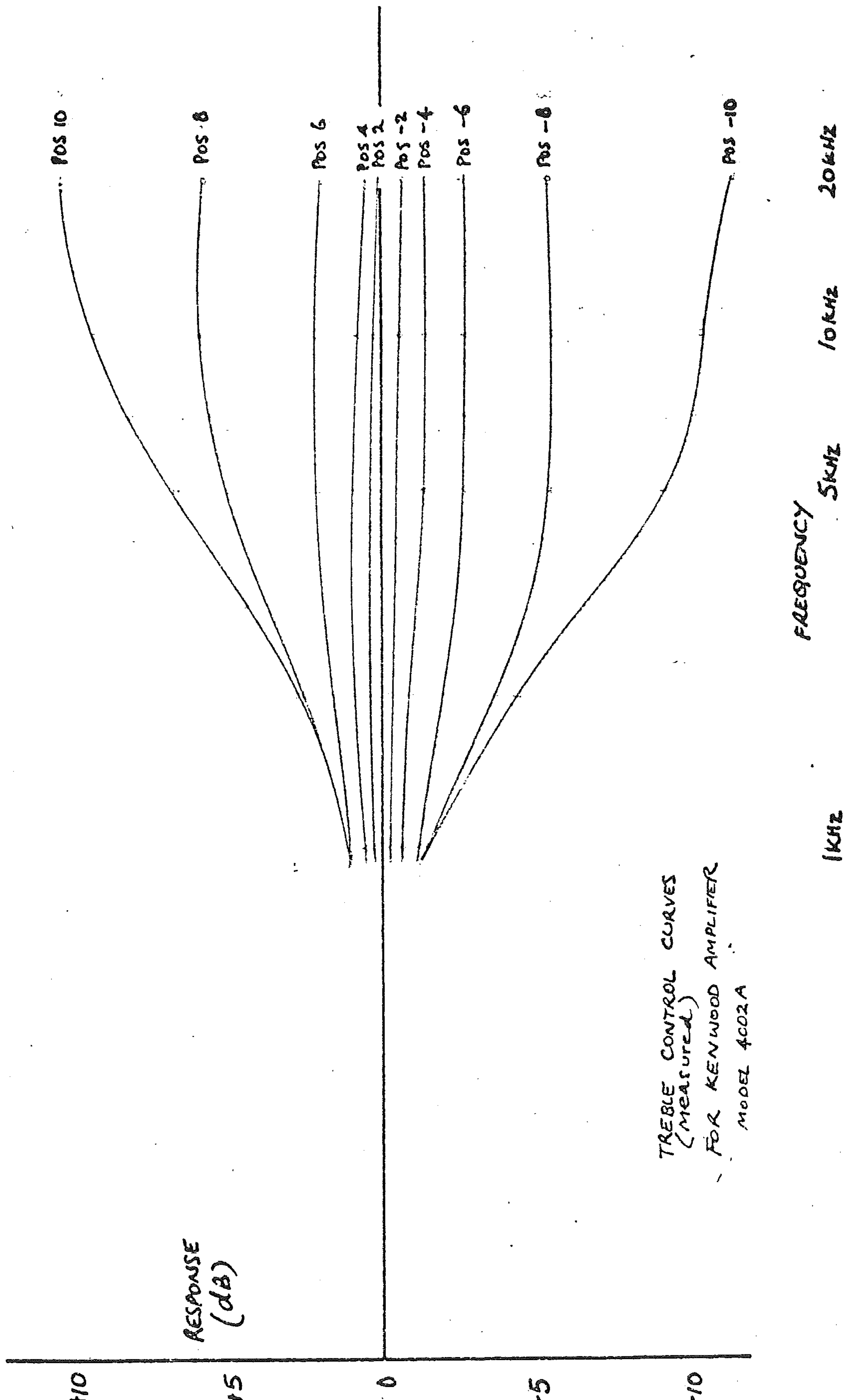
Advantages of using Dolby B and 25 uS de-emphasis seem worthwhile; all new sets can be designed to suit this system, and existing sets suffer no serious incompatabilities.

Ref. 2: Harry Maynard Interviews Adrian Horne of
Dolby Laboratories, London.
AUDIO Feb. 1973 pp. 66-72



RESPONSE (dB)
10
5
0
-5
-10
-15
FREQUENCY
1 KHz
2
3
5
10
15 KHz.
ERROR CURVES
75-25 μS
50-25 μS
75-50 μS
25 μS
50 μS
75 μS
DE-EMPHASIS CURVES

FIGURE 1



RESPONSE (dB)
+10
+5
0
-5
-10
FREQUENCY
1KHz
5KHz
10KHz
20KHz
POS 10
POS 8
POS 6
POS 4
POS 2
POS -2
POS -4
POS -6
POS -8
POS -10
TREBLE CONTROL CURVES (measured)
FOR KENWOOD AMPLIFIER
MODEL 4002A

FIGURE 2

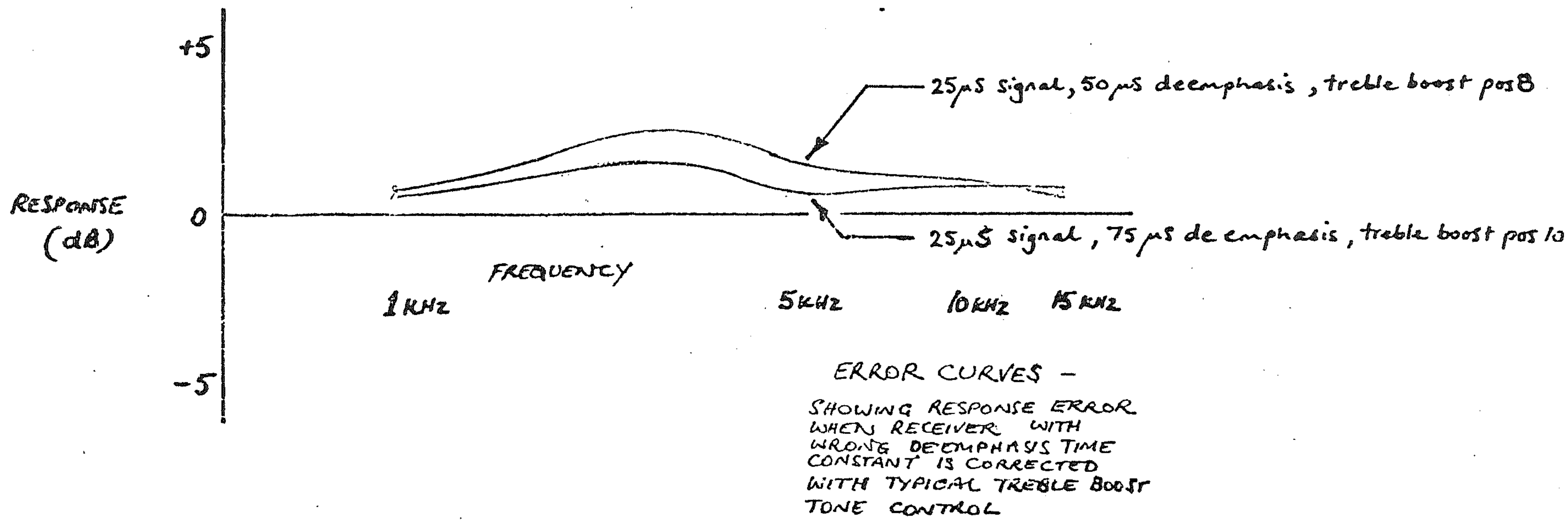

+5
0
-5
RESPONSE (dB)
25µS signal, 50µS deemphasis, treble boost pos 8
25µS signal, 75µS de emphasis, treble boost pos 10
FREQUENCY
1 KHz
5 KHz
10 KHz
15 KHz
ERROR CURVES –
SHOWING RESPONSE ERROR WHEN RECEIVER WITH WRONG DEEMPHASIS TIME CONSTANT IS CORRECTED WITH TYPICAL TREBLE BOOST TONE CONTROL

FIGURE 3

PERFECT RECEIVER

Evaluating the signal required for a perfect receiver with a noise figure of 0dB, and the following parameters:

wavelength 3.08 metre

receiver antenna gain 2.15 dB (dipole)

FM modulation index 5

audio signal to noise ratio 50 dB

de-emphasis time constant 50 uS

receiver system: pilot tone stereo

noise temperature T = 300 $^{\circ}$ K

receiver bandwidth 240 kHz

gives a field strength of 38.5 dBu or 84 uV/metre. This gives an antenna voltage (50 ohm) of 34 uV. This figure is the minimum possible to achieve the specified 50 dB audio signal to noise ratio for the parameters specified above.

For a near perfect receiver having a noise figure of 1.5 dB, the required field strength increased to 100 uV/metre, giving an antenna voltage of 40.5 uV.

For other noise figures:

RECEIVER NOISE FIGURE dB	REQUIRED FIELD STRENGTH		ANTENNA VOLTAGE uV
	dBu	uV	
0	38.5	84	34
1.5	40	100	40.5
3.0	41.5	120	48.6
5.0	43.5	150	60.7
8.0	46.5	212	85.9

PRACTICAL RECEIVERS

Table 1 gives the results of measurements carried out on a number of receivers in the Forward Planning Section.

The better quality receivers give a stereo audio signal to noise ratio of 50 dB for antenna voltages in the range 30 tO 40 uV. Some of these receivers give figures which slightly surpass the values for a perfect receiver (34 uV), indicating a discrepancy in the measurement method or limitations of the theoretical treatment.

For 50 uS de-emphasis, the increase required in signal strength from mono to stereo is 21.6 dB. The measured required increase for some of the receivers is:

RECEIVER	INPUT SIGNAL (uV) FOR SPECIFIED AUDIO SIGNAL TO NOISE RATIO			
	30 dB		50 dB	
	MONO	STEREO	MONO	STEREO
SEQUERRA 1 TUNER	1.5	3.0	3.2	32
LAFAYETTE LT-D10	1.5	-	3.2	39
PIONEER TX9100	1.0	-	3.2	30
PIONEER TX9500	1.2	-	3.0	34
PIONEER TX6200	2.1	5.0	5.0	100 (54dB S/N)
MONARCH 808X	1.9	5.2	6.0	52
MONARCH 5500	2.1	-	4.6	39
MONARCH 88X	2.7	-	8.8	48
BRUNS MONO	3.2		39 (42dB S/N RATIO)	
SILVER AR104 (CAR)	3.2		32	
SILVER PORTABLE MONO	8.2		23	
TOSHIBA PORTABLE RP-75F	4.8		38	
SONY PORTABLE CF550A	5.0		20	150
NATIONAL CASSETTE 444	2.3		5.5	

TABLE 1

RECEIVER	REQUIRED SIGNAL INCREASE FROM MONO TO STEREO (dB)
Sequerra 1	20
Lafayette LT-D10	21.8
Pioneer TX9100	19.5
Pioneer TX9500	21.0
Monarch 808X	18.8
Monarch 5500	18.6
Monarch 88X	14.8

In some cases this is close to the expected 21.6 dB. Where it is lower, either the measured signal strength for stereo is an underestimate, or more likely, the signal strength required for mono is higher than expected because of receiver deficiencies at low signal levels. The difference between measured signal strengths for signal to noise ratios of 30dB and 50dB should be 20dB. In stereo where figures are available (figures are not available for receivers where the stereo demultiplexer disables at low signal levels), the 20dB difference is observed. However this is not so when comparing mono figures; for a 30 dB signal to noise ratio on mono the receiver requires a much higher signal than simple FM theory predicts because of the FM threshold effect.