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Calculation of the field strength of an interfering signal to produce 3 dB reduction of 46 dB4W s/n ratio for a 15 kHz AF bandwidth FM link

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Research & Development
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Abstract

The aim of this Tech. Mem. is to produce an expression for the field strength of an interfering signal which provides a 3 dB loss of signal to noise ratio in an FM channel delivering 46 dB4W in the absence of interference.

The FM channel is taken as having 75 kHz peak programme deviation and 15 kHz audio bandwidth. The receiver aerial is assumed to be a λ/2 dipole for the purpose of the calculation.

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Technical Memorandum R.1151(91)

Calculation of the Field Strength of an Interfering Signal To Produce 3dB Reduction of 46dB4W S/N Ratio for a 15kHz AF Bandwidth FM Link

Issue 1
28/11/91

DESIGN & EQUIPMENT DEPARTMENT

TECHNICAL MEMORANDUM R.1151(91)

CALCULATION OF THE FIELD STRENGTH OF AN INTERFERING SIGNAL TO PRODUCE 3dB REDUCTION OF 46dB4W S/N RATIO FOR A 15kHz AF BANDWIDTH FM LINK

....
(J B Sykes)
for H.D.& E.D.

Written by: P N Moss

A copy of the master is held on disk file. Any amendments must include revision of both the disk file and the paper master, together with a new issue date.

The revision must be approved by the Head of RF Section.

DESIGN & EQUIPMENT DEPARTMENT

TECHNICAL MEMORANDUM R.1151(91)

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CONTENTS

0. SUMMARY

For an assumed total noise figure of 7dB and a receive aerial comprising a half wave dipole it is shown that the required field strength as a function of wavelength for a receive signal to noise ratio of 46dB4W is given by

$$E\ rms = \frac{8.76 \times 10^{-5}}{\lambda}\ V/m \qquad \text{(for a 75kHz peak deviation system)}$$

It is further shown that the required interfering field strengths of a CW signal and a noise-like signal to reduce the signal-to-noise ratio to 43dB4W are given by

$$E'int\ rms = \frac{1.77 \times 10^{-6}}{\lambda}\ V/m \qquad \text{(CW)}$$

$$E'int\ rms = \frac{1.34 \times 10^{-6}}{\lambda}\ V/m \qquad \text{(rms noise in a 30kHz bandwidth)}$$

$$E'int\ (CISPR) \approx \frac{5.4 \times 10^{-6}}{\lambda}\ V/m \qquad \text{(CISPR-receiver measured noise)}$$

For the first two expressions, RF field strength is measured rms; for the third a correction factor for CISPR RF noise measurement is included (see appendix 1). All AF measurements are performed in accordance with CCIR 468 with respect to a line-up deviation of 29.88kHz peak (ie. 75kHz peak deviation at full channel loading).

1. INTRODUCTION

The aim of this Tech. Mem. is to produce an expression for the field strength of an interfering signal which produces a 3dB loss of signal to noise ratio in an fm channel delivering 46dB4W in the absence of interference.

The FM channel is taken as having 75kHz peak programme deviation and 15kHz audio bandwidth. The receiver aerial is assumed to be a λ/2 dipole for the purposes of the calculation.

2. REQUIRED SIGNAL STRENGTH FOR 46dBW

We will make the following assumptions:-

(i) Rx noise figure 6dB

(ii) 'Galactic' noise 3dB above room-temperature 50Ω source.

Assumptions (i) and (ii) together yield a net total noise figure of 7dB.

Now an fm system with SSB phase noise density to carrier ratio L(f) has a total mean square noise between lower and upper frequencies f_1 and f_2 given by

$$\overline{fm^2}\ (tot) = 2 \int_{f_1}^{f_2} f^2\ L(f)\ df \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

If L(f) is taken to be constant over the channel bandwidth equation (1) yields

$$\overline{fm^2}\ (tot) = 2/3\ L(f)\ [f_2^3 - f_1^3] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

The system signal-to-noise ratio can be expressed as:-

$$s/n = \frac{f^2 dev}{2\ \overline{fm^2}\ (tot)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

where fdev is the peak carrier deviation.

To modify this expression for 'dB4W' use, allow 4.5dB (empirically determined) correction for the effect of the pseudo-peak metering; another 4.5dB correction for the response of the CCIR 468-4 weighting filter to a 'blue' noise spectrum and 8dB for the difference between PPM6 and PPM4 line-up levels. All these corrections act in the same direction to yield:-

$$dB4W\ s/n = 10 \log \left[\frac{f^2\ dev}{100\ \overline{fm^2}\ (tot)}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

substituting (2) into (4) yields

$$dB4W\ s/n = 10 \log \left[\frac{f^2\ dev}{67\ L(f)\ [f_2^3 - f_1^3]}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

Eq (5) can be used to work out the required L(f)for a given dB4W s/n.

De-emphasis at 50µs has not been considered; it is found empirically that for a blue noise spectrum* the weighted signal-to-noise ratio will improve by 8dB when de-emphasis is applied.

(*To 15kHz. A 20kHz bandwidth requires very similar correction factors.)

If then we require 46dB4W after de-emphasis, 38dB4W is required flat.

Re-arranging eq (5) yields

$$L(f) = \frac{f^2 dev}{67\ 10^{dB4W/10}\left[f_2^{\ 3} - f_1^{\ 3}\right]} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (6)$$

substituting $f\ dev = 75kHz$
$f_2 = 15kHz$
$f_1 = 40Hz$
$dB4W = 38$

yields $L(f) = 3.94 \times 10^{-9}$

now $L(f) = \frac{(\delta Vn)^2}{A^2}$ where δVn is peak value of SSB phase noise vector and A is peak carrier amplitude

δVn is related to Vn, the total single sideband am and pm noise by

$$\delta Vn = Vn\ (rms)$$

so $L(f) = \frac{Vn^2\ (rms)}{A^2}$ .... (7)

Vn^2 (rms) in a 50Ω system is given by:-

$Vn^2\ (rms) = 4kTR$ .... (8)

Hence the total equivalent input noise taking account of a noise figure F is

$Vn^2(rms)tot = 4FkTR$ .... (9)

Now $F = 10^{7/10} \approx 5$ so

$$Vn^2(rms)tot = 4.1 \times 10^{-18}$$

substituting into (7) yields

$$A^2 = \frac{4.14 \times 10^{-18}}{3.94 \times 10^{-9}} = 1.05 \times 10^{-9}$$

Therefore A = 32.4 μV emf (16.2 μV pd). (peak) .... (10)

[= 11.5μV pd rms]

3. REQUIRED FIELD STRENGTH VS FREQUENCY (0dB aerial gain ref. λ/2 dipole)

The maximum aerial aperture of a λ/2 dipole is given by:

$$Ae = 0.13\ \lambda^2 \qquad \text{...............} \quad (11)$$

The mean available power is thus (Erms = incident E field. Zf = free space impedance)

$$Pmean = \frac{E^2 rms}{Zf}\ 0.13\ \lambda^2 \qquad \text{...............} \quad (12)$$

The required power (from (10)) is $(11.5 \times 10^{-6})^2/50 = 2.65 \times 10^{-12}$ W

Re-arranging eq (12)

$$E\ rms = \frac{1}{\lambda} \sqrt{\frac{Zf\ Pmean}{0.13}} \qquad \text{................} \quad (13)$$

so $$\underline{E\ rms = \frac{1}{\lambda}\ 8.76 \times 10^{-5}} \qquad \text{................} \quad (14)$$

4. ALLOWABLE INTERFERING SIGNAL AND FIELD STRENGTH FOR 43dB4W

4.1. Tone interferer

The frequency offset from carrier of the worst case interfering tone with respect to weighted signal to noise ratio (with de-emphasis) is the frequency corresponding the maximum of the function G(f) given by

$$G(f) = f\ W(f)\ D(f) \qquad \text{................} \quad (15)$$

where W(f) is the response of the weighting network and D(f) the response of the de-emphasis network. The factor of f accounts for the rising demodulated output of an fm detector when flat pm is applied.

Because the functions f and D(f) are complementary for frequencies higher than about 5kHz, the maximum of G(f) is simply the maximum of W(f) ie. about 6.3kHz. The actual net effect of W(f) and D(f) at 6.3kHz is

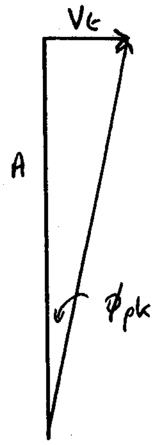
$$W(f)\ D(f) = \frac{1}{\sqrt{1 + \left(\frac{6.3}{3.18}\right)^2}}\ 10^{1.22/2} = 1.836\ (+\ 5.3\text{dB})$$

$$\text{...............} \quad (16)$$

Now the tone above must yield a weighted signal-to-noise ratio of 46dB4W for the total net s/n to be 43dB4W. The tone level must therefore be 46 + 5 = 51dB below line up.

Peak system deviation = 75kHz
line-up deviation = 29.9kHz pk
Therefore acceptable tone deviation = 84Hz pk at 6.3kHz

Now $\phi pk = \dfrac{fm(pk)}{f} = 1.33 \times 10^{-2}$ rad .... (17)



From the diagram, $Vt = A\phi pk$ therefore $Vt = 1.33\mathrm{x}10^{-2}$ A or -37.5dBc

.... (18)

The maximum corresponding field strength Eintrms is hence

$$E\ rms\ 1.33 \times 10^{-2}$$

$$\underline{Eint\ rms = \frac{1.77 \times 10^{-6}}{\lambda}\ V/m} \qquad .... (19)$$

4.2. Noise-like interferer

For a noise-like interferer to degrade the signal-to-noise ratio by 3dB, it must raise the total available noise power at the receiver input by 3dB. Since this is already 7dB above kT, ie. 5kT/Hz, a further 5kT/Hz of noise power must be present.

So $\overset{\prime}{E}intrms = \dfrac{1}{\lambda}\sqrt{\dfrac{Zf\ 5kT}{0.13}}$ from (13) .... (20)

$$\overset{\prime}{E}intrms = \frac{7.75 \times 10^{-9}}{\lambda}\ V/m/Hz^{1/2}$$

(Where Eint rms is noise rms field strength in 1Hz bandwidth).

Assessing the noise over a 30kHz channel bandwidth (= 2 x AF bandwidth) yields

$$\underline{\overset{\prime}{E}intrms\ (30kHz) = \frac{1.34 \times 10^{-6}}{\lambda}\ V/m}$$

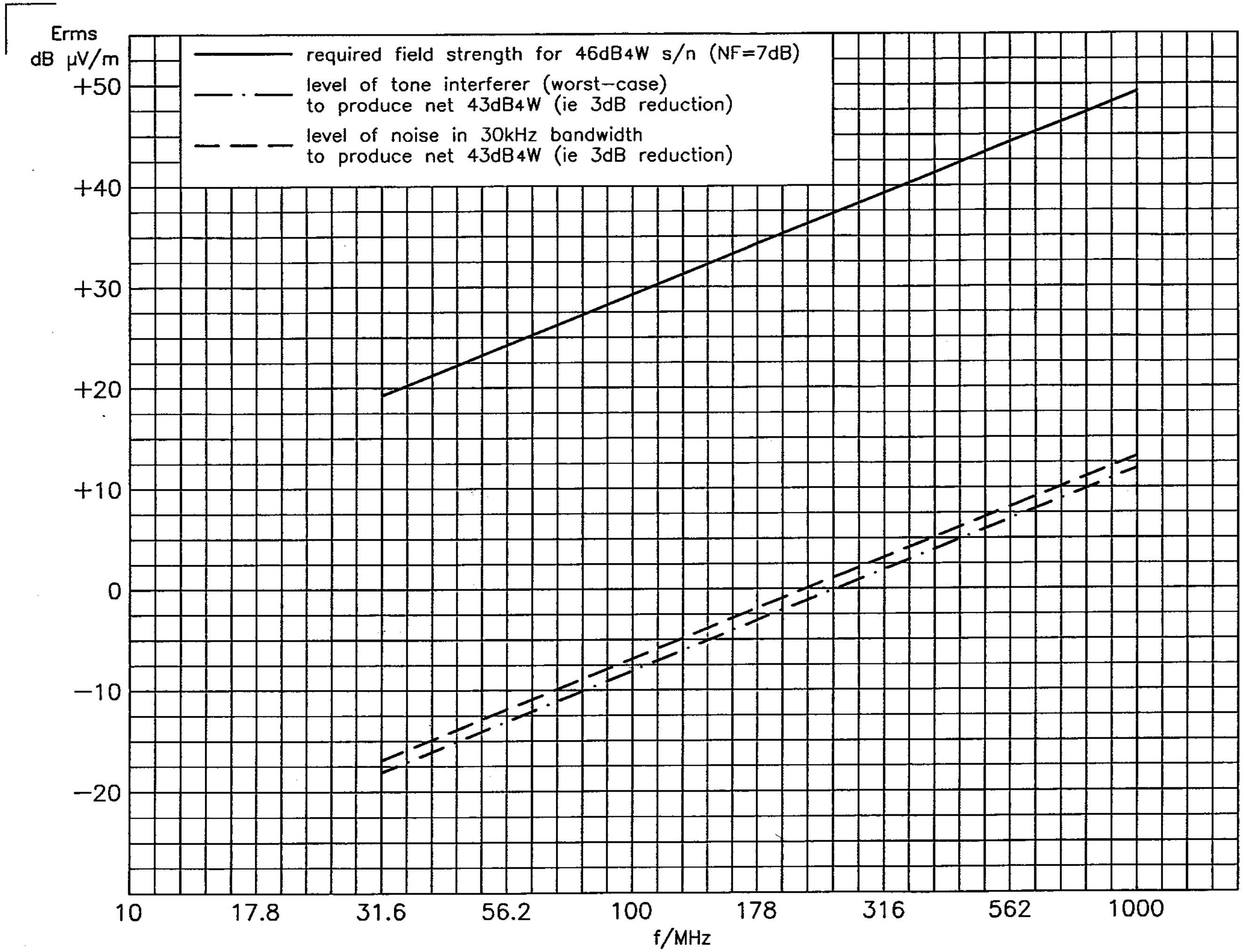
Appendix 1: corrections for CISPR receiver noise measurement

A CISPR receiver has a pseudo-peak RF noise measurement characteristic and a measuring noise bandwidth of around 92kHz. It is found empirically that the pseudo-peak metering reads about 7.2dB higher than rms metering on a white noise spectrum. The total correction to apply to the expression for E'intrms above to make it correct for a CISPR measurement is thus

$$7.2\text{dB} + 10 \log \frac{92}{30} = 12.1\text{dB}$$

Hence $$E'_{int}\,(\text{CISPR}) \approx \frac{5.4 \times 10^{-6}}{\lambda}\ \text{V/m}$$

DSK28579A3



NOTES
1 Total noise figure (Rx + galactic) assumed to be 7dB
2 All RF measurements rms
3 All AF measurements dB4W
4 Aerial taken to be $\frac{\lambda}{2}$ dipole
5 Interferer is CW RF for "tone" curve and broadband noise for alternative curve

Music Link Signal and Interference Levels

$\frac{\lambda}{2}$ dipole 75kHz peak dev. 15kHz af bandwidth

DSK28579A3/4

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SCALE –

THIRD ANGLE PROJECTION

ORIGINAL FRAME SIZE
277mm X 400mm

ISS	CHANGE
1	10/9/91
2	24/9/91
3	11/10/91
4	Copyright added to Chart. Surround revised. Info P.Moss/J.Sykes 28.9.94. edb

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MUSIC LINK
SIGNAL AND RMS INTERFERENCE LEVELS

All dimensions in millimetres unless otherwise stated : Normal tolerances :
no decimal place – ± 1 mm
one decimal place – ± 0.3 mm
two decimal places – ± 0.1 mm
Unless otherwise stated

C.A.D.	LSF
CKD	
APPD	PNM

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