

Development of analytical
tools to evaluate the performance
of very high capacity
microwave (VHCM) systems.
prepared by J. Sinclair

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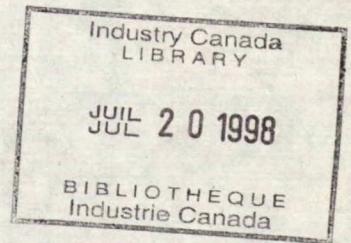
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DEVELOPMENT OF ANALYTICAL TOOLS
TO EVALUATE THE PERFORMANCE OF VERY
HIGH CAPACITY MICROWAVE (VHCM) SYSTEMS



Prepared by:

J. Sinclair Ing.

Authorized by:

A. E. Walther

A.E. Walther, P. Eng.
Director of Engineering
ADGA Systems International Limited

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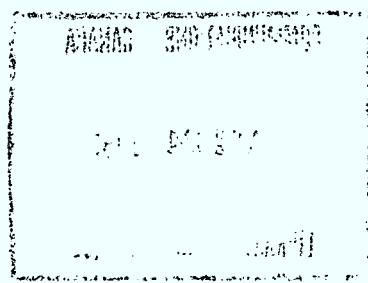


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INTRODUCTION

The purpose of this investigation is to develop analytical tools to evaluate the performance of Very High Capacity Microwave (VHCM) systems (used by the CATV industry to carry video signals) in the presence of interference. More specifically, the video modulated carriers to be considered are AM-VSB, AM-DSB and narrow-band FM. The theoretical carrier-to-thermal noise ratios required to produce a bit error rate of 10^{-3} for several digital modulation schemes were also investigated.

The work is covered under three tasks:

Task A

Develop analytical tools to define the subjective performance of TV video signals in a mutual interference environment between:

- a) 6-MHz AM-VSB signal carrying NTSC/M composite TV signal.
- b) 12.5 MHz bandwidth FM modulated signal carrying 4.2 MHz NTSC video signals with up to 4 associated audio sub-carriers
(The audio subcarriers may be as high as 6 MHz)

For each interference mechanism, the "just perceptible" threshold and the protection ratios as a function of quality grade are developed for the co-channel, adjacent channel and intermediate off-set channel cases.

Task B

Develop the same analytical tools for mutual interference between:

- a) AM-DSB signal carrying an NTSC composite signal, and
- b) 12.5 MHz bandwidth FM signal as in b) of Task A.

Task C

Conduct a literature research to provide a list of the C/N ratios required in the absence of other interference and distortion by the following listed digital modulation methods to allow operation at a BER of 10^{-3} :

- 64 QAM
- 16 QAM
- 4 QAM
- 8 PSK
- 4 PSK
- 2 PSK
- 4 QPRS
- 8 FSK
- 4 FSK
- 2 FSK

The report is presented in three parts; each part dealing with one of the tasks presented above, i.e.:

- Part A addresses Task A;
- Part B addresses Task B;
- Part C addresses Task C.

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PART A

AM-VSB AND NBFM TV INTERFERENCE PERFORMANCE

PART A
AM-VSB TV AND NBFM TV INTERFERENCE PERFORMANCE

1. INTRODUCTION

This section considers the performance characteristics of an AM-VSB TV signal in the presence of interference from other AM-VSB TV signals and from narrowband (NB)FM TV signal in the presence of interference from other NBFM TV signals and from AM-VSB TV signals.

1.1. TV Signal Characteristics

The characteristics of the TV signals are:

a) VSB-AM TV

6 MHz bandwidth carrying an NTSC/type M composite video signal as used in the VHF and UHF terrestrial TV broadcast service.

b) NBFM TV

12.5 MHz FM modulated signal carrying a 4.2 MHz NTSC video signal with up to 4 associated audio subcarriers. (The audio subcarriers frequencies may be as high as 6 MHz).

The Cable TV service employs two types of narrowband FM carriers:

- 1) peak deviation of 1 MHz (this corresponds to a bandwidth of 12.5 MHz with the top audio carrier at ≈ 5.25 MHz).
- 2) peak deviation of 4 MHz (bandwidth 18 MHz).

This latter NBFM TV signal is used by terrestrial radio relay systems. Both types of narrowband FM TV signals were considered.

1.2. Interference Mechanisms

For each type of TV signal (i.e. VSB-AM and NBFM), four types of interfering signals will be considered. These are:

- CW signal.
- random noise signal.
- AM-VSB TV signal.
- NBFM TV signal.

Interference from a CW signal is generally the most destructive and generates the worst-case picture impairment, and hence could be regarded as the maximum protection ratio required for a given quality grade. It also has a practical use since spurious emissions are generally CW in nature. Interference from random noise, on the other hand, is the least destructive to picture quality and hence determines the best picture quality that can be achieved in an interference and distortion-free environment.

1.3. TV Picture Quality Assessment

The quality of a TV picture is assessed by subjective means. Unfortunately, there appears to be several quality scales in current use. This report considers the two scales used in North America:

- TASO six-point scale.
- CCIR five-point scale.

These quality scales are described in Tables A1-1 and A1-2. It is often necessary to be able to express a certain quality in the TASO scale in terms of the CCIR scale and vice versa. This can be done using the curves in Figure A1-1. This figure was obtained from CRC Report No. 1307, 1983. It indicates that to a first approximation, the following relationship holds for the same value of baseband S/N:

TASO Grade	1	1.5	2.0	2.5	3.0	3.5	4.0
CCIR Grade	4.5	4.0	3.5	3.0	2.5	2.0	1.5

The CRC Report does not include references as to the origin of this relationship.

The picture quality defined as the "just perceptible" impairment grade is an important one since it is defined in terms of the protection ratio (C/I) or the signal-to-noise ratio (S/N) and not specifically in terms of the two scales. It is important because the "just perceptible" protection ratio is generally used as the specification value of (C/I) for a single entry interference in a long-haul system in which there are several sources of interference or multiple entries from the same system. In the TASO scale, the difference in protection ratio or (S/N) from the "just perceptible" grade to the TASO 3 grade is from 13 to 15 dB, but 15 dB is often used for the conversion.

do we want to set standards?

1.4. Technical Approach

The approach taken in this investigation was to research the literature for the required information on subjective test results of AM-VSB TV systems and NBFM TV systems. The main sources of information were:

- a) TASO committee Report Proc IEEE, July 1960 (AM-VSB);
- b) FCC Labs Project 2229-63, June 1974;

- c) DOC Project 6, Report of CRTPB Ad Hoc Committee (AM-VSB);
- d) CCIR volumes X/XI, 1986 (AM-VSB, FM);
- e) SMPTE Television Quality Conference 1984 (FM);
- f) CRC Report NO. 1307, 1983 (FM).

These documents contained information on AM-VSB TV systems and wideband FM TV systems. However, there was considerable variance in the results. The average of the worst-case values was used in those instances where there were considerable variations.

No information was found on subjective tests of NBFM TV systems and DSB-AM systems. For these cases, the known relationships between AM-VSB and AM-DSB systems and between wideband FM and narrowband FM systems were used to extrapolate results from the AM-VSB and WBTV TV systems to the DSB-AM and NBFM cases.

No subjective tests were conducted to obtain the required information or to verify the proposed performance characteristics.

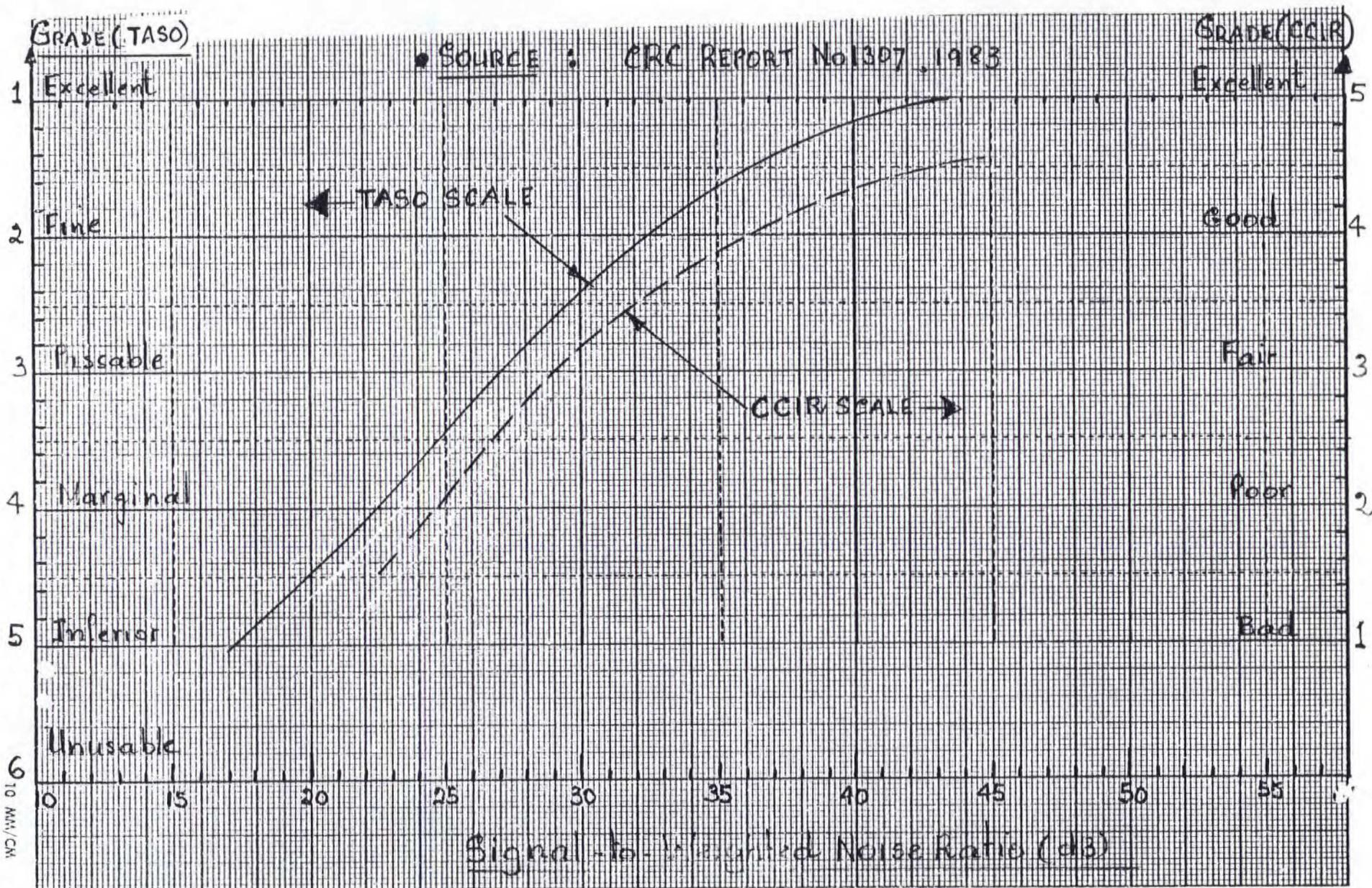
Table A1-1: TASO Quality Scale

GRADE	TITLE	DESCRIPTION
1	Excellent	Quality is as good as one could desire
2	Fine	Interference is perceptible but viewing is enjoyable
3	Passable	Interference is not objectionable; quality is acceptable
4	Marginal	Interference is somewhat objectionable
5	Inferior	Picture is poor but watchable though interference is definitely objectionable
6	Unusable	Picture is just not watchable

Table A1-2: CCIR Five-Point Quality Scale

GRADE	TITLE	IMPAIRMENT
5	Excellent	Imperceptible
4	Good	Perceptible
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very Annoying

Figure A1-1: Comparison of TASO and CCIR Quality Scales for the Same S/Nw



2. AM-VSB TV INTERFERENCE PERFORMANCE CHARACTERISTICS

2.1. Random Noise Interference

For this source of interference, the performance parameter is expressed in terms of signal-to-weighted noise ratio rather than in terms of protection ratio (PR) which is the ratio of the desired carrier's power level (C) to the interference carrier's power level (I) at the receiver's input.

Unfortunately, there are several definitions of SNR currently in use, depending on whether the signal is defined at RF or baseband, the noise at RF or baseband and the type of noise weighting networks used. The various definitions are given in Table A2-1 while the relationships between the various SNRs are given in Table A2-2. Table A2-3 gives the effects of the various weighting networks used to obtain the relationships in Table A2-2.

Figures A2-1 and A2-2 give the variation of SNR vs percent of viewers using the TASO grade as a parameter. Figure A2-1 represents the results of measurements made in 1960 while Figure A2-2 represents the results made in 1974. Figure A2-3 shows the SNR for any particular TASO grade as assessed by 50% of the viewers. These curves indicate that due to increased viewer's expectations, a 3 dB higher SNR is required for the same quality grade. More recent tests performed by CRC in 1983 indicates that a further 2 to 5 dB of SNR is now required for the same quality grade. The "just perceptible" point seems to occur for a SNR of 48 to 52 dB.] *

2.2. Interference from a CW Signal

The results of tests conducted using the FM sound signal as the interferer (s) are shown in Table A2-4. Based on these results, CCIR recommended the template (or mask) shown in Figure A2-4 for the "just perceptible" protection ratio for CW interferers.

As part of the study to investigate the mutual interference between AM-VSB TV signals and the Land Mobile Service signals, DOC conducted tests using narrowband FM carriers as interferers. These results are summarized in Figure A2-5.

Based on the above two results and other data, the template proposed for use for "just perceptible" protection ratio for CW interference is given in Figure A2-6.

2.3. Interference from AM-VSB Signal

This interference was investigated in great detail by the TASO committee for the co-channel and adjacent channel cases. The results are presented in Appendix 1.

The FCC labs also conducted detailed tests to study the effect of "UHF taboo channels." The results for the cases of TASO Grade 3 and 50% of the viewers are given in Table A2-5, columns 1 and 2. The specifications used by the FCC for the Grade B contour protection ratio is given in column 3. The Grade B contour quality corresponds to the TASO Grade 3 quality. The specifications used by the DOC for the same purpose are given in the fourth column. Using the empirical rule that the "just perceptible" grade is 15 dB above the TASO Grade 3 level, the estimated "just perceptible" protection ratios are given in the fifth column. Note that for the co-channel case, 50 dB is proposed. The value of 41 dB appears at specific discrete frequencies related to multiples of the frame rate (e.g. 604 Hz). A value of 35 dB is more appropriate for the offset less than 1000 Hz and based on this value for TASO 3, a "just perceptible" PR of 50 dB is proposed. This is compatible with a CW interference of ~~-X~~ 55 dB.

For the case of carrier offsets between the co-channel and adjacent channel cases (shown in Figure A2-7), the argument used was that the picture and colour subcarriers could be considered the two sensitive frequencies in the wanted AM-VSB spectrum. The

interfering AM-VSB signal, also, may be regarded as two CW signals located at the picture and sound carriers. The protection ratio becomes 50 dB (for "just perceptible" grade) when f_{IP} (picture carrier of interferer) coincides with f_{WP} or f_{WC} (suffix "w" denotes wanted signal and w_c the wanted colour subcarrier).

However, when the sound subcarrier falls on f_{WP} or f_{WC} , the protection ratio would fall by 7 dB (relative level of this subcarrier to the picture carrier).

At carrier offsets of ± 6 MHz, the interferer will be located at the adjacent channels, at which offsets the "just perceptible" protection ratio becomes 0 dB.

The template of Figure A2-7 is proposed for the "just perceptible" mask for offsets between the co-channel and adjacent channel offsets.

2.4. Interference from NBFM TV

The protection ratios required by the AM-VSB TV signal against interference from FM TV carriers are shown in Figure A2-8. The curves for FM carriers with peak-to-peak deviations of 22 MHz, 16 MHz and 8 MHz were extracted from CCIR Report 634; the curve for the 2 MHz peak-to-peak deviation was obtained by extrapolation from the other three curves.

Also shown on the curves are the "just perceptible" impairment points. These points appear to occur at the grade of 4.5. Figure A2-9 shows the PR vs frequency offset for FM interference.

2.5. Interference from Random Noise and FMTV Carrier

Figure A2-10 shows the results of determining the protection ratio of interference from an FM TV carrier ($\Delta F_{pp} = 18$ MHz) in the presence of random noise.

When $S/N < 42$ dB, the protection ratio required to produce a "just perceptible" change in impairment to the picture quality is given by $PR = SNR + 2$ dB.

At $S/N = 46$ dB, the $PR = SNR + 4$ dB will produce a just noticeable degradation in the picture at that S/N .

2.6. Multiple Interference Entries

For the co-channel case, the effect of multiple entries (at least up to 3 entries) can be found by adding the power of the interferers on a power basis and then using that summed power as a single entry. The curves provided can then be used to obtain the picture quality.

This does not apply for the adjacent channels. In this case, the impairment tends to degrade very rapidly once a threshold level of interference is exceeded. However, below this level, power addition is acceptable.

Table A2-1: Definitions of SNR for AM-VSB TV

SYSTEM	DEFINITION
NCTA	Signal: rms power of RF signal during the sync pulse Noise: rms noise power in 4 MHz wide RF channel Measurements are made at RF before the demodulator
TASO	Signal: rms power of RF signal during the sync pulse Noise: rms power in 6 MHz wide RF channel Measurements are made at RF before the demodulator
EIA	Signal: difference in voltage between the sync tip and white level Noise: rms noise voltage (nominally between 10 kHz and 4 MHz) weighted by the Colour TV weighting curve Measurements are made at baseband after the demodulator
CCIR	Signal: difference in voltage between blanking and white levels Noise: rms noise voltage weighted by CCIR network Measurements are made at baseband after the demodulator
BTL (Bell)	Signal: difference in voltage between sync tip and white level Measurements are made at baseband after the demodulator Noise: rms noise voltage weighted by CCIR network

Source: Strauss, NCTA 1974, pp 58-63

Table A2-2: Relationships Between SNRs

- $(SNR)_{TASO} = (SNR)_{NCTA} - 1.8 \text{ dB}$
- $(SNR)_{EIA} = (SNR)_{NCTA} + 0.1 \text{ dB}$
- $(SNR)_{CCIR} = (SNR)_{NCTA} - 0.2 \text{ dB}$
- $(SNR)_{BTL} = (SNR)_{NCTA} + 2.7 \text{ dB}$

Table A2-3: Noise Weighting Improvement

Noise Spectrum Weighting	White Noise DSB-AM	Triangular Noise FM	Vestigial AM Noise VSB-AM
EIA	4.0 dB	6.4 dB	4.1 dB
CCIR	6.1 dB	10.2 dB	6.7 dB

Table A2-4: "Just Perceptible" Protection Ratio for AM-VSB from Interference Due to Sound Channels

Number of Sound channels	Frequency Spacing Between channels (kHz)	Protection Ratio (dB) For "Just Perceptible" Impairment.				
		"Off-air" Broadcast Picture		Philips #14	SMPTE #1	
		Unmodulated Carriers	FM Sound Carriers	FM Sound Carriers	FM Sound Carriers	FM Sound Carriers
2	50	45 ~ 52	44 ~ 50	39 ~ 46	47 ~ 53	48 ~ 57
4	50	47 ~ 56	46 ~ 54	42 ~ 49	50 ~ 55	51 ~ 56
10	50	50 ~ 53	50 ~ 53	43 ~ 46	50 ~ 54	52 ~ 53
20	100	50	50	46	50	49
40	50	53	52	49	50	48
Picture Quality Assessors		4 expert viewers	4 expert viewers	5 non-expert viewers	4 expert viewers	4 expert viewers

- NOTES : (1) Sound channel , FM , $\Delta f_p = 15 \text{ kHz}$, $f_{mod} = 400 \text{ Hz}$
- (2) "Just perceptible" corresponds to Grade 4.5 on CCIR 5-point scale
- (3) A protection ratio of 50 dB is recommended for "just perceptible" impairment of an AM-VSB picture due to interference from in-band narrow-band FM sound channels.
- (4) Source : CCIR Report 634

Table A2-5: Interference into AM-VSB from AM-VSB - Results and Specifications

Items Interference Sources	TASO Measurements Grade: TASO3	FCC Labs Measurements Grade: TASO3	FCC SPECS: Terrestrial TV Grade B Contour	DOC SPECS: Terrestrial TV Grade B Contour	Estimated "Just" Permissible" Level based on [TASO3 + 15dB]
Random Noise	27	29	-	-	44
<u>AM-VSB Co-channel (n=0)</u>					
• Offset < 50Hz	22	-	-	-	
• Offset < 1000Hz	41*	45*	45*	35	50*
• Offset at 10,010Hz	18	28	28	18	43
• Offset at 20,020Hz	18	28	28	18	43
<u>Adjacent Channel (n = ±1)</u>					
• Lower	-26	-15	-15	-36	0
• Upper	-27	-15	-15	-36	0
<u>Alternate Adjacent channel (n±2)</u>					
• Lower	-	-13	-	-	+2
• Upper	-	-16	-	-	-1
Sound Image channel (n±14)	-	-22	-23	-46	-7
Picture Image channel (n±15)	-	-6	-6	-28	+1

* Occurs at specific discrete frequencies related to multiples of frame frequency (e.g. 604Hz)

Figure A2-1: AM-VSB Impairment due to Random Noise (Measured in 1960)

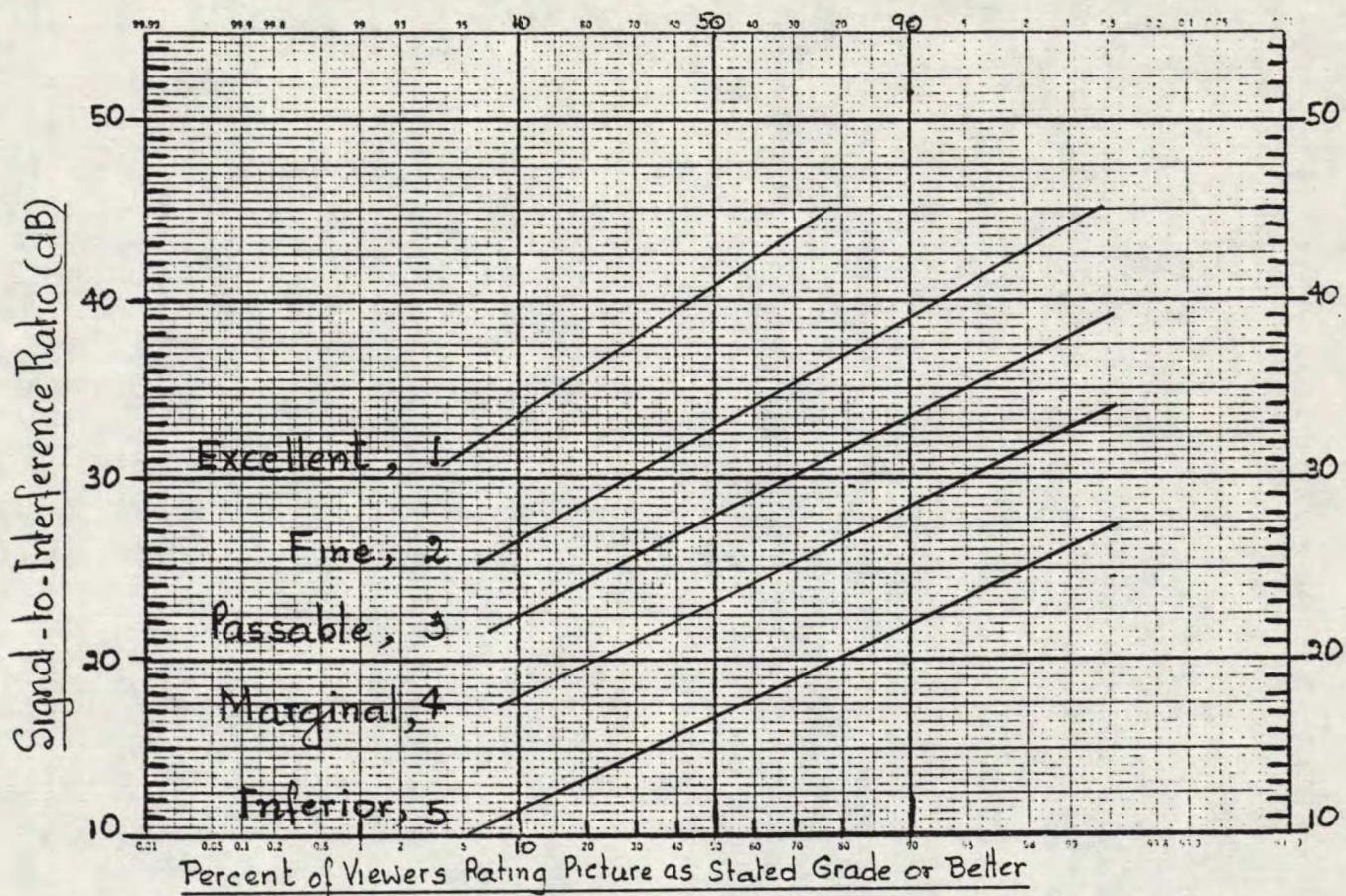


Figure A2-2: AM-VSB Impairment due to Random Noise (Measured in 1974)

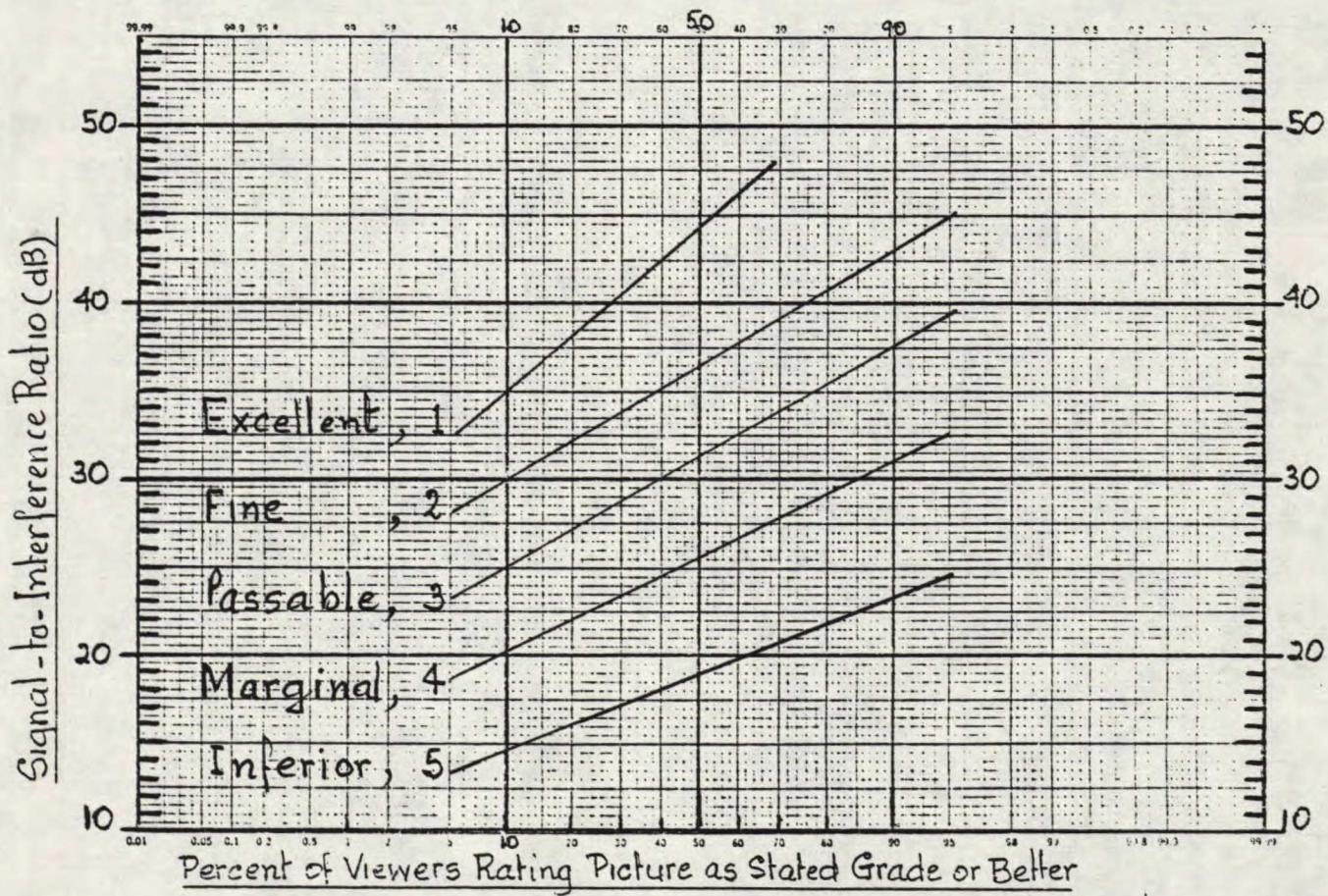


Figure A2-3: AM-VSB Picture Impairment due to Random Noise

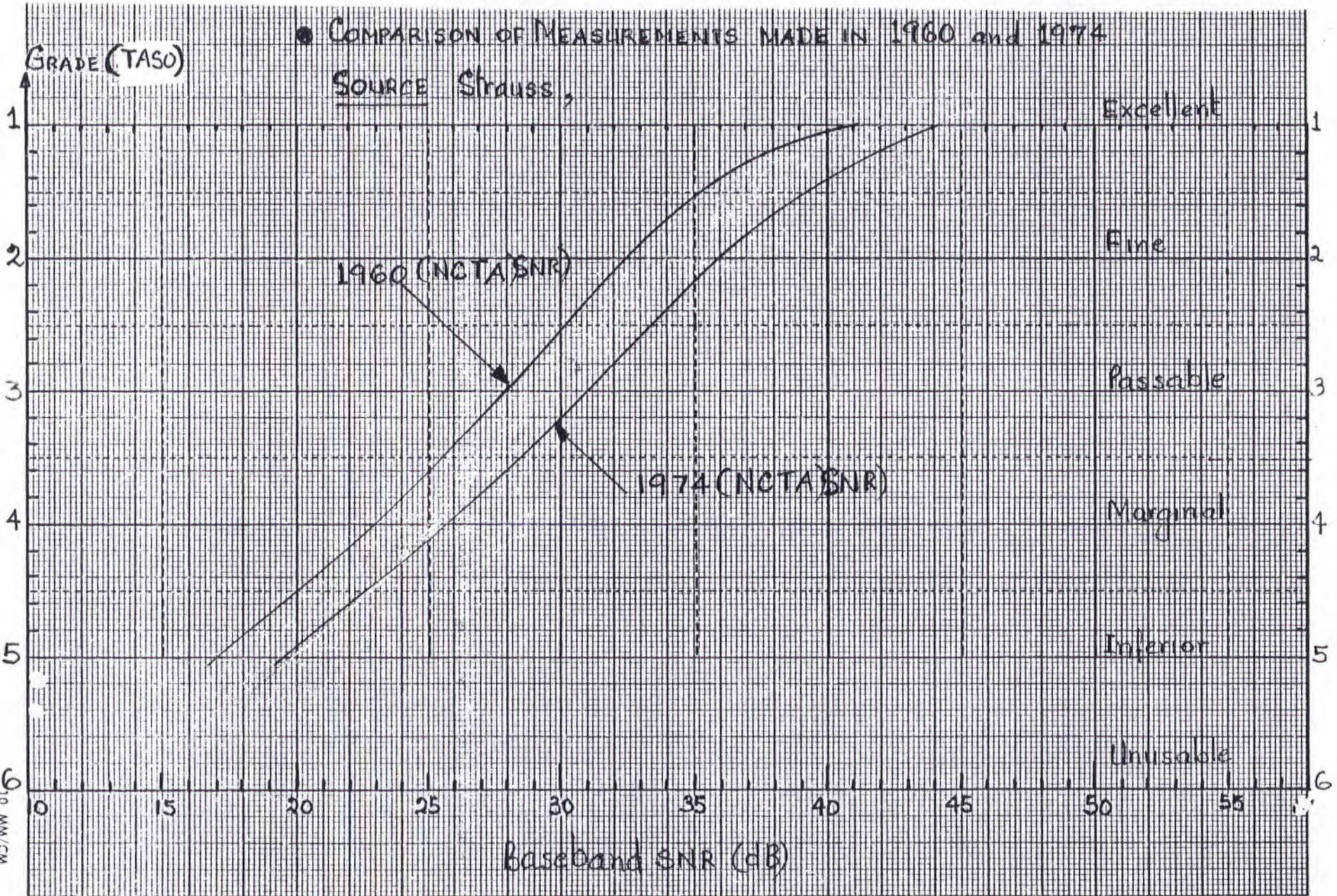


Figure A2-4: "Just Perceptible" Impairment to AM-VSB from CW Interference

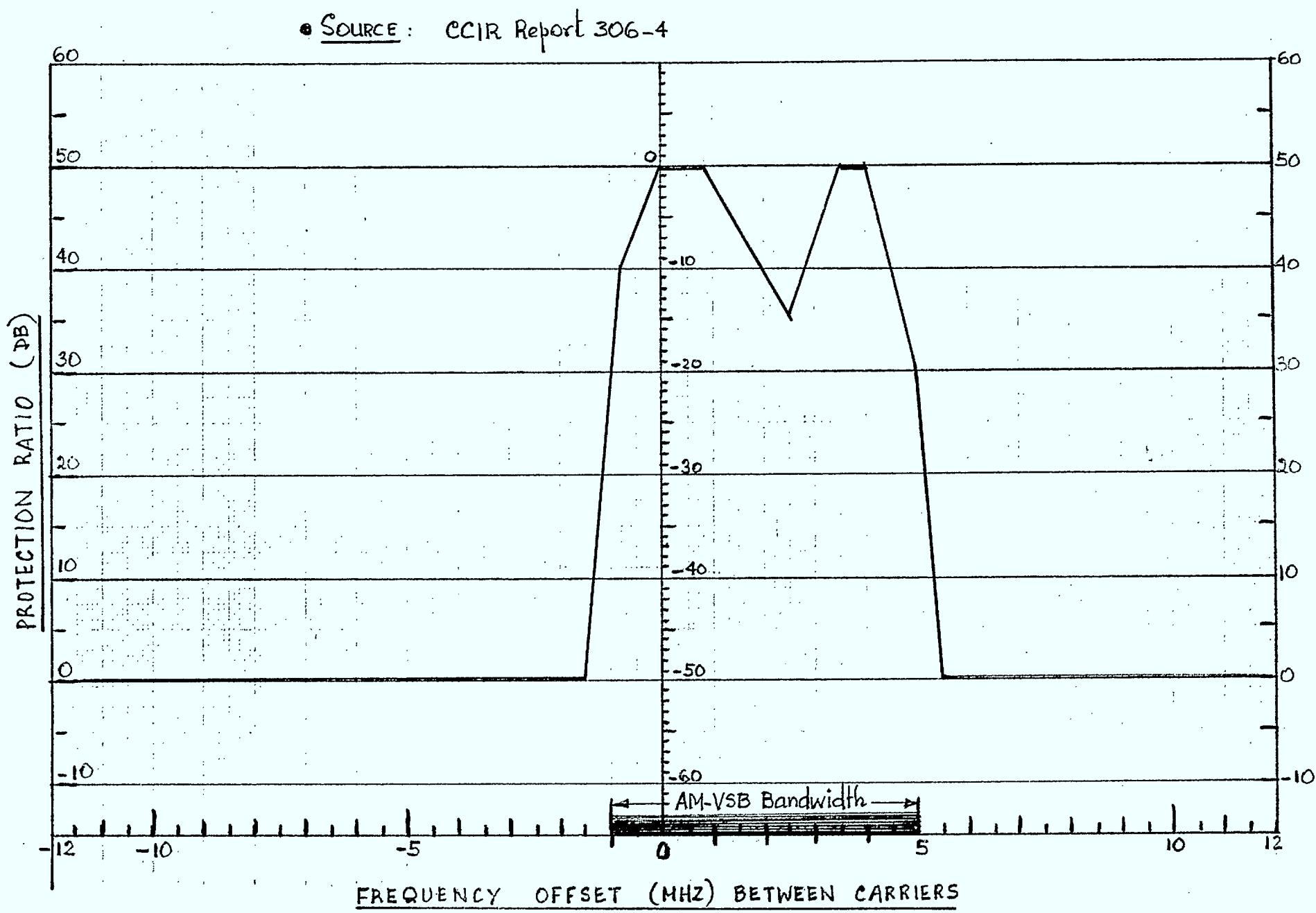


Figure A2-5: "Just Perceptible" Impairment to AM-VSB from Two Equi-Level NBFM Carriers

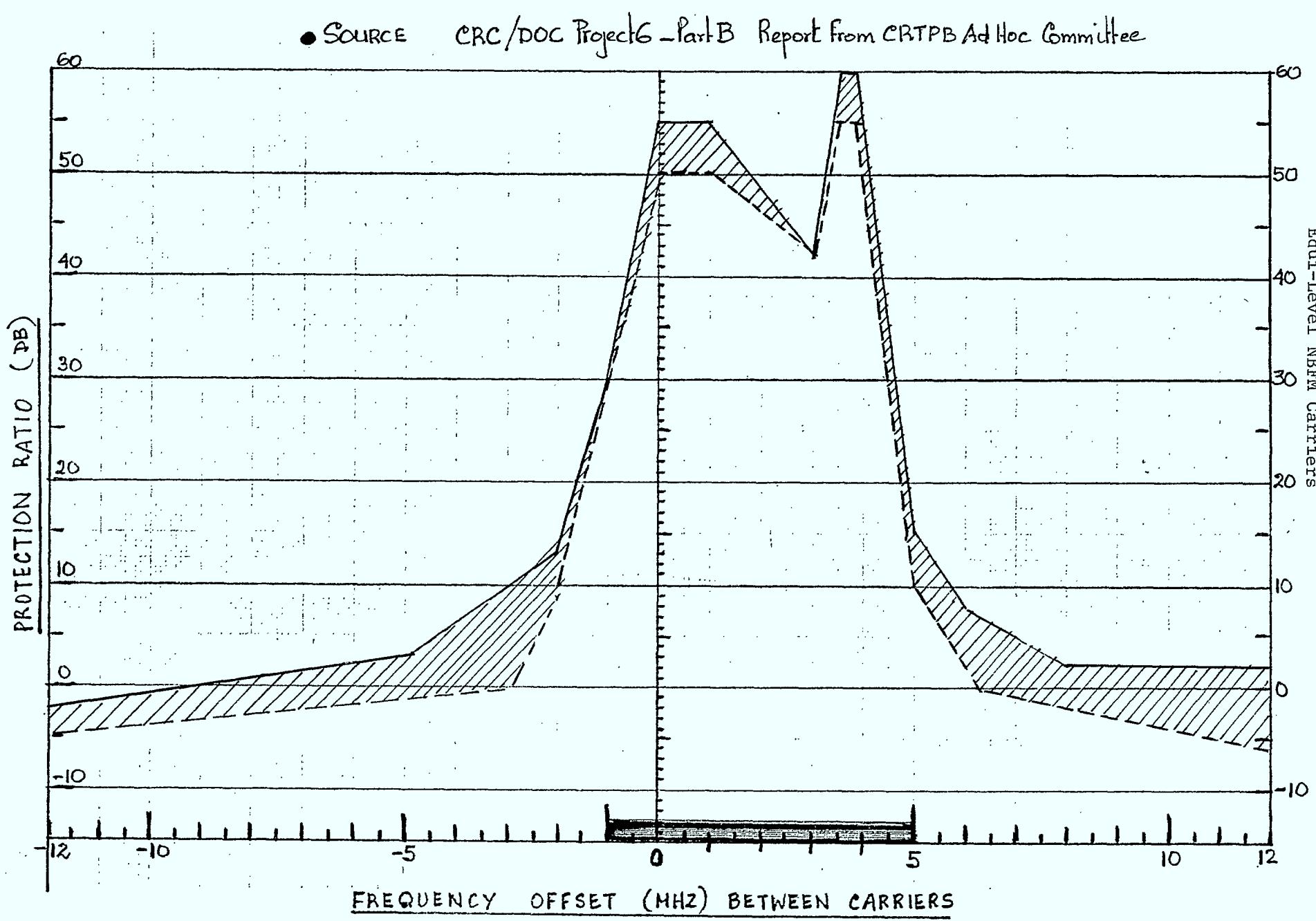


Figure A2-6:

Proposed "Just Perceptible" Mask for Interference

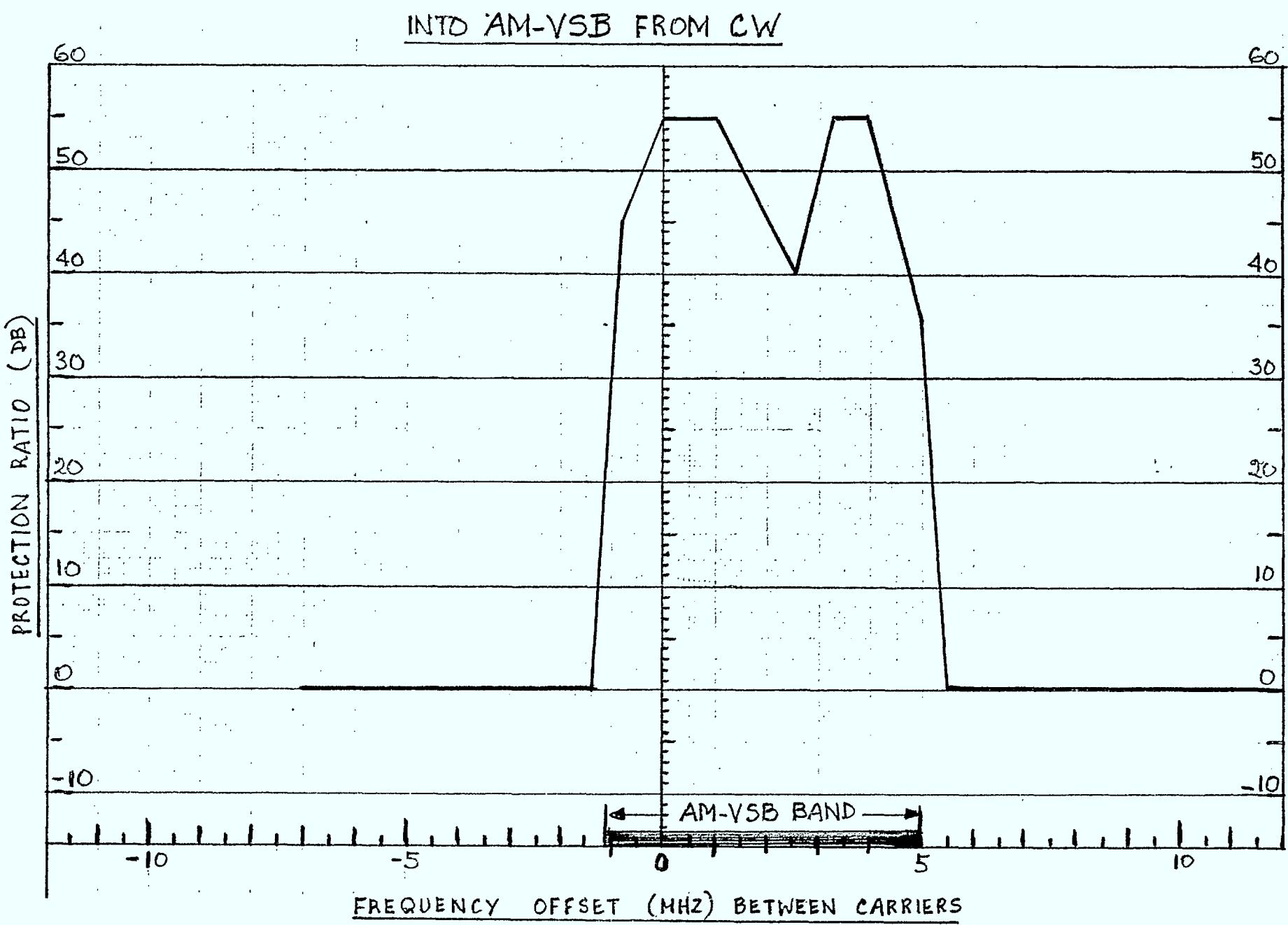


Figure A2-7: Estimated "Just Perceptible" Mask for Interference into AM-VSB from AM-VSB vs Frequency Offset

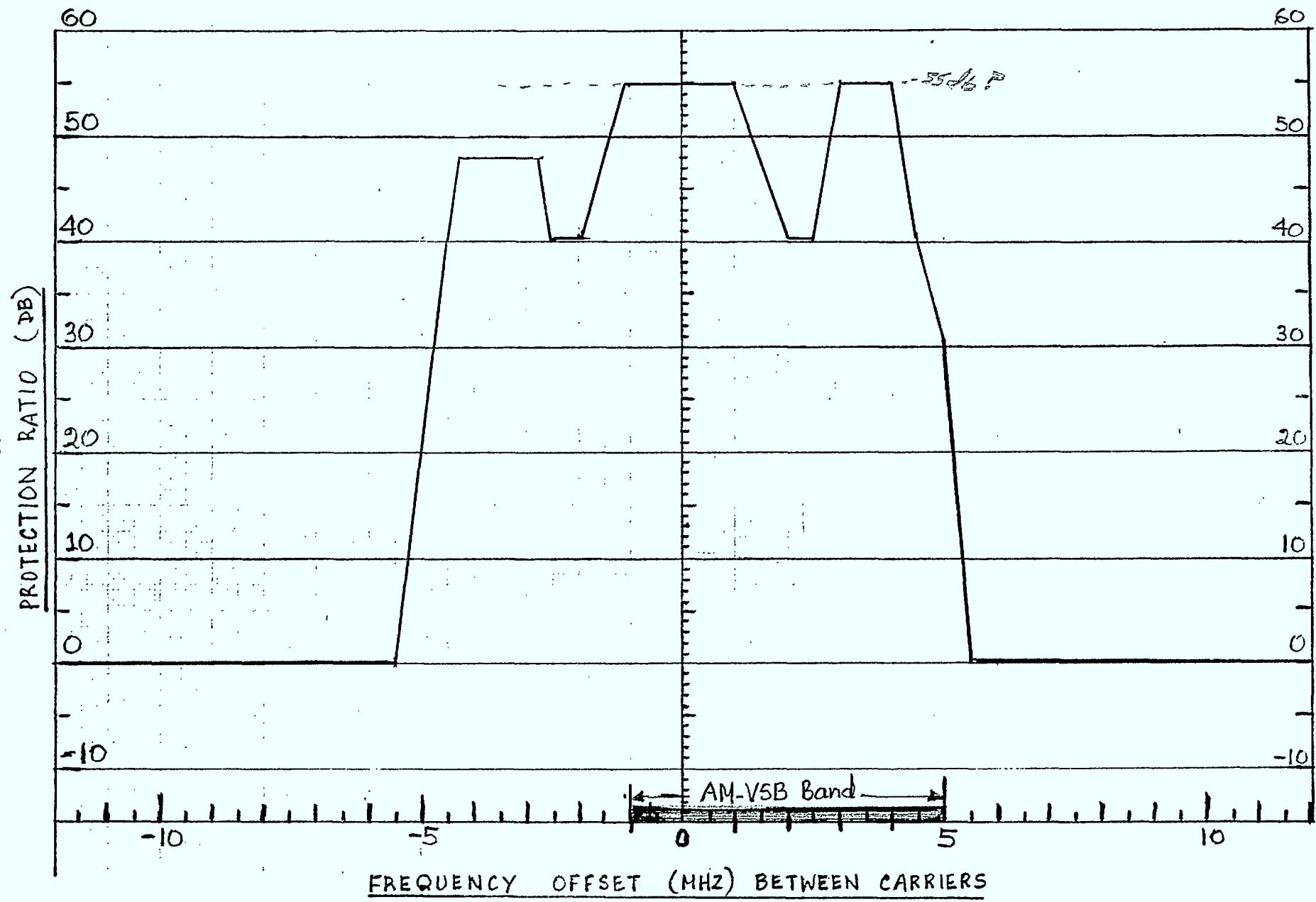


Figure A2-8: AM-VSB Picture Quality vs Co-channel Interference from FM TV

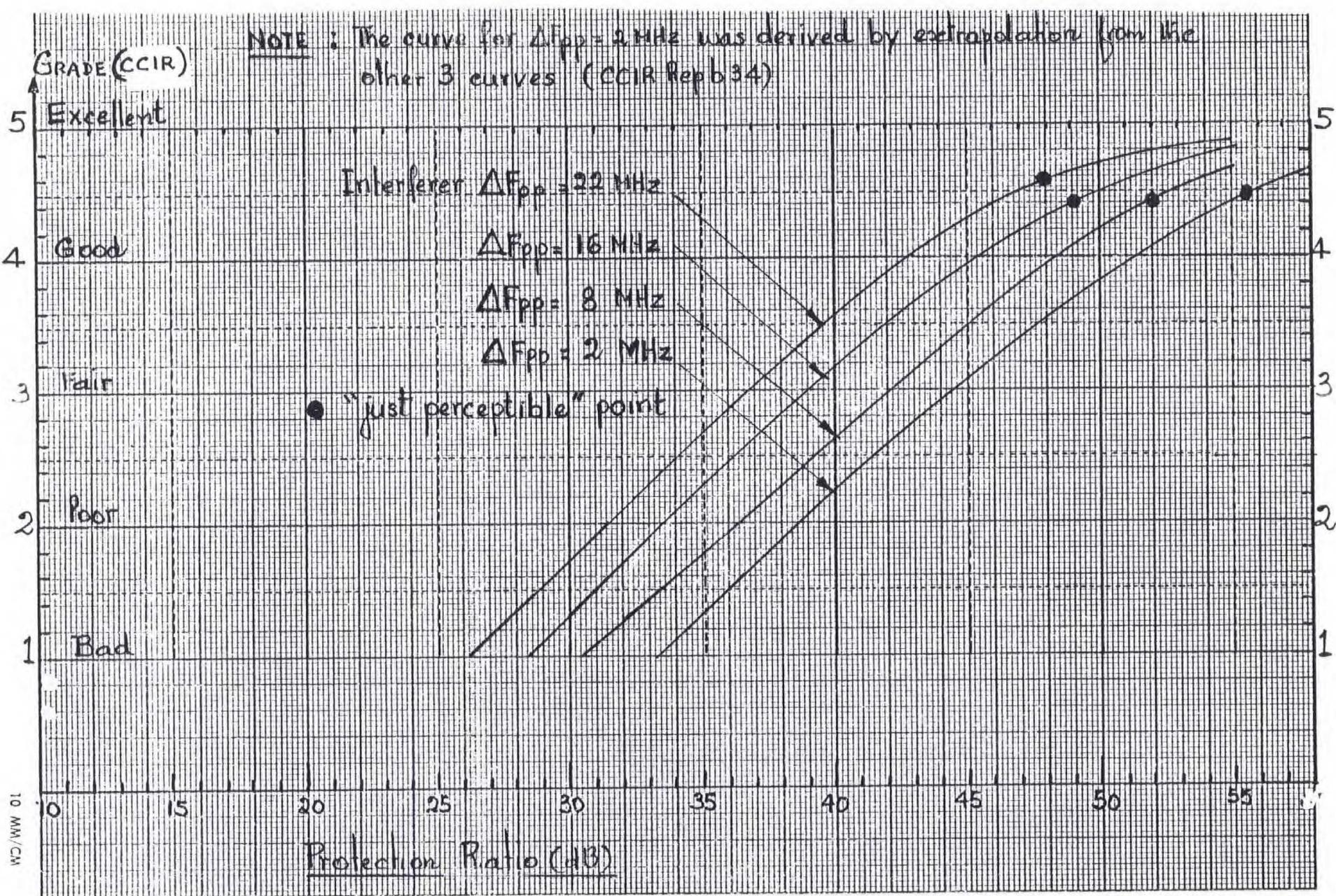


Figure A2-9: AM-VSB TV Interference from FM TV for "Just Perceptible" Impairment

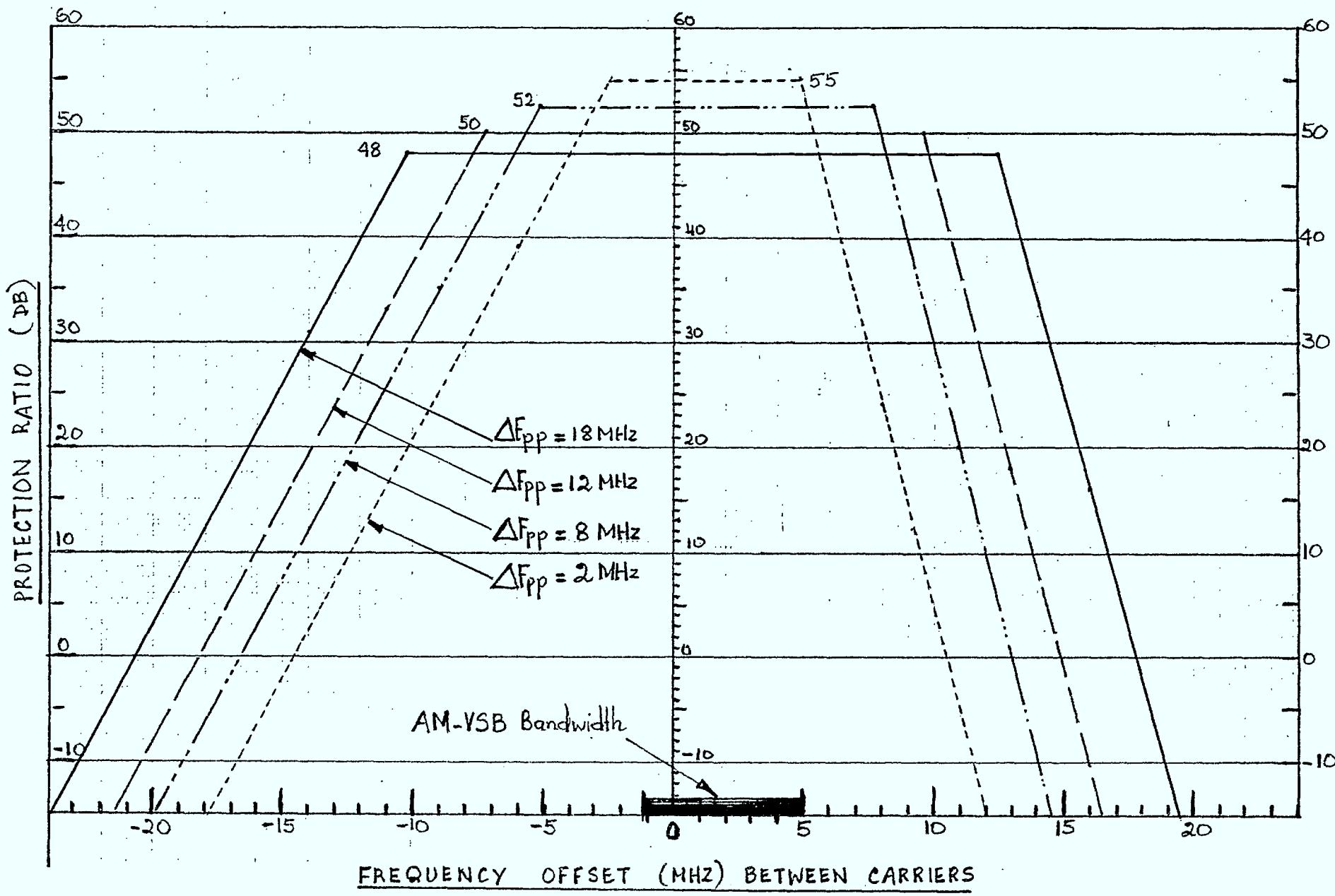
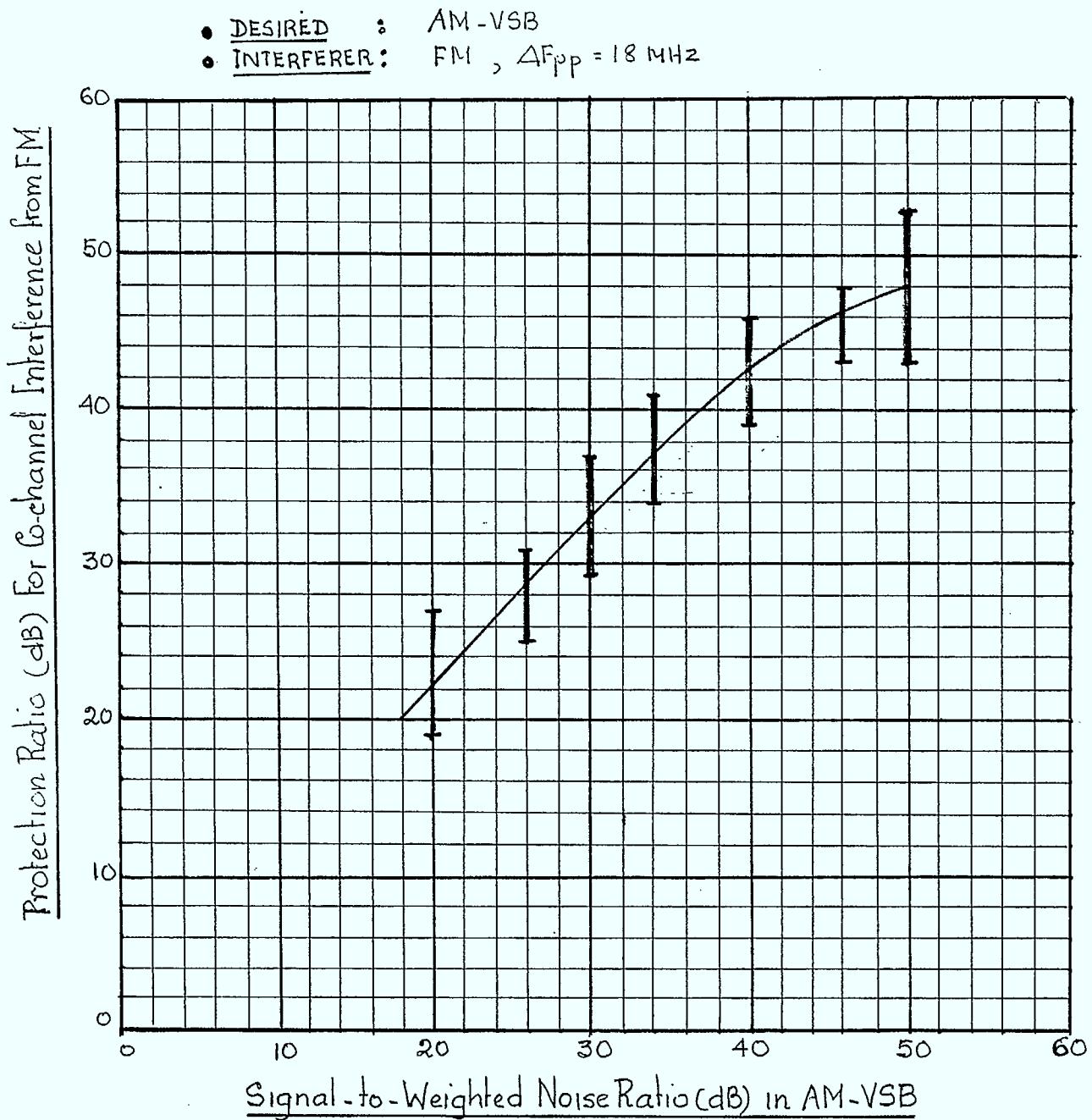


Figure A2-10: "Just Perceptible" Protection Ratio vs SNR



CONCLUSIONS : For $\text{SNR} < 42 \text{ dB}$, Average PR = $\text{SNR} + 2 \text{ dB}$
 , Peak PR = $\text{SNR} + 7 \text{ dB}$

For $\text{SNR} = 46 \text{ dB}$, 50% of viewers saw no interference when
 PR = SNR and experts saw no interference
 when PR = $\text{SNR} + 4 \text{ dB}$

3. FMTV INTERFERENCE PERFORMANCE CHARACTERISTICS

Interference into FM TV systems is somewhat simpler because the effect of interference depends on:

- a) the peak-to-peak frequency deviation of the wanted FM carrier. The protection ratio required for a wanted carrier of peak-to-peak frequency deviation of D_v MHz can be related to the protection ratio of another FM carrier of peak-to-peak frequency deviation of 12 MHz (eg.) by $20\log_{10} (D_v/12)$. The smaller deviation carriers will require a higher protection ratio than the larger deviation carriers for the same interference level. This permits extrapolation of results measured at a specific deviation to carriers with other deviations.
- b) the protection ratio appears to be rather insensitive to the nature of the interfering signals; only the interference power level seems to be significant.

3.1. Interference from Random Noise

The effect of random noise on the impairment of an FM TV picture is shown in Figure A3-1. Two curves are shown: one proposed by Canada and the other by the USA. Since the measurements are made at baseband, the results are independent of the frequency deviation of the wanted carriers.

It is often of interest to be able to relate measurements made at baseband (SNR) to measurements at RF or IF (CNR). The equations used by terrestrial TV systems are given in Figure A3-2 and those used by the satellite TV systems are given in Figure A3-3. If the CCIR weighting and a bandwidth of 4.2 MHz is used with the satellite system equation, there is approximately 1 dB of difference between the two equations.

The satellite systems will soon be using the "unified" weighting network and a bandwidth of 5 MHz for all types of TV systems- NTSC, PAL, etc: Table A3-1 gives the modifications to the de-emphasis and weighting advantages this would entail.

3.2.

Interference due to CW

Measurements conducted in China on a D/PAL TV system with $\Delta F_{pp} = 8$ MHz gave a "just perceptible" mask as shown in Figure A3-4. Peaks occur when the CW interferer is located at the wanted carrier frequency (picture) and at the colour sub-carrier frequencies on either side of the wanted carrier. The "just perceptible" protection ratio for the monochrome TV for the co-channel case appeared to be 2 dB below that for the colour TV case. The difference is usually 1 dB.

These results apply to the NTSC system too but for our deviations, the co-channel "just perceptible" PR will be:

$$\Delta F_{pp} = 8 \text{ MHz}, PRo = 31 \text{ dB}$$

$$\Delta F_{pp} = 2 \text{ MHz}, PRo = 41 \text{ dB}$$

The "just perceptible" mask for CW interference for the above two cases will have a peak at the co-channel offset of PRo, secondary peaks at ± 3.6 MHz at a PR of 3 dB less than PRo, and troughs at ± 1.8 MHz, about 5 dB below PRo. The levels at ± 5 MHz will also be PRo - 5 dB. Thereafter, the curve will decrease rapidly. Figure A3-5 presents the estimated template for this case.

3.3.

Interference from FMTV

Figure A3-6 gives the impairment grade vs protection ratio for the cases of $\Delta F_{pp} = 8$ MHz and 2 MHz for co-channel interference. Since the protection ratio is relatively insensitive to the nature of the interferer, these curves apply for interference from FMTV, AM-VSB, DSB-AM, CW, 4-PSK digital modulations and FDM-FM carriers.

3.4. Effects of Multiple Entries

As in the AM-VSB case, the powers of the interferers can be added on a power basis and the total interference power treated as the power of a single entry interferer.

3.5. Effects of Carrier Offsets in Frequency

Figure A3-7 shows the measured "just perceptible" protection ratio for the case of FMTV interfering with FMTV when both carriers have a peak-to-peak frequency deviation of 9.52 MHz. The proposed template for this case is also shown. The equations for this template are:

$$\text{for neg. frequencies, } PR = \begin{cases} 46 x_n + 39.9 & \text{for } \dots x_n > -0.52 \\ 27.7 x_n + 30.4 & \dots -0.52 > x_n > -0.882 \\ 48.05 x_n + 48.38 & \dots -0.882 > x_n \end{cases}$$

$$\text{for pos. frequencies, } PR = \begin{cases} -66.29 x_n + 51.09 & \text{for } \dots x_n < 0.669 \\ -24.67 x_n + 23.23 & \dots 0.669 < x_n < 0.96 \\ -46.96 x_n + 44.67 & \dots 0.96 < x_n \end{cases}$$

where $x_n = \Delta f / \text{CBW} = \text{frequency offset}/\text{carbons bandwidth}$
and $\text{CBW} = 2(\Delta F_p + f_m)$

Figure A3-8 shows the measured protection ratio for the case of $\Delta F_{pp} = 8.4$ MHz and the template using the previous mentioned equations proposed by CRC for the $\Delta F_{pp} = 9.52$ MHz case. This template is a rather "tight fit" with no margin. The equations are probably for the $\Delta F_{pp} = 9.52$ MHz case, only, though this was not specifically stated. Also shown in this figure is a template which is more appropriate to the $\Delta F_{pp} = 8.4$ MHz (and $\Delta F_{pp} = 8$ MHz) case.

Figure A3-9 shows the templates for the $\Delta F_{pp} = 9.52$ MHz and 8.0 MHz cases. The template for the $\Delta F_{pp} = 2$ MHz was derived from these templates and the fact that for the $\Delta F_{pp} = 2$ MHz, the following conditions apply:

- a) "just perceptible" PR = 43.5 dB for the co-channel offset and for offsets of ± 3.6 MHz.
- b) at offsets corresponding to the adjacent channel locations, the "just perceptible" protection ratio should be approximately 0 dB. The estimated template for $\Delta F_{pp} = 2$ MHz case is also shown.

Figure A3-1: FM TV Picture Impairment due to Random Noise

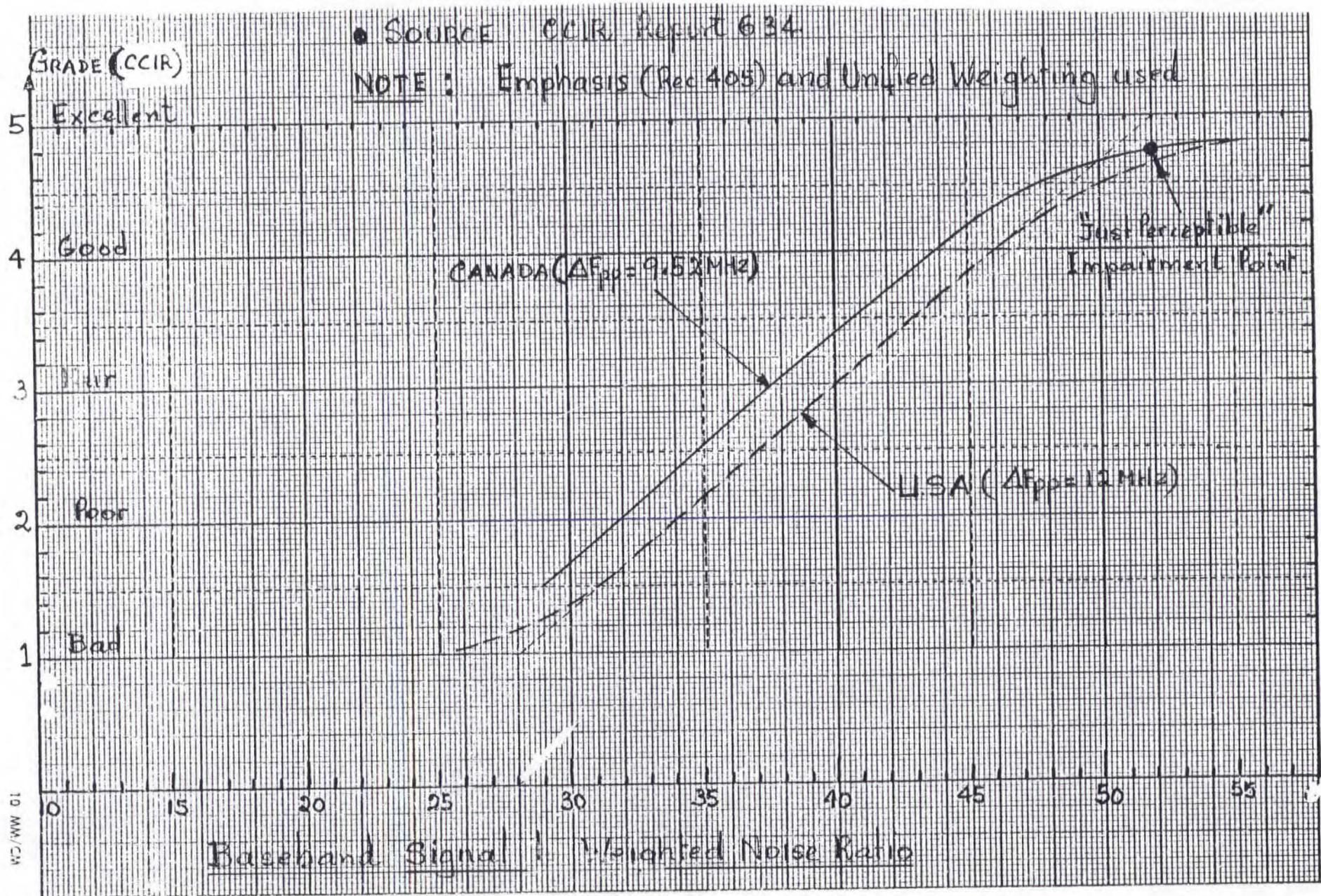


Figure A3-2: Baseband SNR vs CNR for Terrestrial TV Systems

$$\text{Baseband } \left[\frac{S}{N} \right]_{\text{dB}} = \left[\frac{C}{N_0} \right]_{\text{dB-MHz}} + 10.8 + 20 \log \left| \frac{\Delta F_s}{10} \right| - 30 \log b_n \left| \frac{10}{\Delta F_s} \right| \text{ MHz}$$

where S = peak to peak signal

N = rms noise

C = carrier power at RF or IF

N_0 = random noise power density at RF or IF

$[C/N_0]$ is expressed in dB-MHz

ΔF_s = peak frequency deviation of the signal in MHz

ΔF_v = peak frequency deviation of the video waveform

which consists of the picture signal plus the sync pulses

$0.714 \Delta F_v$ = peak frequency deviation of the picture signal only

b_n = factor that includes the effect of de-emphasis (D), weighting (W) and the output low pass filter (F) in MHz.

Corresponds to equivalent noise bandwidth.

STANDARD	ΔF_s	UNWEIGHTED b_n $b_n(D, F)$ in MHz	WEIGHTED b_n $b_n(D, F, W)$ (MHz)
CCIR Rec 421-3 (1974)	$0.714 \Delta F_v$	3.357	1.574
NTC Report No 7 (1975)			
EIA RS-250A (1967)	ΔF_v	-	2.2
Bell Telephone Labs (1971)	ΔF_v	-	1.574
Proposed CCIR Rep 410 (1974)	$0.714 \Delta F_v$	3.960	1.608
Proposed EIA Prop 1193 (1974)			

SOURCE: IEEE Trans. Cable TV, October 1976, pp 25-30, L. Clayton

Figure A3-3: Baseband SNR vs RFCNR for Satellite FM TV Systems

$$\text{Baseband } \left[\frac{S}{N} \right]_{\text{dB}} = \left[\frac{C}{N_0} \right]_{\text{dB-MHz}} + 7.8 + 20 \log_{10} \frac{\Delta F_v}{f_m} - 10 \log_{10} f_{vn} + Q$$

where S = peak-to-peak luminance or picture signal voltage

N = rms noise voltage

C = carrier power at RF or IF

N_0 = noise power spectral density at RF or IF

$\left[\frac{C}{N_0} \right]$ expressed in dB-MHz

ΔF_v = peak frequency deviation of the carrier by the video waveform

f_m = video bandwidth ($= 4.2 \text{ MHz}$)

f_{vn} = noise bandwidth at baseband ($\approx 4.2 \text{ MHz}$) determined by the low-pass filter

Q = factor in dB which includes the effect of de-emphasis and weighting on the baseband triangular noise

$= 12.8 \text{ dB}$ for $f_{vn} = 4.2 \text{ MHz}$ and CCIR weighting and de-emphasis

$= 13.8 \text{ dB}$ for $f_{vn} = 4.2 \text{ MHz}$ and "unified" weighting

$= 14.8 \text{ dB}$ for $f_{vn} = 5.0 \text{ MHz}$ and "unified" weighting

SOURCE : Comsat Review, Fall 1972, pp 467-470.

Table A3-1:

De-emphasis and Weighting Factors Used in 525-Line NTSC/M Systems

Measured Bandwidth (MHz)	Weighting	De-emphasis Factors (dB)		Weighting Factors (dB)				Weighting + De-emphasis (dB)	
		(a) White Noise	(b) Triangular Noise	(c) White Noise	(d) Triangular Noise	(e) De-emphasized White Noise	(f) De-emb: Triangular Noise	(g) White Noise	(h) Triangular Noise
4.2	M	-0.4	2.9	6.2	10.3	2.7	9.9	2.3	12.8
4.2	Unified	-0.4	2.9	6.8	11.5	2.7	10.9	2.3	13.8
5.0	Unified	0.0	3.1	7.4	12.2	3.3	11.7	3.3	14.8

NOTE : (a) + (e) = (g)

(b) + (f) = (h)

SOURCE : CCIR Report 637-2

Figure A3-4: "Just Perceptible" Protection Ratio for FM TV from CW Interference

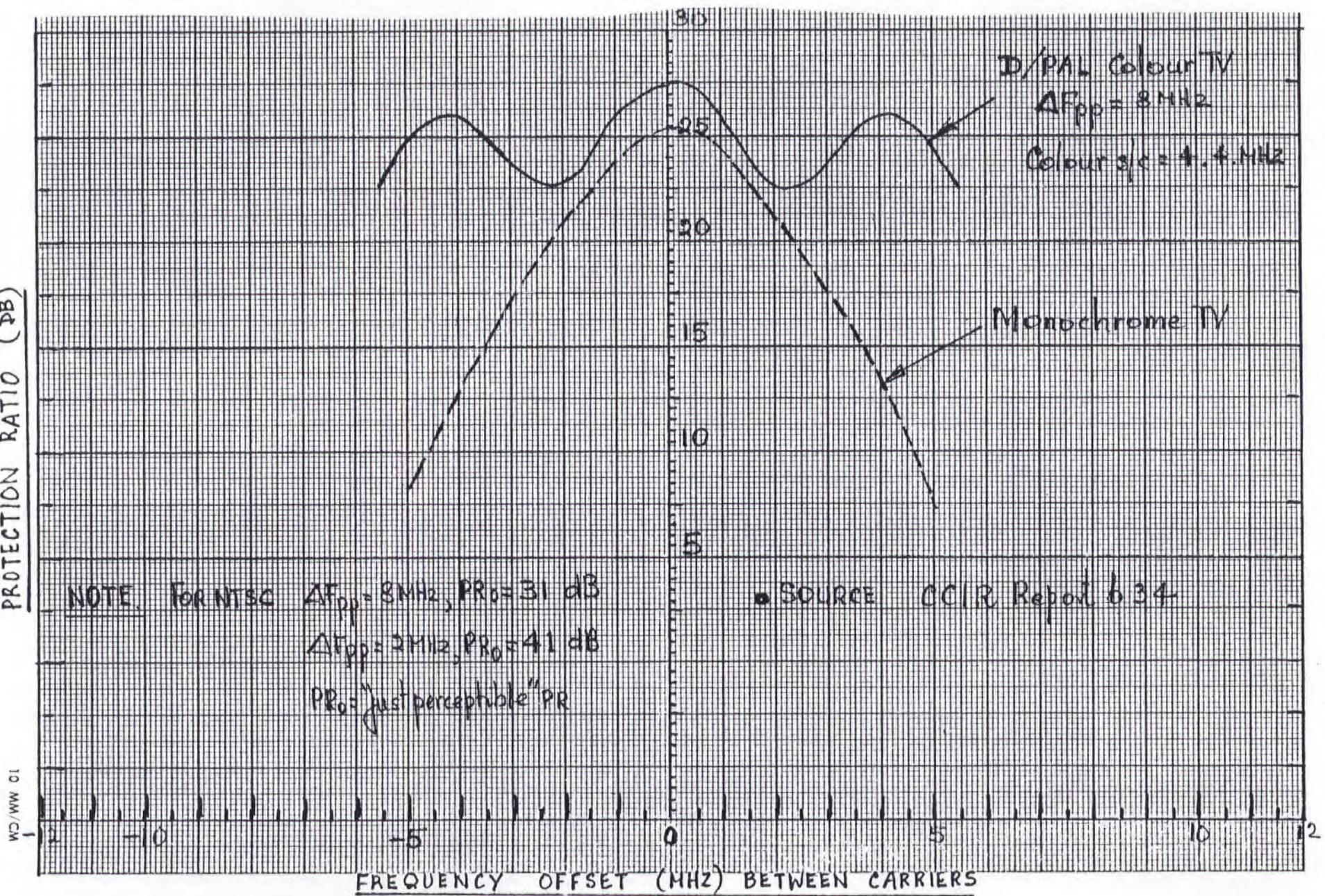


Figure A3-5: "Just Perceptible" Protection Ratio FM into FMTV
as a Function of Frequency Offset

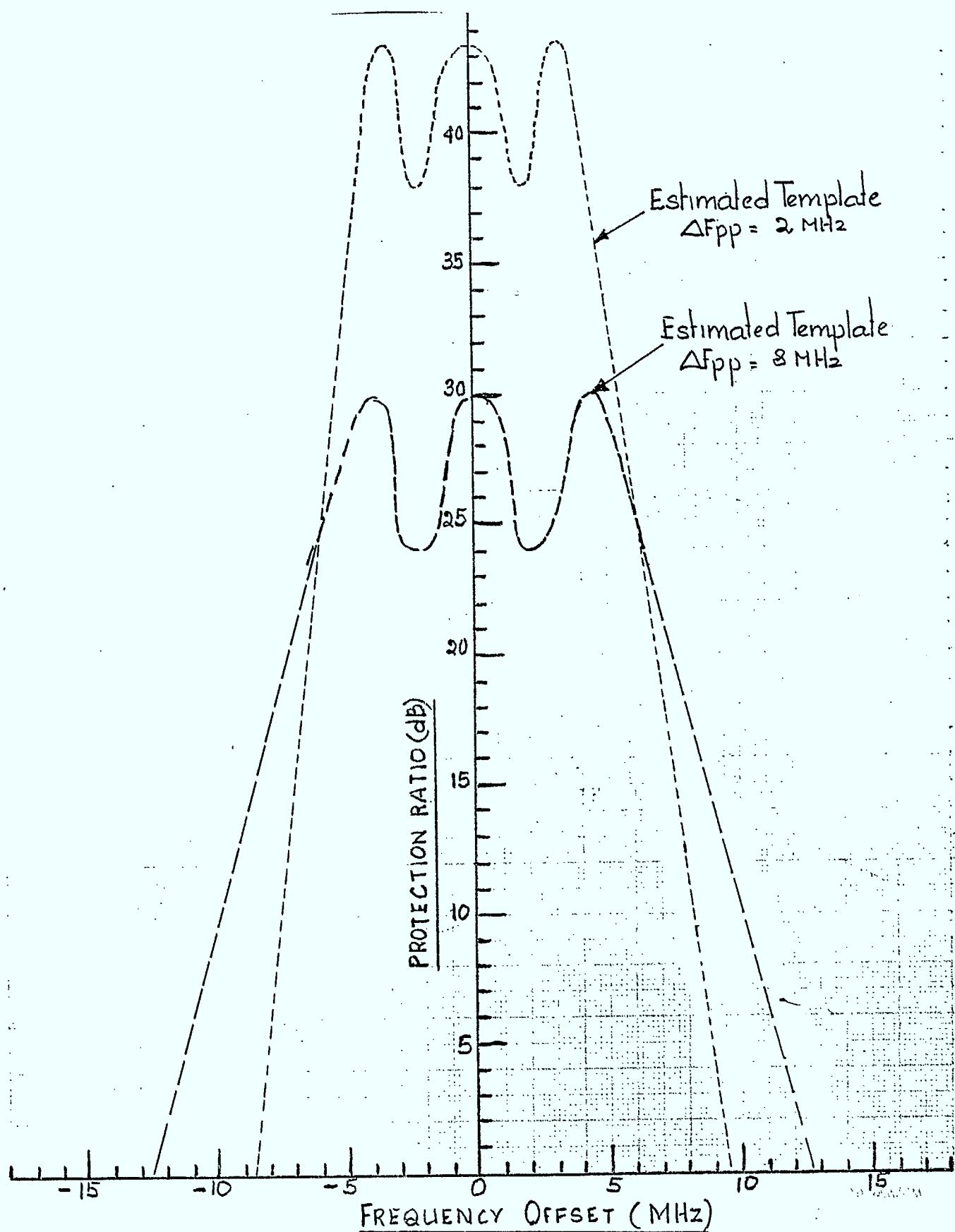


Figure A3-6: FM TV Picture Impairment vs Co-channel Interference

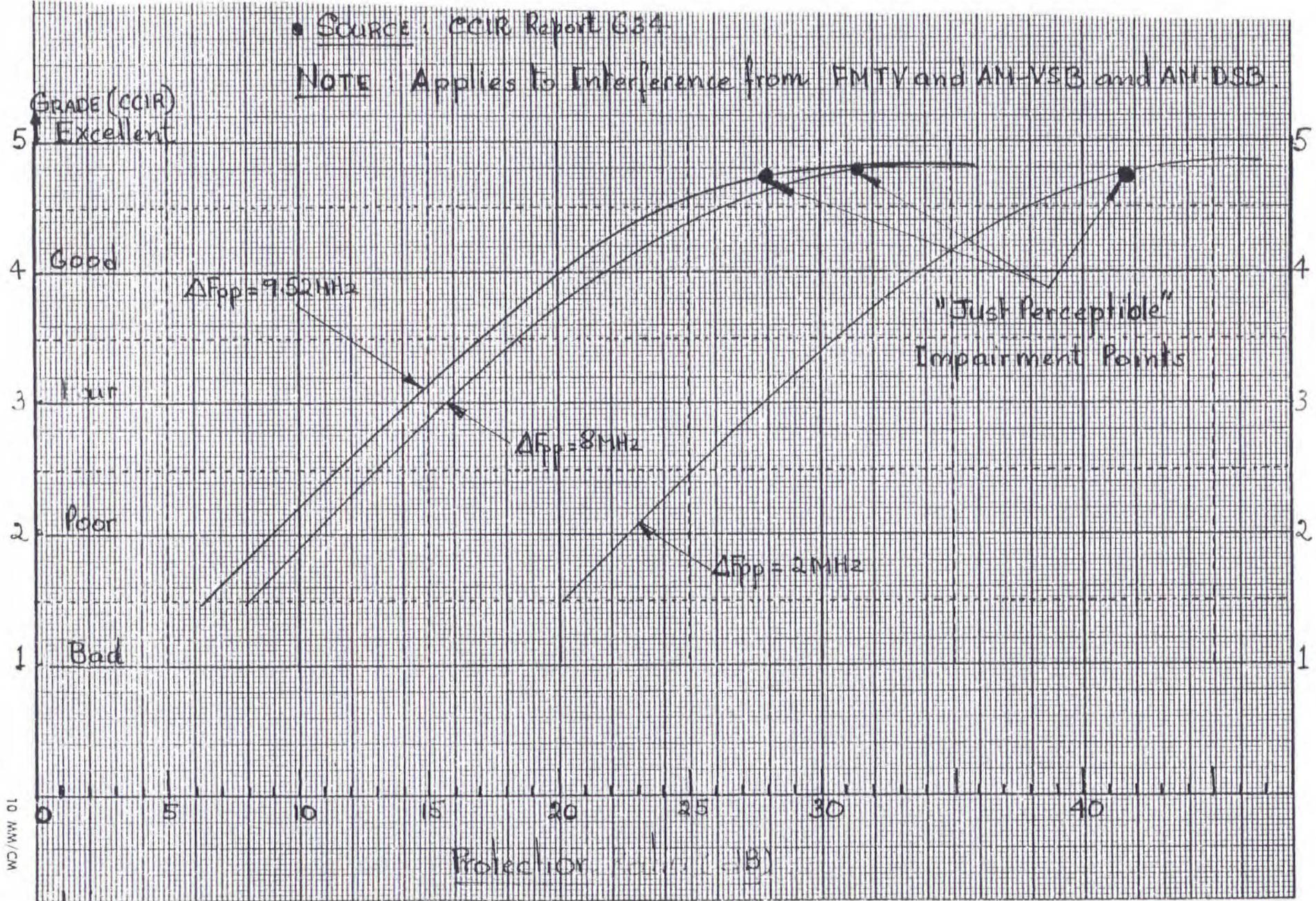


Figure A3-7: FM TV Interference into FM TV - "Just Perceptible"

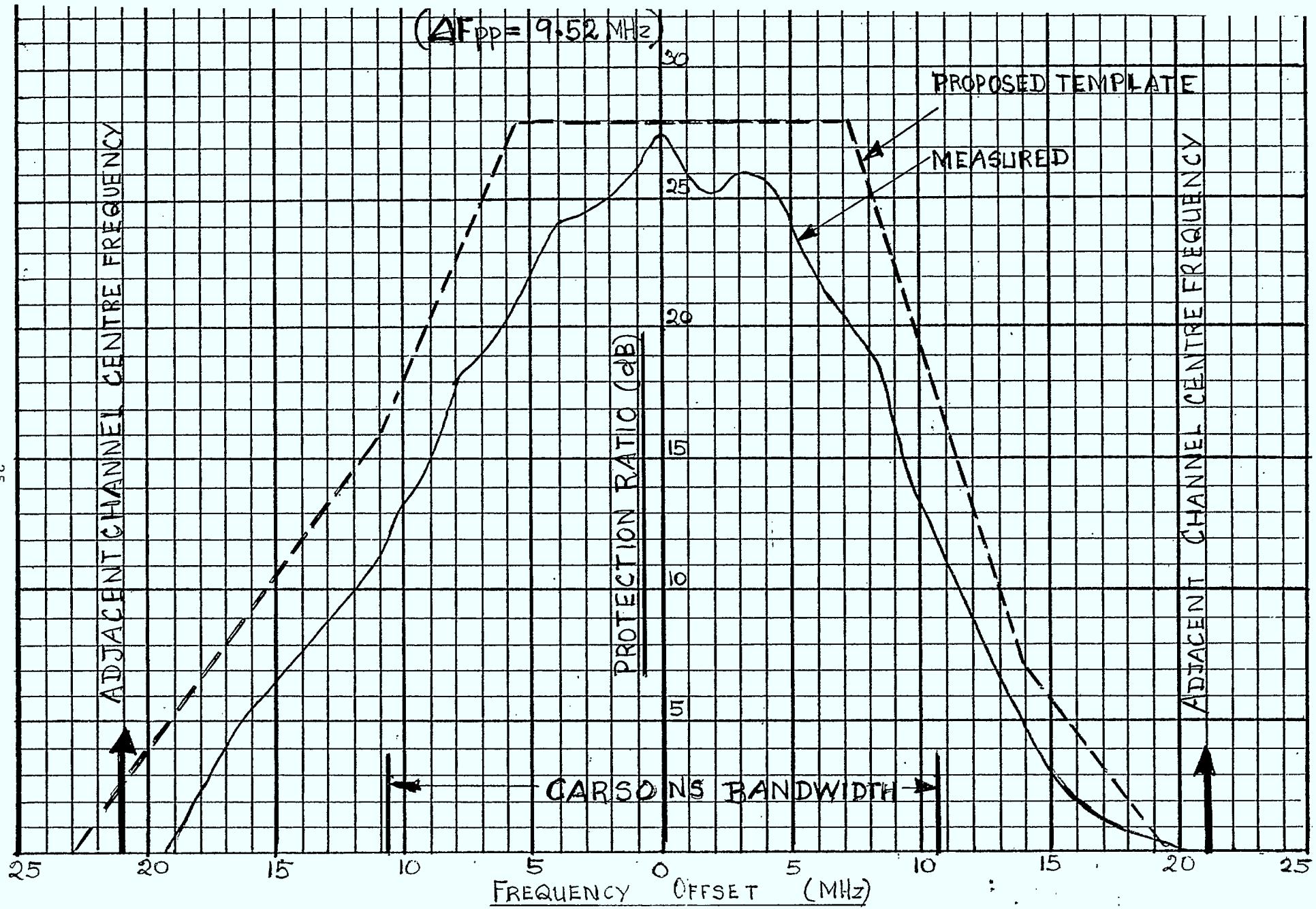


Figure A3-8: FM TV into FM TV "Just Perceptible" Interference

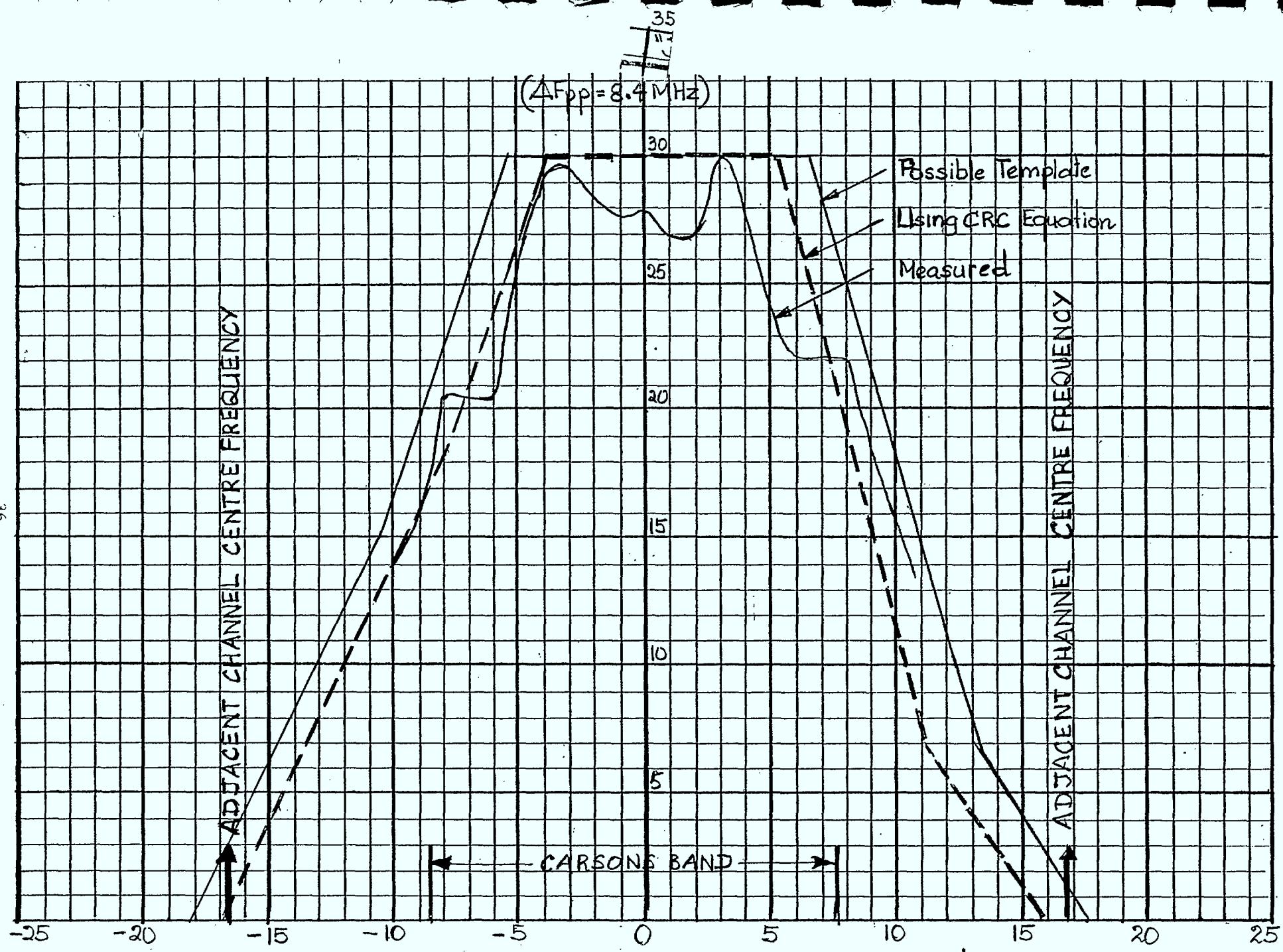
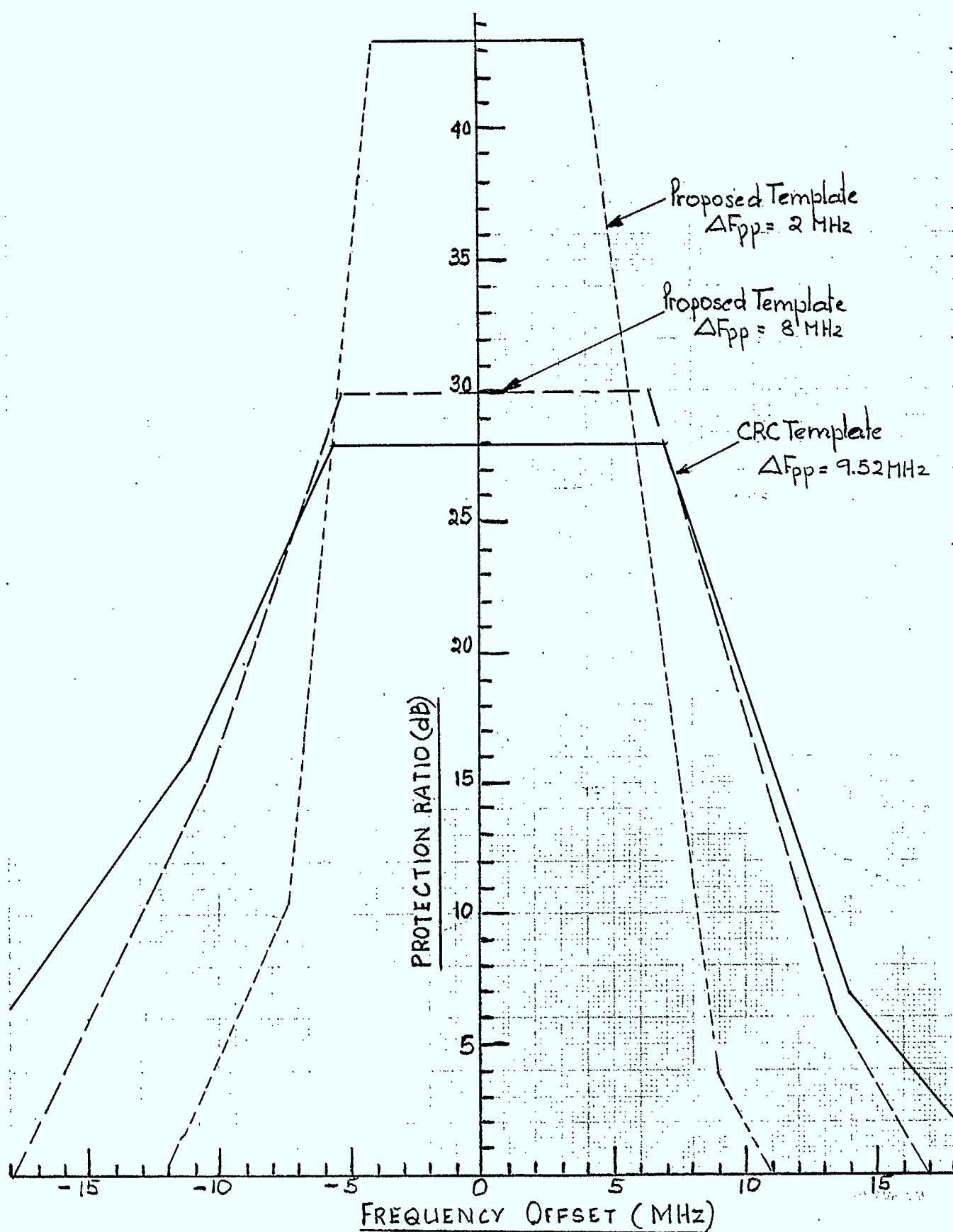


Figure A3-9: "Just Perceptible" Protection Ratio FM into FM TV
as a Function of Frequency Offset



4.

CONCLUSIONS

- a) The objective of this investigation was to provide the Department of Spectrum Management Systems (SMS) of DOC with analytical tools to evaluate the performance of CATV VHCM systems carrying AM-VSB and narrowband FM TV signals in an interference environment.
- b) To meet the above objective, the investigation concentrated on determining the following performance characteristics for each of the above CATV signals:
 - "just perceptible" template or mask for a particular source of interference as the interference carrier frequency is offset from the co-channel case to the adjacent channels.
 - the variation of the picture quality as the protection ratio is varied from the "just perceptible" value to the "unusable" picture quality for both the TASO scale and the CCIR scale.

The "just perceptible" impairment is of particular importance because:

- i) it is the value that is generally used in most systems as the design value for a single entry interference protection ratio.
- ii) it is the value at which the subjective assessments of non-experts and experts show the least disagreement.
- iii) it is independent of the quality grading scale used.

The relationship between picture quality and protection ratio is of importance in allocating impairments to different points in the transmission link from the TV camera to the TV receiver.

The above information is generally required in both quality grading scales used in North America:

- the TASO six-point scale;
 - the CCIR five-point scale.
- c) Though the effects of interference from AM-VSB and narrowband FM TV systems only were required by the Statement of Work, the investigation also considered two additional interference sources:
- continuous wave (unmodulated) carrier;
 - random noise of uniform spectral density at RF or IF.

The effect of CW interference is important since interference from spurious emissions from other systems are generally CW in nature. Moreover, CW interference generally is the most destructive to TV picture quality and CW protection ratio limits may be considered the "worst case" protection ratio for any TV system.

Interference from random noise, also, is important since it is the most prevalent form of interference and is the main determinant of picture quality. It is also the least destructive form of interference and for that reason may be considered as setting the "best case" protection ratio for any TV system for a given picture grade.

- d) Conducting subjective measurements to obtain the desired information did not form part of the Statement of Work. The information was extracted from published literature on the subject. Unfortunately, the published literature only treated certain aspects of the interference phenomena, so to obtain the information required, considerable extrapolation of the published data was necessary. The extrapolated results are only valid to the extent that the relationships

used in the extrapolation are valid; the relationships used in the extrapolation were described in detail.

- e) In arriving at the desired information, the average of the "peak values" of the measured data were used. This was judged to be the most appropriate value to use since a single "peak" or "trough" value is generally an indication of an anomalous measurement rather than an indication of true impairment.

Considerable variation exists in the published literature on the protection ratio for a given grade of quality. This is not surprising since the testing is done subjectively. The factors that affect the result are:

- picture quality assessment scale which, in itself, is rather vaguely defined and on the different scales used.
- types of viewers used: non-experts, interested, experts.
- types of receivers used: filter bandwidths and picture tube types, etc.
- expectations of the viewers.
- viewing conditions: distance from receiver and the ambient lighting conditions.
- the wanted signal characteristics: still picture, moving picture, type of still picture,, off-the-air broadcast picture - used in tests.
- the interfering signal characteristics used in the tests.

- presence of other sources of impairment to the picture (such as random noise, transmission waveform distortion, etc) during the tests.

For this reason, the data provided in this investigation should not be treated as "accurate" - the results cannot be more accurate than the data from which they are derived. However, since the average of worst-case results were used, the suggested templates are probably on the conservative side and hence could be used for developing specifications, but not necessarily for predicting the performance of any particular measurement.

- f) The information provided in this investigation is intended for use in developing specifications. However, no recommendations are made regarding what the specification protection ratio should be at a certain point in the transmission link. Table A4-1 is provided to help in this regard. The protection ratio that will cause a "just perceptible" impairment to the picture at a specific value of (S/N) may be taken as that (S/N) plus 4 dB.

Table A4-1: Television Quality in Canada

*

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QUALITY AT OUTPUT OF:	Signal-to-Noise Ratio (dB)	K-Factor (%)	Resolution (Lines)
TV Camera	55	1	500~600
Video Tape Recorder	52~54	1	500
Studio	50~55	2	500
Microwave Relay Links	48~52	2~3	450~500
Satellite Links	48~52	2~3	450~500
Transmitter	46~50	3~5	335
Cable System	40~50	4~6	300~320
Receiver Accessories	38~48	5~7	275~300
Receiver	35~50	5~20	200~250

SOURCE : A.G.DAY , SMPTE Television Conference, 1984

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PART B

INTERFERENCE INTO DSB-AM AND NBFM TV SYSTEMS

PART B
INTERFERENCE INTO DSB-AM AND NBFM TV SYSTEMS

1. INTRODUCTION

This section investigates the interference performance characteristics of AM-DSB TV and NBFM TV systems in an interference environment consisting of the following interferers:

- random noise;
- CW;
- DSB-AM TV;
- NBFM TV.

No information could be found on measured subjective test results on DSB-AM TV systems. The results presented in this section were derived largely by heuristic reasoning based on results from the AM-VSB TV case.

2. DSB-AM INTERFERENCE PERFORMANCE CHARACTERISTICS

2.1. Relationship Between AM-VSB and AM-DSB

The main characteristics of a modulated AM-DSB carrier modulated by a video waveform is shown in Figure B2-1; the sync tip corresponds to peak single voltage of $A_c(1 + m)$ where A_c is the peak amplitude of the unmodulated RF carrier and m is the modulation index. Full 100% amplitude modulation is not used because of possible distortions to the reference white level; rather 87.5% modulation or less is used.

The relationship between baseband SNR and RF CNR is also given in Figure B2-1 for the general modulation index.

The relationship between baseband SNR and RF CNR for the AM-VSB case is presented in Figure B2-2. The sketches in Figure B2-3 are provided to explain the derivations of the equations in Figure B2-2. These derivation were extracted from the paper by Strauss, NCTA, 1974, pp 58 - 63.

The significant point to be drawn from the foregoing is that for the same C_p (peak RF signal rms power) and modulation index, AM-DSB has 3 dB higher SNR than AM-VSB; or for the same SNR, AM-VSB requires 3 dB higher C_p .

An alternate way of achieving the same result would be to consider the DSB-AM signal as consisting of a carrier with two symmetrical sidebands, each of relative level m_s . At the detector output, the two sidebands are coherent and hence add on a voltage basis to give an output voltage proportional to $(2m_s)$. The RF noise at the same frequencies as the signal sidebands may be represented by vectors of amplitude m_n . At the detector output, the noise voltage will be proportional to $\sqrt{2} m_n$ since the two noise sidebands are not coherent.

$$\text{The resulting SNR} = 2m_s / \sqrt{2} m_n \text{ or } \sqrt{2} (m_s / m_n)$$

For the VSB-AM case, since there is only one sideband, the SNR at the detector output is (m_s / m_n) . In terms of logarithms, the DSB-AM is 3 dB less susceptible to noise interference than VSB-AM for the same modulation index and RF noise spectral density. This is the same result as was obtained by a more rigorous derivation in Figures B2-1 and 2.

An interfering CW may be regarded as a vector of amplitude M_{cw} located at the signal frequency. In the AM-VSB case, the SNR at the detector output will be $(\text{SNR})_{AM - VSB} = m_s / M_{cw}$ in voltage terms. For the AM-DSB case, $(\text{SNR})_{AM - DSB} = 2m_s / M_{cw}$. In this case, the AM-DSB system will have a 6 dB higher SNR than AM-VSB for the same (C/I) or protection ratio at RF; or, in other words, require 6 dB less protection ratio for interference from a CW interferer.

For the case of co-channel interference between two AM-DSB carriers, the protection ratio will result in the same output SNR as for the AM-VSB. Thus, the two interference sidebands will add

on a voltage basis so that the output SNR = $2m_s/2m_i$, as is also the case for the AM-VSB signal. However, in the DSB-AM case, when the offset is $\approx \pm 8$ MHz, the sound subcarrier falls on the colour subcarrier requiring a PR of 7 dB less than the case of co-channel interference from an AM-DSB carrier.

In the instance of co-channel interference from a NB FM carrier, the FM sidebands will either cancel or appear as RMS addition at the AM demodulator output, depending on the relative phases of the wanted and interfering carriers. Relative to AM-VSB, AM-DSB will require 3 dB less protection ratio.

2.2. **AM-DSB Interference from Random Noise**

The quality grade vs random noise S/N is shown in Figure B2-4.

2.3. **AM-DSB Interference from CW**

The proposed template is shown in Figure B2-5.

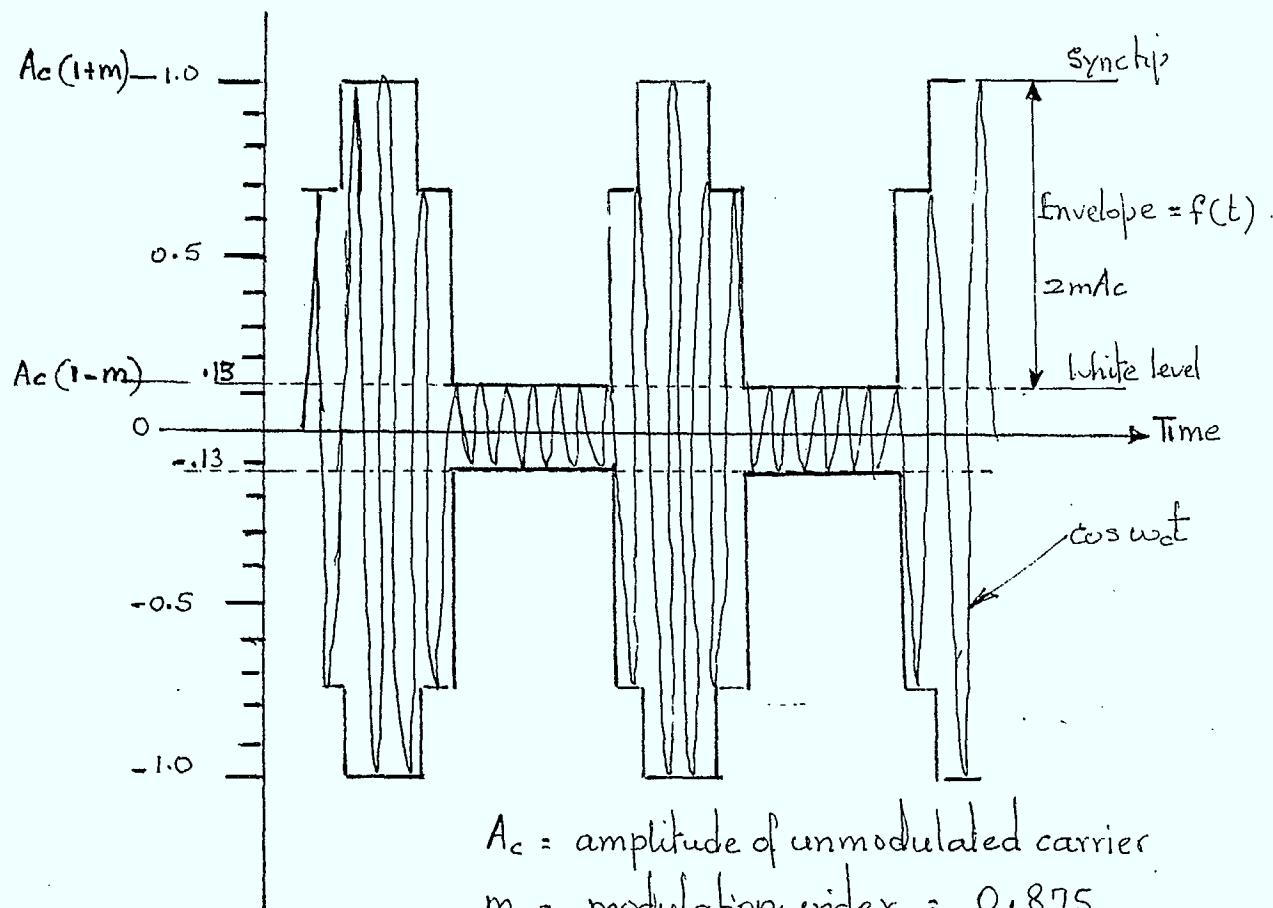
2.4. **AM-DSB Interference from AM-DSB TV**

The proposed template is shown in Figure B2-6.

2.5. **AM-DSB Interference from NBFM TV**

The picture quality vs co-channel FMTV interference is given in Figure B2-7.

Figure B2-1: Illustrating SNR vs CNR for DSB-AM



(a) DSB-AM MODULATED CARRIER WAVEFORM.

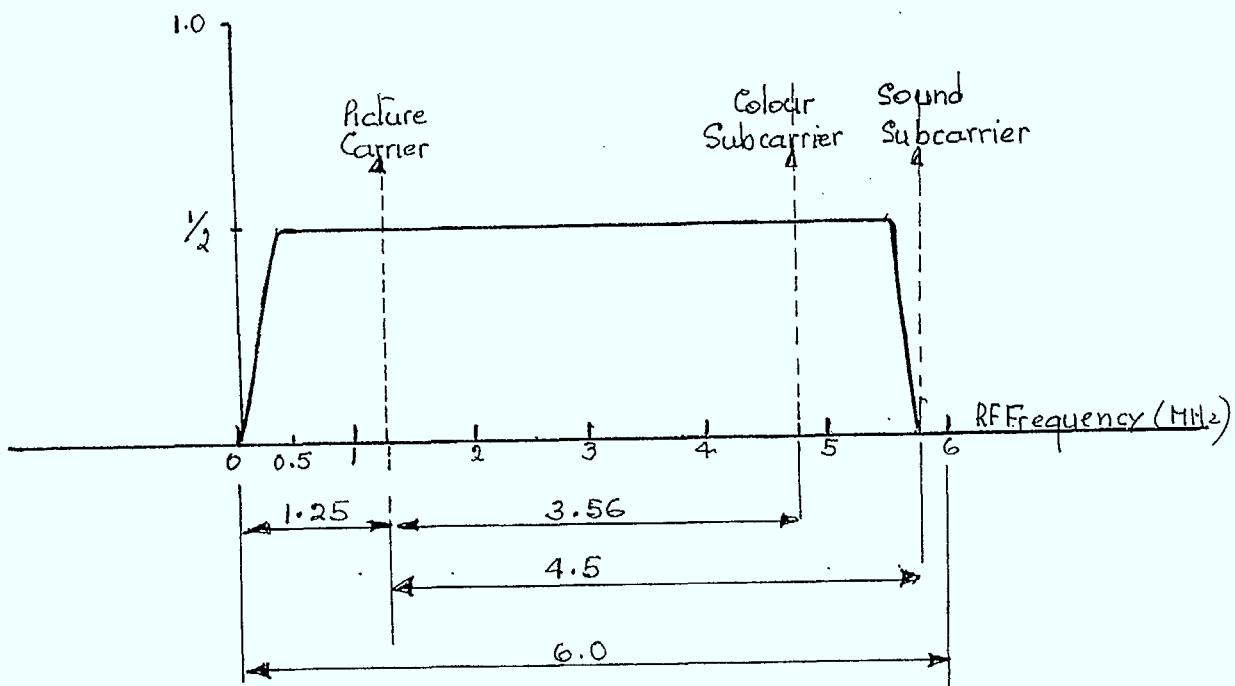
- DSB-AM. waveform equation = $g(t) = A_c [1 + m \cdot f(t)] \cos \omega_c t$
 - Carrier envelope varies from $A_c(1+m)$ to $A_c(1-m)$
 - The detected peak-to-peak RF voltage is proportional to $2mA_c$
 - Noise is uniform , of density D and RF bandwidth = $2B$, B =video bandwidth
 - Detected peak to peak signal power = $\frac{(S)}{N_{\text{DSB-AM}}} = \frac{(2mA_c)^2}{D(2B)}$
 - The rms carrier power at peak of modulation cycle , $C_p = \frac{A_c^2}{2}(1+m)^2$ or
 - In terms of Φ , $\frac{(S)}{N_{\text{DSB-AM}}} = \left(\frac{2m}{1+m}\right)^2 \cdot \left(\frac{\Phi}{DB}\right)$ (1) $A_c^2(1+m)^2/2$
- where maximum $m = 0.875$

Figure B2-2: Illustrating DSB-AM and VSB-AM Performance

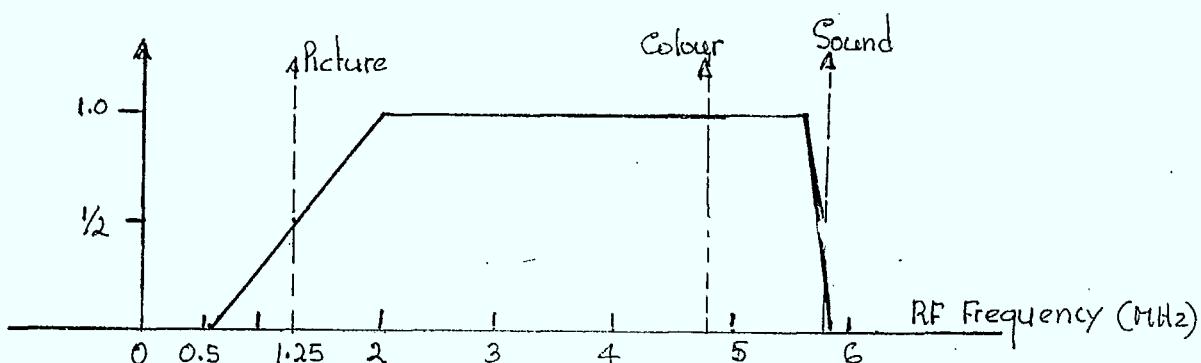
- In AM-VSB, the envelope variation factor $(\frac{2m}{1+m})$ relative to the envelope peak is the same as for DSB-AM
- The AM-VSB is passed through an RF bandpass filter with characteristic shown in Figure (B2-3b). The effects are to :
 - reduce the carrier power by half
 - modify the baseband noise spectrum < 0.75MHz as shown in Figure (B2-3b). Let its noise bandwidth be B_N
- $\left(\frac{S}{N}\right)_{VSB-AM} = \left(\frac{2m}{1+m}\right)^2 \cdot \left(\frac{1}{2} \cdot \frac{C_p}{B_N}\right) \dots\dots\dots(1)$
- $$\frac{(SNR)_{DSB-AM}}{(SNR)_{VSB-AM}} = 2 \cdot \frac{B_N}{B} \quad (2)$$
- For the same m ($= 0.875$) and the same C_p , DSB-AM has a baseband SNR which is 3 dB higher than the VSB-AM baseband SNR since $10 \log \frac{B_N}{B} \approx -0.1 \text{ dB}$.

Source: Strauss, NCTA 1974, pp 58 - 63

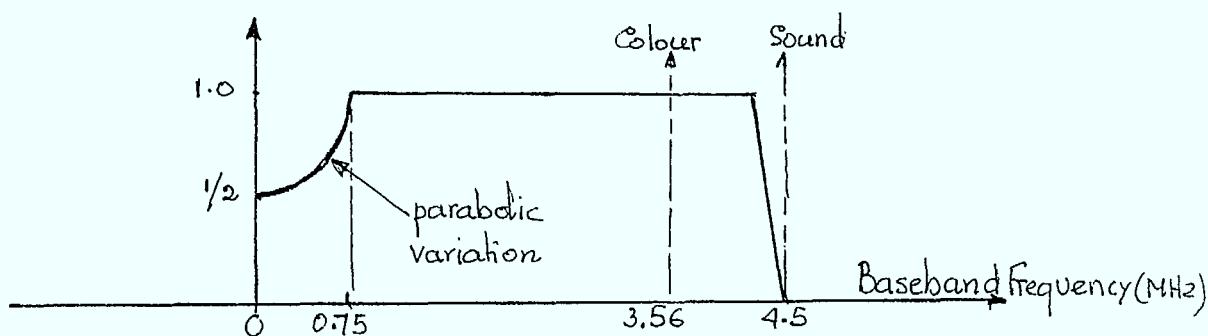
Figure B2-3: AM-VSB Signal and Noise Characteristics



(a) AM-VSB RF Spectrum



(b) AM-VSB Pre-Demodulator Filter Characteristic



(c) AM-VSB Baseband Noise Spectrum

Figure B2-4: AM-DSB Picture Quality vs S/N_w

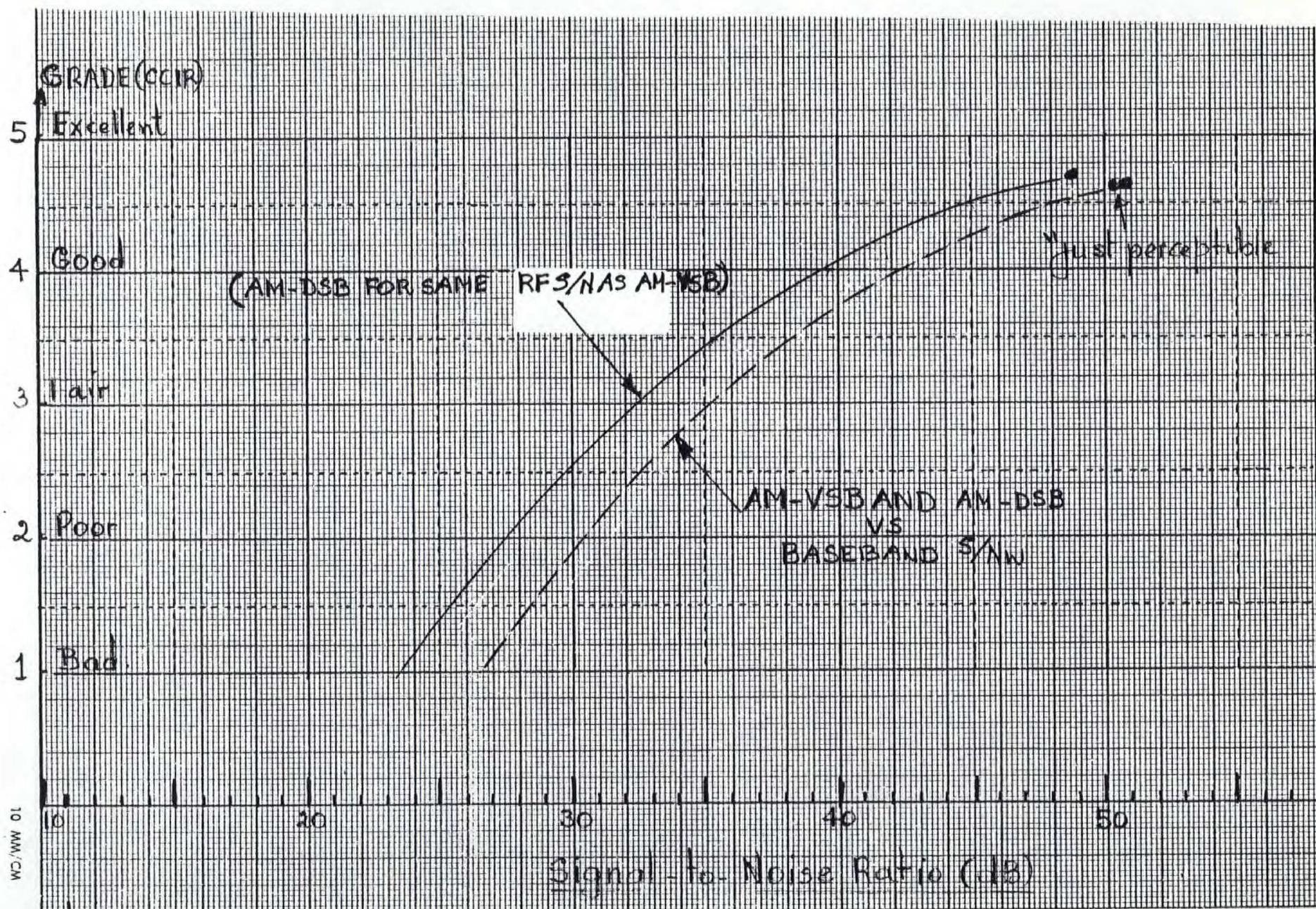


Figure B2-5: Estimated "Just Perceptible" Mask for Interference into AM-DSB from CW

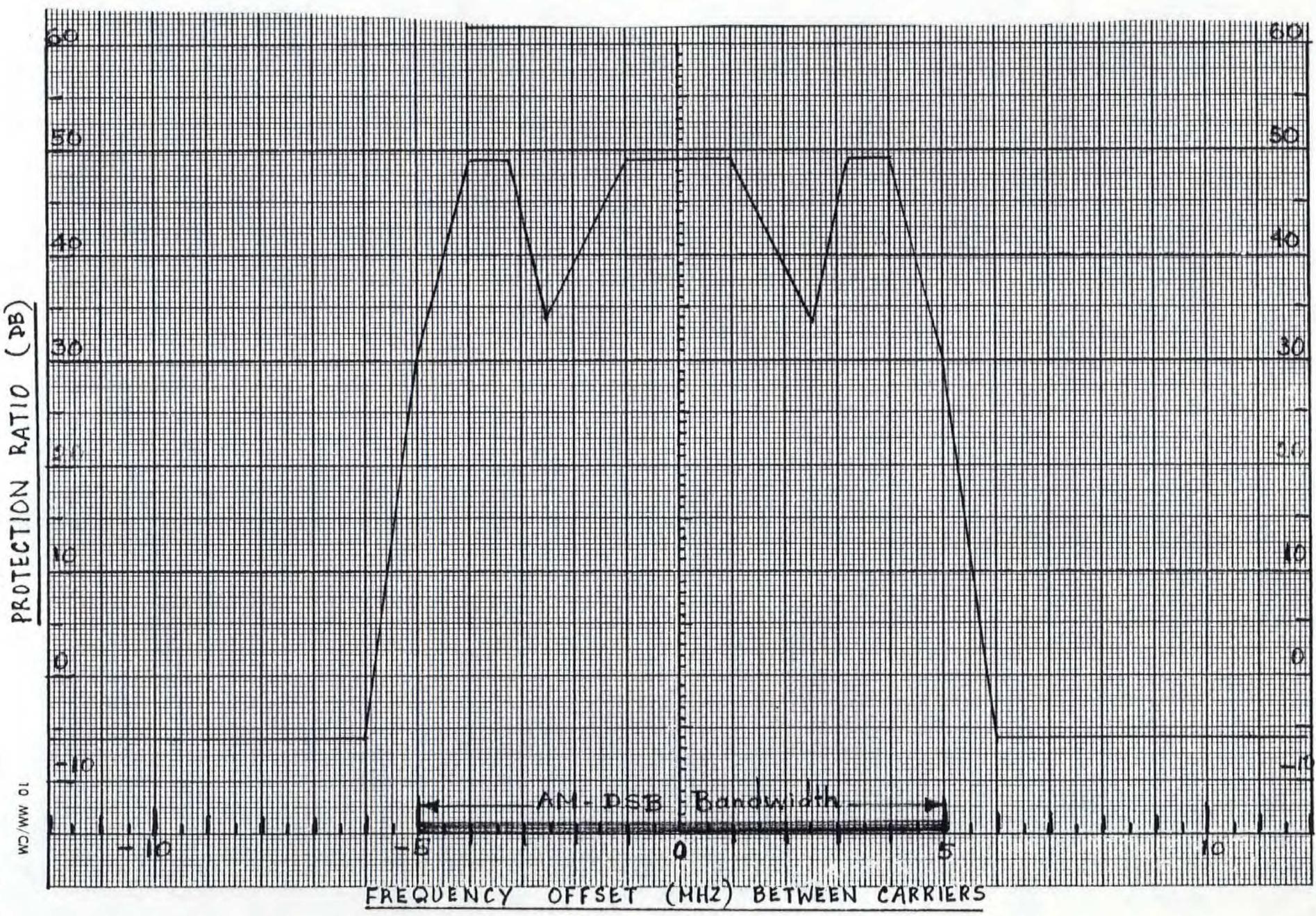


Figure B2-6: Proposed "Just Perceptible" Mask for Interference into AM-DSB

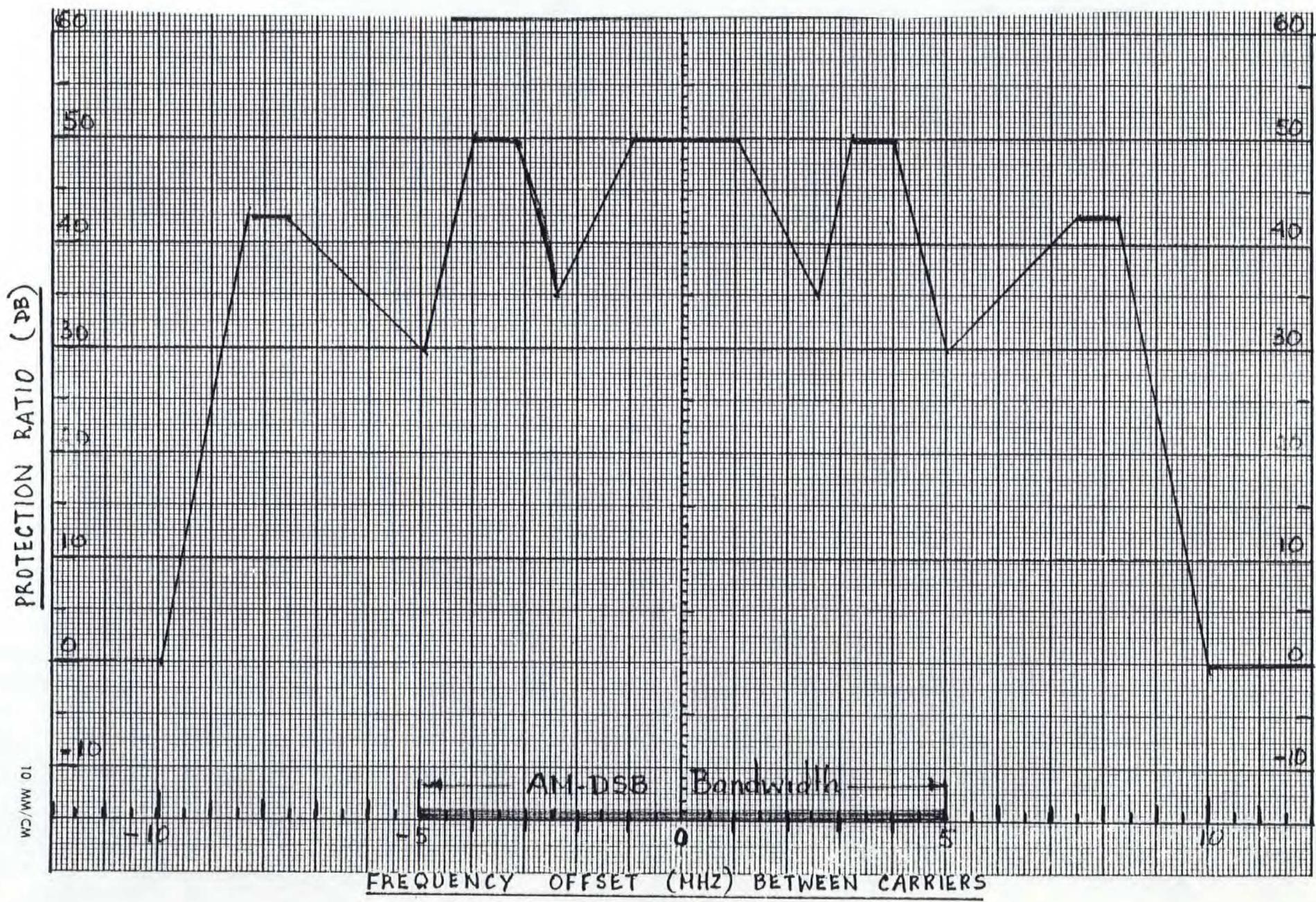
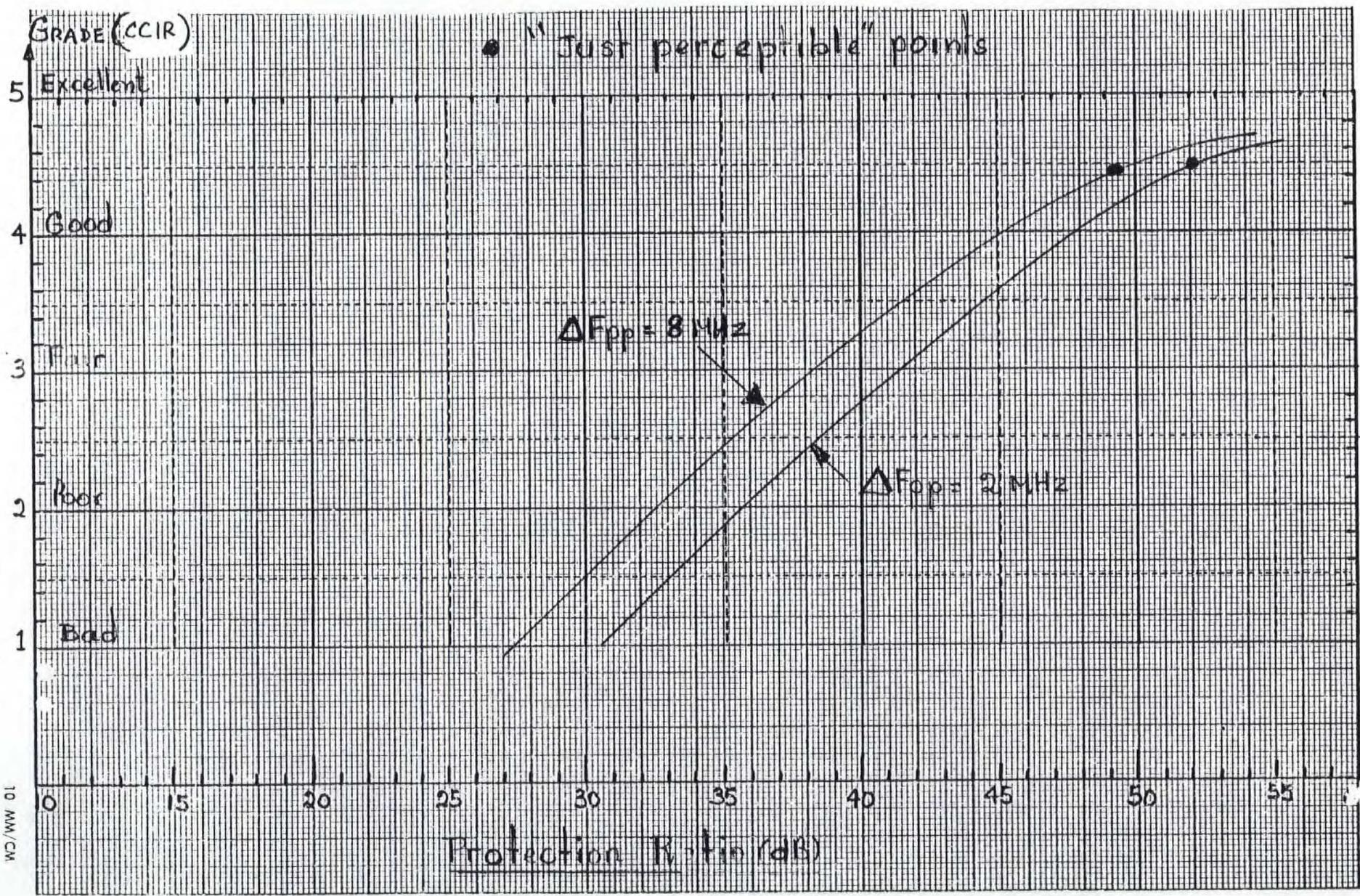


Figure B2-7: AM-DSB Picture Quality vs Co-channel Interference from NBFM TV



3. NBFM TV INTERFERENCE PERFORMANCE CHARACTERISTICS

In section A3, it was indicated that the effect of interference into an FM TV system depended largely on the peak frequency deviation of the wanted FM TV carrier and was rather insensitive to the nature of the interfering carrier. Therefore, the characteristics of section A3 will apply for interference from AM-DSB TV signals.

4. CONCLUSIONS

The characteristics derived for the interference into the AM-DSB TV carrier depended on the relationships established between AM-VSB and AM-DSB signals. Unfortunately, no published data was available on the interference susceptibility of AM-DSB TV signals so it was not possible to check any of the proposed characteristics.

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PART C

LIST OF C/N RATIOS FOR BER 10^{-3}

PART C
LIST OF C/N RATIOS FOR BER⁻³

1. INTRODUCTION

The task objective was to use a literature search to gain a list of C/N ratios at a bit error rate (BER) of 10^{-3} . The ratios were required for the following digital modulation methods: 64QAM, 16QAM, 4QAM, 8PSK, 4PSK, 2PSK, 9QPRS(I), 8FSK, 4FSK and 2FSK. An ideal system was to be considered, i.e. one which experiences only average white gaussian noise in a Nyquist bandwidth.

2. LITERATURE SEARCH

A comprehensive literature search failed to produce much direct data relating theoretical C/N to a bit error rate (BER) of 10^{-3} [1;2]. Extrapolation to 10^{-3} is sometimes necessary (and therefore undesirable) [1], and units lack clarity [2]. Data given as "S/N" almost certainly takes into account the real (rather than ideal) system bandwidth [3], although this was never too clear. Most information, however, is presented in the form of Eb/No [3;4], since "...it tends to be more independent of the implementation of a practical system than the carrier to noise ratio" [4]. Further, Eb/No is more often related to the probability of symbol error (P_s) [5] than to the probability of bit error (P_b) [6], and the literature can be ambiguous ([7] pp 278, 280). Also used is the term "probability of error," $P(e)$; this is to be interpreted as P_s , though for binary modulation $P_s = P_b$ (sec.C.3).

Because of the uncertainties in interpretation, and the significant errors that can be introduced by reading from a contracted graph scale, it was decided (where feasible) to reach the C/N values entirely via calculation.

3. BIT ERROR RATE

Equations for relating the probability of error to signal-to-noise ratio tend to be in terms of $P(e)$ and E_b/N_0 : The first step must be to relate the BER at 10^{-3} to $P(e)$.

For M-ary signalling, the general equation for conversion is:

$$\text{BER} = \frac{2^m - 1}{2^m - 1} P(e) \quad (1)$$

where $m = \log_2 M$

This expression assumes the possibility of symbol interference with the remaining $M-1$ symbols. For PSK modulation, it is only necessary to consider interference between adjacent phases. The equation can be further simplified by considering Gray coding, where a single bit position separates adjacent symbols:

$$\text{BER} \approx \frac{P(e)}{\log_2 M} \quad (2)$$

Similarly for QAM and QPSK modulations with Gray coding, we have:

$$\text{BER} \approx \frac{P(e)}{\log_2 L} \quad (3)$$

where $L = \sqrt{M}$

4. E_b/N_0

Where applicable, both coherent and non-coherent modulations have been considered: PSK is necessarily coherent, and the differential PSK has also been included. The equations for coherent signalling include a complimentary error function term, where the term is a function of E_b/N_0 :

$$\text{erfc}(x) = 1 - \text{erf}(x)$$

$$x = f(E_b/N_0)$$

Standard erf(x) tables supplies a quick solution for x and hence for E_b/N_0 . However, the exact treatment for some equations requires computational numerical analysis [(5), (8)], and for these cases graphical readings and/or upper bounds were taken.

FSK COHERENT

$$P(e) = \operatorname{erfc} \sqrt{(E_b/N_o)} \quad M = 2, \text{ binary} \quad (4)$$

$$P(e) = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \exp(-u^2/2) [1 - \operatorname{erfc}(u + \frac{2E_b \log_2 M}{N_o})]^{M-1} du, \quad M > 2 \quad (5)$$

$$P(e) \leq (M-1) \operatorname{erfc} [\sqrt{(E_b \log_2 M / N_o)}] \text{ upper bound, } M > 2 \quad (6)$$

FSK NON-COHERENT

$$P(e) = 1/2 \exp(-E_b/(2N_o)) \quad M = 2, \text{ binary} \quad (7)$$

$$P(e) = \sum_{k=1}^{M-1} \frac{(-1)^{k+1}}{k+1} \binom{M-1}{k} \exp(-kE_b \log_2 M / [(k+1)N_o]), \quad M > 2 \quad (8)$$

$$P(e) \leq \frac{M-1}{2} \exp[-(E_b \log_2 M / 2N_o)] \text{ upper bound} \quad (9)$$

PSK COHERENT

$$P(e) = \operatorname{erfc} \sqrt{(2E_b / N_o)} \quad M = 2 \quad (10)$$

For $\frac{E_b \log_2 M}{N_o} \gg 1$;

$$P(e) \approx 2 \operatorname{erfc} \sqrt{\left(\frac{2E_b \log_2 M}{N_o}\right) \sin^2 \frac{\pi}{M}} \quad M > 2 \quad (11)$$

PSK DIFFERENTIAL

$$P(e) = 1/2 \exp(-E_b/N_o) \quad M = 2 \quad (12)$$

There is no closed-form M-ary expression for P(e), though an approximation is:

$$P(e) \approx 2 \operatorname{erfc} \sqrt{\left(\frac{2E_b \log_2 M}{N_o}\right) \sin^2 \frac{\pi}{M\sqrt{2}}}, \quad M > 2 \quad (13)$$

QAM

With L = \sqrt{M} ;

$$P(e) = 2 \left(1 - \frac{1}{L}\right) \operatorname{erfc} [\sqrt{\log_2 L} \sqrt{6/(L^2 - 1)} \sqrt{E_b/N_o}] \quad (14)$$

[L = 2 for 4 QAM and 4 CPSK]

the values obtained are of questionable use due to the assumption required.

QPRS

With L = No. of levels on each quadrature channel prior to filtering

$$P(e) = \frac{2}{L^2} (1 - \frac{1}{4}) \operatorname{erfc} [\frac{\pi \sqrt{\log_2 L}}{4} \sqrt{6/(L^2 - 1)} \sqrt{E_b/N_o}] \quad (15)$$

5. C/No

Since C is a product of the energy per bit, E_b , and the transmitted bit rate, f_b ;

$$C/No = f_b E_b/No(\text{dB-Hz}) \quad (16)$$

where No = noise power in 1Hz bandwidth. In Table 1, the data are displayed in increasing order of Δ , the difference in E_b/No (or C/No) ratios of the modulation of interest and the 2 CPSK modulation. The precise path followed in reaching the E_b/No figures, is clearly noted in the table. For example, those values taken from graphs do not correspond exactly with calculation - for 4 CPSK there are three values, $(E_b/No)_{dB} = 7.0, 6.8$ and 6.6 dB, obtained via various combinations of BER conversion, and E_b/No calculation or graph reading: The combination of Eq. (10) with the general BER to $P(e)$ conversion [Eq. (1)] gives the first figure, whereas the final value was read from a graph (Fig. 6.18 of [7]) assuming Gray coding for the BER to $P(e)$ conversion [Eq. (2)]. The 6.8 dB figure is reached using three different paths; a combination of:

- i) equation (10) with a BER to $P(e)$ conversion using Gray coding [Eq.(2)].
- ii) a graph reading (Fig.6.18 of [7]) with general BER to $P(e)$ conversion [Eq. (2)].

iii) a graph reading (Fig. 6.27 of [7]). The Y axis of this graph is already in terms of BER.

C/N (dB)	(dB)	MOD.	COMMENTS (IN ESTABLISHING Eb/No)	GRAY CODING FOR P(e) BER CONVERSION?	(C/No) dB-Hz PLOTTED (FIG.5)
5.8*	-1.0	8 CFSK	GRAPH READING (FIG.6.12 [7])		
6.2*	-0.6	8 CFSK	UPPER BOUND (EQ.3.9)		
9.7	-0.2	4 CPSK	GRAPH READING (FIG.6.18 [7])	/	
6.8	0.0	2 CPSK	EXACT (EQ.3.10)		
	/				
9.8	0.0	4 CPSK	GRAPH READING (FIG.6.27 [7])		/
9.8	0.0	4 CPSK	APPROXIMATION (EQ.3.11)	/	/
9.8	0.0	4 QAM			
6.8*	0.0	2 NCFSK	GRAPH READING (FIG.24.19 [8])		
9.8	0.0	4 CPSK	GRAPH READING (FIG.6.18 [7])		
6.9*	0.1	4 CFSK	GRAPH READING (FIG.6.12 [7])		
10.0	0.2	4 CPSK	APPROXIMATION (EQ.3.11)		
7.1*	0.3	8 NCFSK	UPPER BOUND (EQ.3.9)		/
7.4*	0.6	4 CFSK	UPPER BOUND (EQ.3.6)		
7.9	1.1	2 DPSK	EXACT (EQ.3.12)		/
8.3*	1.5	4 NCFSK	GRAPH READING (FIG.24.19 [8])		
8.4*	1.6	4 NCFSK	UPPER BOUND (EQ.3.9)		/
12.4	2.6	4 DPSK	APPROXIMATION (EQ.3.13)	/	
14.4	2.9	8 CPSK	GRAPH READING (FIG.6.27 [7])		
12.7	2.9	4 DPSK	GRAPH READING (FIG.6.18 [7])	/	
9.8*	3.0	2 CFSK	EXACT (EQ.3.4)		/
14.8	3.2	8 CPSK	APPROXIMATION (EQ.3.11)	/	/
16.2	3.4	64 QAM	GRAPH READING (FIG.6.27 [7])		
15.2	3.7	8 CPSK	APPROXIMATION (EQ.3.11)		
16.6	3.8	16 QAM	EXACT (EQ.3.14)	/	/
10.9*	4.2	2 NCFSK	EXACT (EQ.3.7)		
15.4	4.3	9 QPRS(I)	EXACT (EQ.3.15)	/	
16.1	4.5	8 CPSK	GRAPH READING (FIG.6.18 [7])	/	
16.4	5.0	8 CPSK	GRAPH READING (FIG.6.18 [7])		
17.7	6.1	8 DPSK	APPROXIMATION (EQ.3.13)	/	/
18.0	6.4	8 DPSK	GRAPH READING (FIG.6.18 [7])	/	
22.3	7.8	64 QAM	GRAPH READING (FIG.6.27 [7])		
23.1	8.5	64 QAM	EXACT (EQ.3.14)	/	/

*NARROWBAND LIMIT

C = COHERENT

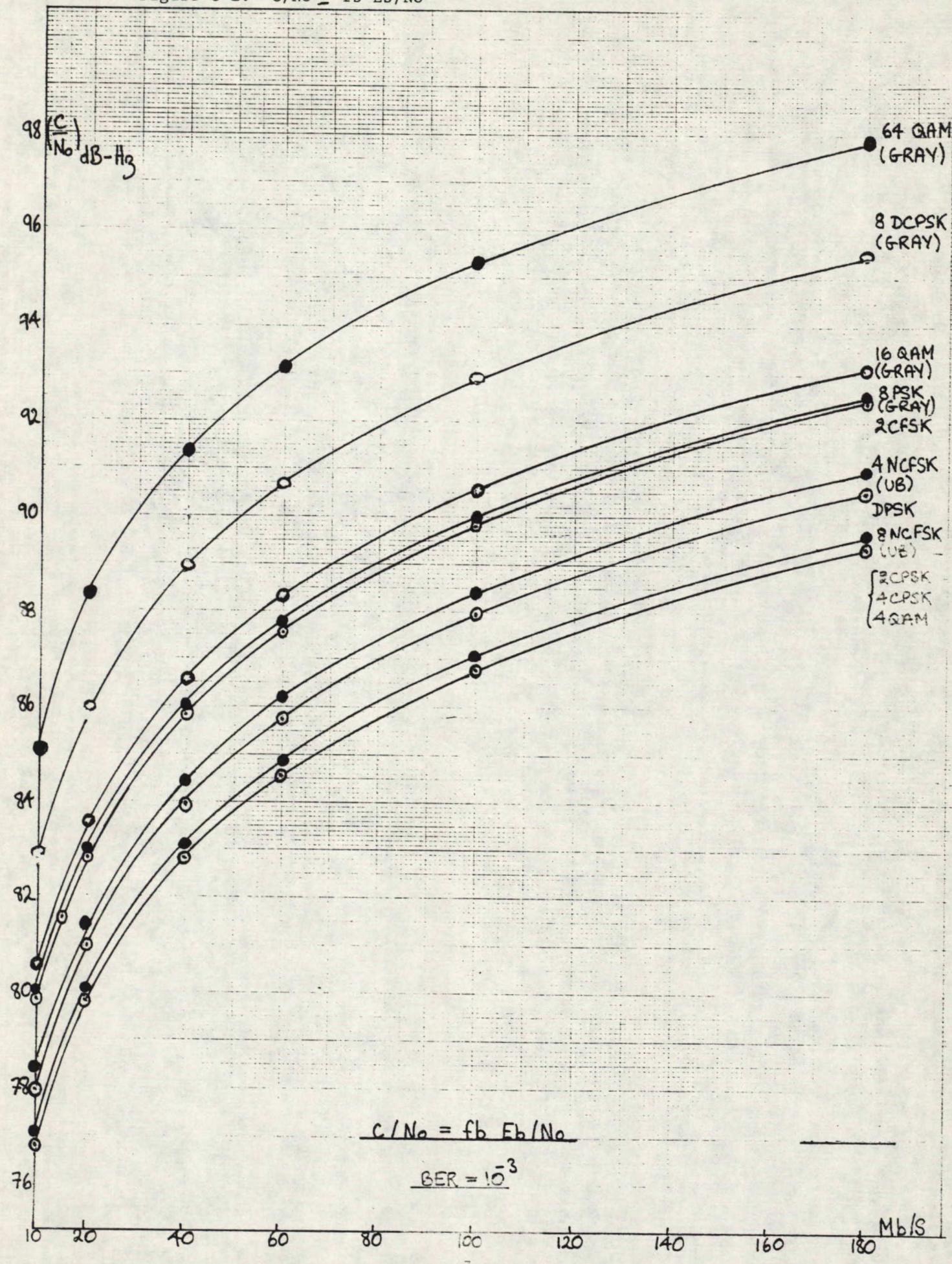
NC = NON-COHERENT

D = DIFFERENTIAL

$$\begin{aligned}
 \Delta &= (\text{Eb/No})_{\text{dB}} - (\text{Eb/No})_{\text{dB}} \\
 &\quad \text{MOD} \qquad \qquad \qquad \text{2CPSK} \\
 &= (\text{C/No})_{\text{dB}} - (\text{C/No})_{\text{dB}} \\
 &\quad \text{MOD} \qquad \qquad \qquad \text{2CPSK} \\
 (\text{Eb/No}) &= 6.8 \text{ dB} \\
 &\qquad \qquad \qquad \text{2CPSK}
 \end{aligned}$$

Table C-1: C/No vs Bit Rate

Figure C-1: $C/N_0 = f_b E_b/N_0$



6. C/N

The remaining problem is to relate E_b/No to C/N , which is a $f(\text{bandwidth})$. In order for these ratios to be independent of system application, an ideal Nyquist bandwidth will be used.

Average white gaussian noise can be described as having either a two-sided power spectral density (Fig.C.2a) or a one-sided power spectral density (Fig.C.2b). The total noise power is given by:

$$N = NoB \quad (17)$$

where No = single sided noise density (18)

$No = 2 \times$ double sided noise density (19)

and $B = 1/T_s$ where T_s = symbol duration = $\frac{1}{f_s}$ and $B = \frac{1}{T_s}$

From Eqs. (16) and (17) we have for both cases:

$$\frac{E_b}{No} = \frac{C}{N} \frac{B}{f_b} \quad (20)$$

For this study, the modulations will be treated in the Nyquist bandwidth, for which $B = 1/T_s$ and from (20):

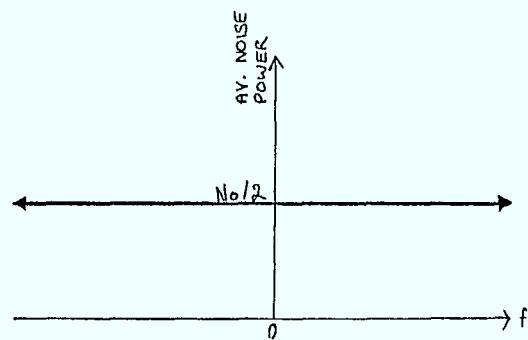
$$\frac{E_b}{No} = \frac{C}{N} \frac{f_s}{f_b} \quad (21)$$

In M-PSK modulation, the bit stream is split into $\log_2 M$ channels, each of which has its own modulator and a rate of:

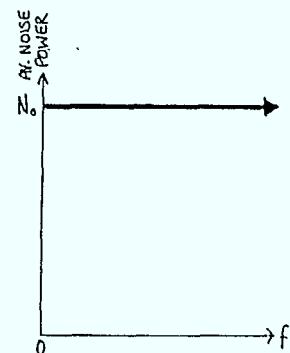
$$f_s = \frac{f_b}{\log_2 M}$$

therefore $\frac{E_b}{No} = \frac{C}{N} \frac{1}{\log_2 M}$ (22)

Figure C-2: White Noise Spectrum



a) TWO-SIDED POWER SPECTRAL DENSITY



b) ONE-SIDED POWER SPECTRAL DENSITY

With M-QAM the bit stream is split into $2\log_2 L$ channels, so the symbol rate in each independent channel is:

$$f_s = \frac{f_b}{2\log_2 M}$$

therefore $\frac{E_b}{N_0} = \frac{C}{N} \frac{1}{2\log_2 L}$ (23)

Whereas for QPRS, the bit stream is split into two independent channels:

$$f_s = \frac{f_b}{2}$$

However, on considering the Northern Telecom DRS-8 system, which has a bit rate of 92.6 Mb/s and a bandwidth of 40 Mb/s [8], we have the peculiar situation of the actual bandwidth being less than the Nyquist bandwidth (46.3 Mb/s). Assuming that a 5dB allowance has been made for additional interference, then a f_b/f_s ratio of $92.6/40 = 2.3$ is a better estimate for the theoretical minimum bandwidth. Hence:

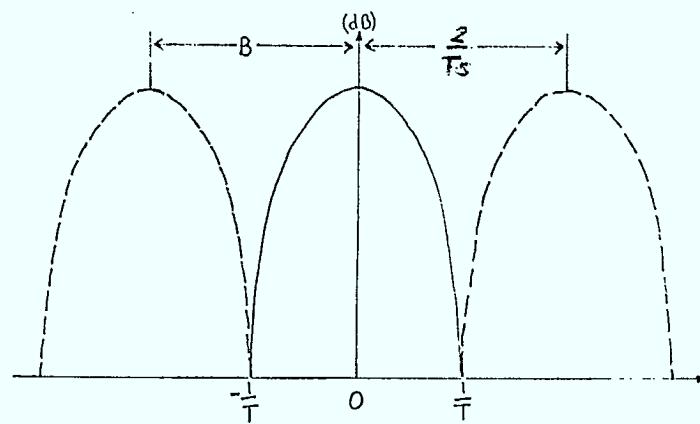
$$\frac{E_b}{N_0} = \frac{C}{N} \frac{1}{2.3} \quad (24)$$

For noncoherent detection of M-FSK, there is a bank of M filters, each centred on one of M frequencies. Each filter has an envelope detector (decision based on largest envelope output): Therefore, for all frequency separation f , noncoherent detection experiences noise approximating to the narrow band limit. Narrowband filters are also used in coherent detection of FSK and a similar assumption applies.

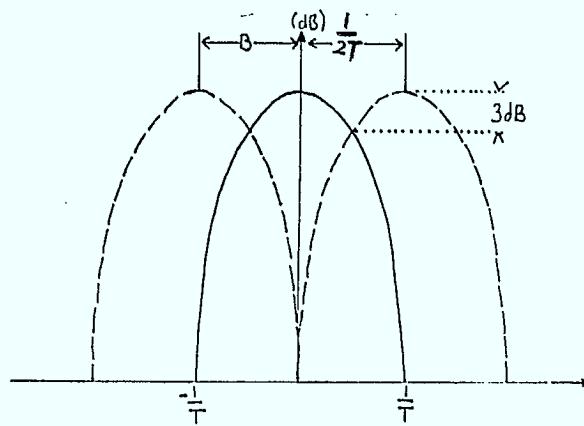
The relationship between B and T_s for M-FSK is illustrated in Fig. C-3. The bandwidth must be defined for a suitable separation of the main spectral lobes: A minimum separation of $B = 2/T_s$ (Fig. C-3a) is too unrealistic. In reality, the separations are generally such that the neighbouring lobe crosses at a point 3dB-8dB down from the peak. In choosing the 3dB point, the bandwidth is seen to be:

$$B = \frac{M}{2T_s}$$

Figure C-3: FSK Bandwidth



$$a) B = \frac{2}{Ts}$$



$$b) B = \frac{1}{2Ts}$$

For the case when one frequency is selected for any one pulse interval; one frequency slot of bandwidth $B_s = 1/T_s$ and energy E_b/N_0 , we therefore have:

$$\frac{E_b}{N_0} = \frac{C}{N} \quad (25)$$

We are now equipped with a complete set of equations for converting the previously acquired E_b/N_0 ratios to C/N^1 [see (22) to (25)]. The results are tabulated in Table C-1.

¹ Please note that the E_b/N_0 values (and therefore C/N too) decrease with increasing M for FSK at a BER of 10^{-3} (Fig.6.12 [7], Table C-1). For all other modulations E_b/N_0 increases with M .

REFERENCES

- [1] HANDBOOK OF DIGITAL COMMUNICATIONS;
MICROWAVE SYSTEMS NEWS; 9, 54, 1979
- [2] NOGUCHI.T ET AL;
IEEE INT. COMM. CON.; 3, F2.4.1, 1983
- [3] BYNUM B.T. AND ALLEN E.W.;
IEEE INT. COMM. CON.; 3, F2.5.1, 1983
- [4] CHAN H.C. ET AL;
INTELSAT 3RD INT. CONF. ON DIGITAL SATELLITE COMM;
56, 1975
- [5] BORGNE M;
IEEE TRANS. ON COMM.; 33, 442, 1985
- [6] WILSON G.W. ET AL;
IEEE INT. COMM. CON.; 3, 6F.1.1, 1982
- [7] SMITH D.R.;
DIGITAL TRANSMISSION SYSTEMS;
LIFETIME LEARNING PUBLICATIONS; 1985
- [8] REFERENCE DATA FOR ENGINEERS;
EDITOR E.C. JORDAN;
W. HOWARD SAMS & CO.INC.; 1985
- [9] PRIVATE COMMUNICATION, DOC

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APPENDIX 1

TASO MEASUREMENT RESULTS

Appendix 1
TASO Measurement Results

This appendix contains all the significant results of the measurements made on the subjective effects of interference in television reception by TASO and published in:

Proc IRE June 1960, pp 1035 - 1049, Charles E. Dean, "Measurements of the Subjective Effects of Interference in TV Reception"

This information is presented because it provides a complete set of results of measurements and analyses made under the same conditions and, hence, should exhibit a high degree of consistency. However, care should be exercised in the use of this information because:

- the results may not be relevant due to the increased expectations of present day viewers. For a given quality grade, the protection ratio should be increased from 5 to 9 dB over the values given in this TASO report;
- the curves for the "excellent" (grade 1) grade appear to be in error because of the presence of a high level of random noise during the tests;

These curves present the worst-case results which were obtained using the "Kitchen scene" slide rather than the "Miss TASO" scene.

This information is included in this report for information purposes, only, and especially since it relates percent of viewers to picture quality.

Figure 1: AM-VSB Co-channel Random Noise (S/Nw) Rating

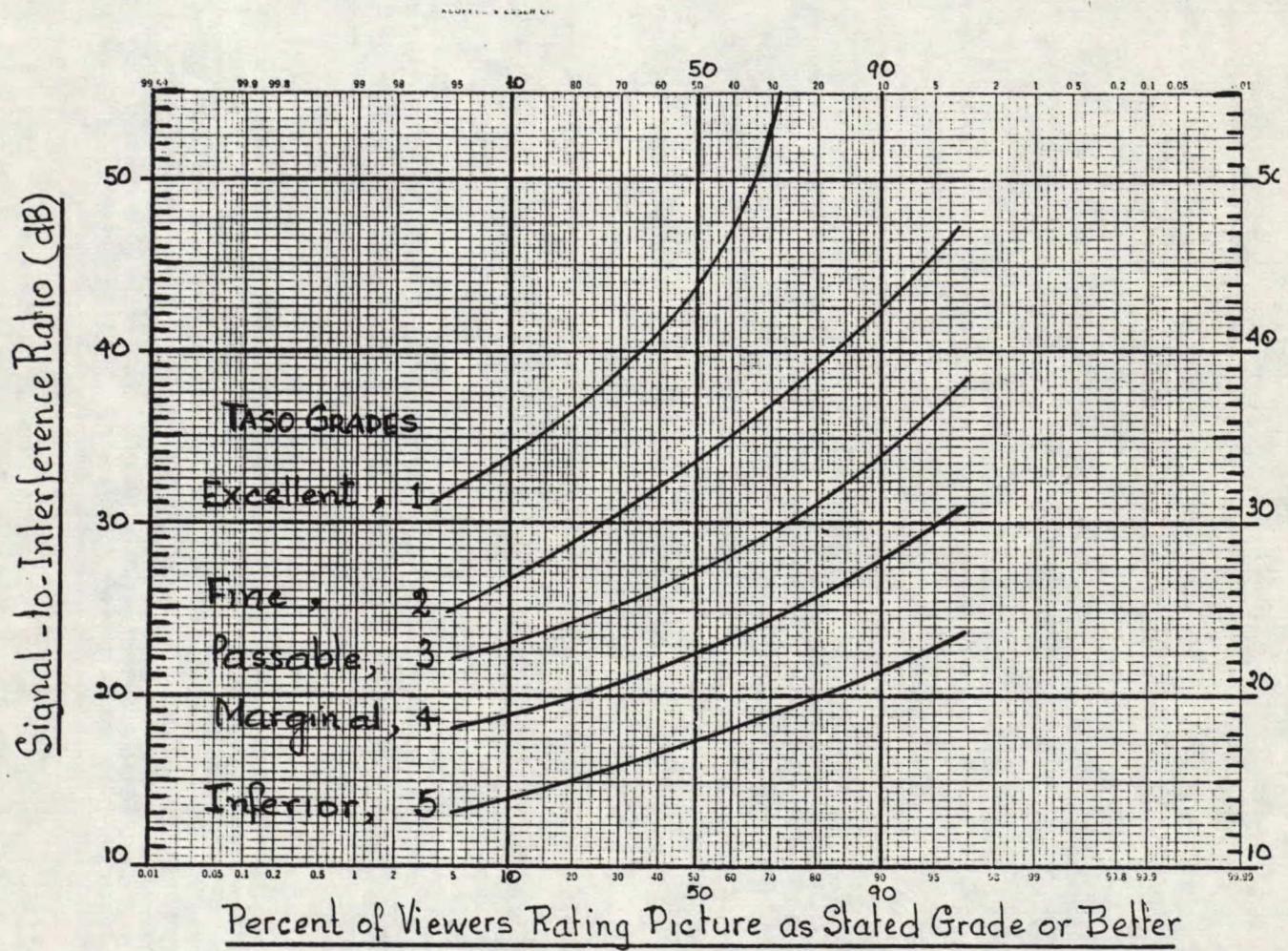


Figure 3: AM-VSB Co-channel (offset = 604Hz) Protection Ratio Rating

Interference: Single entry, AM-VSB, colour

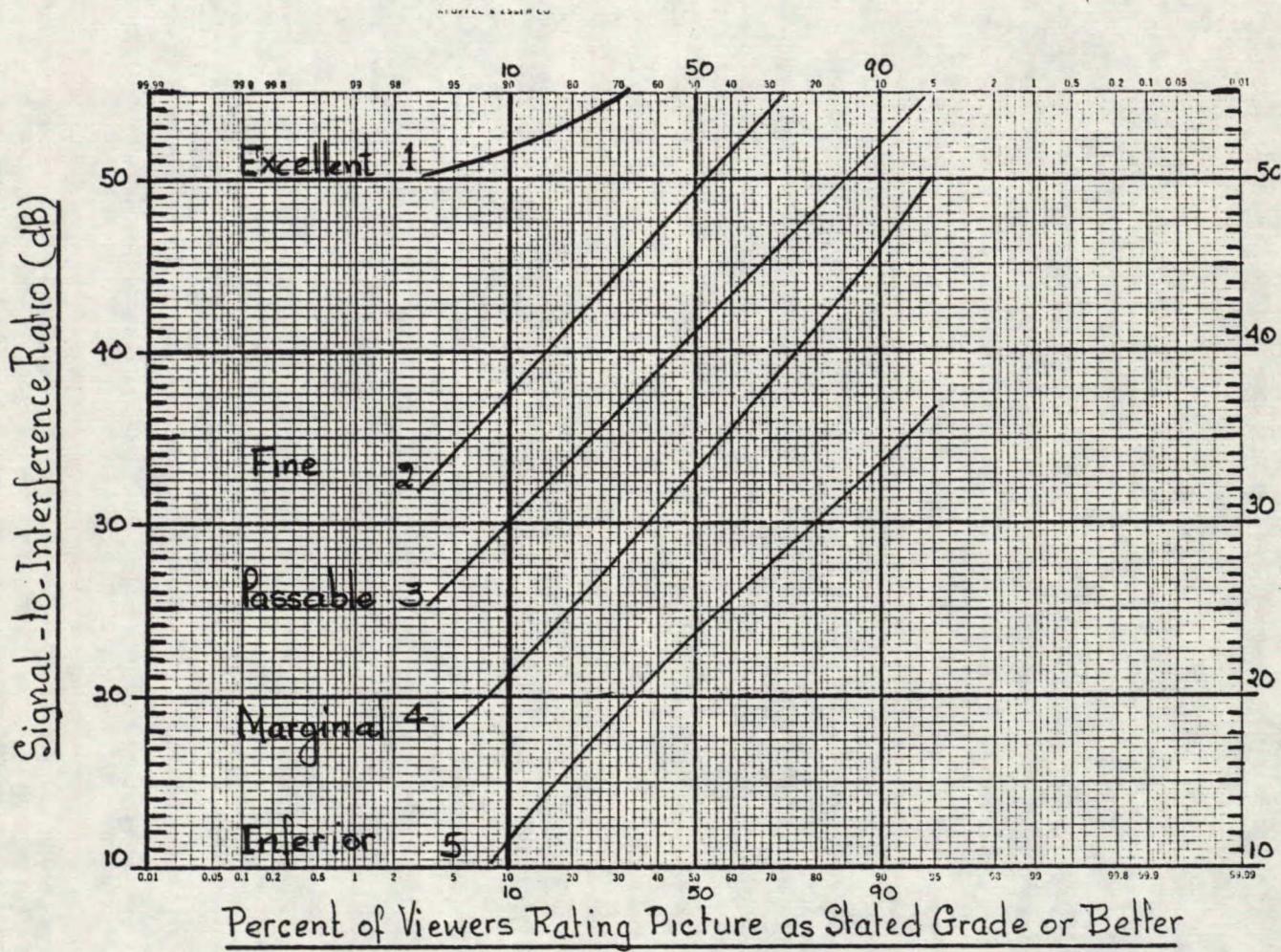


Figure 4A: AM-VSB Co-channel (offset= 9,985Hz) Protection Ratio Ratings

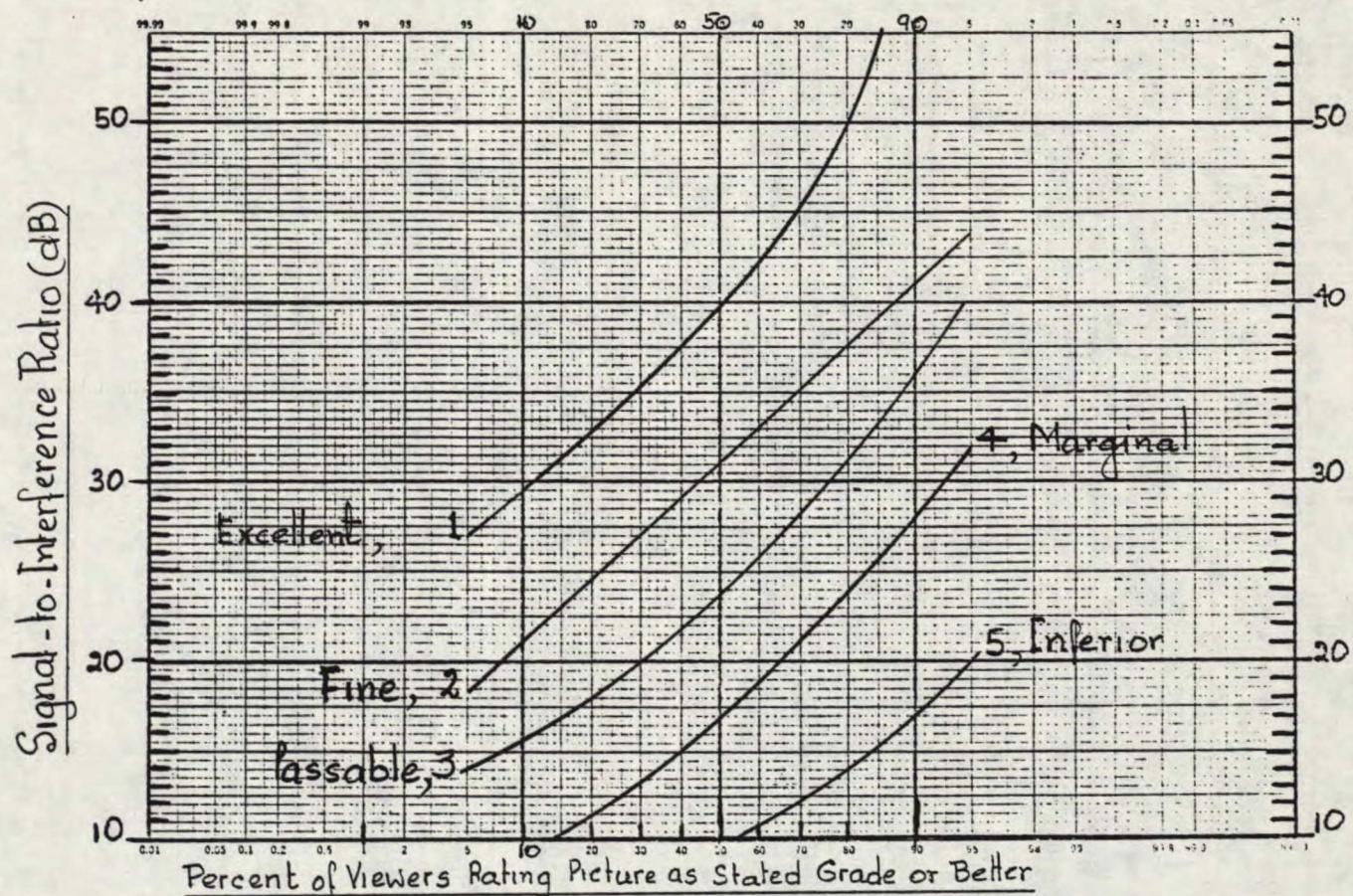


Figure 4B: AM-VSB Co-channel (offset = 10,010Hz) Protection Ratio Rating

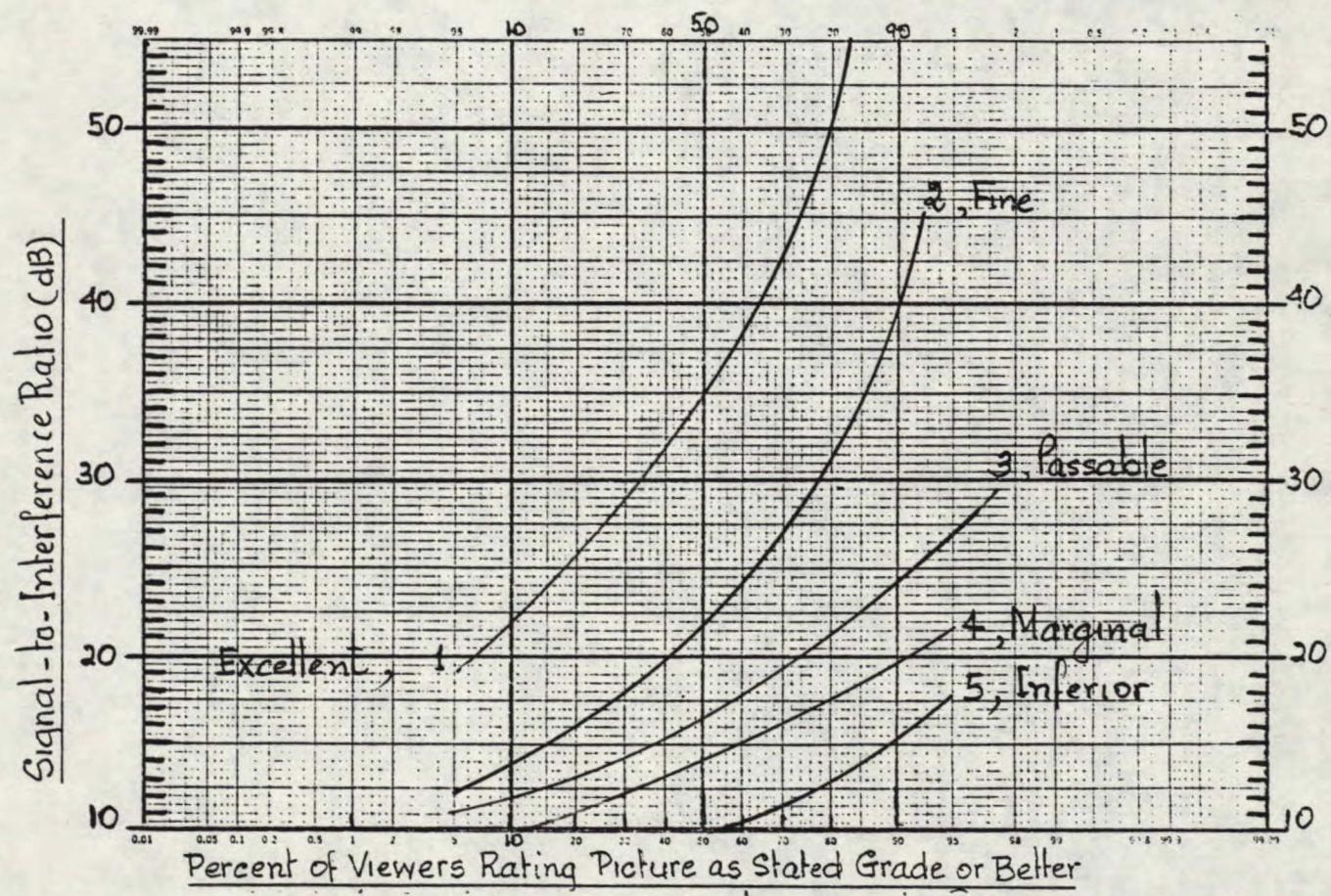


Figure 5A: AM-VSB Co-channel (offset = 19,995Hz) Protection Ratio Rating

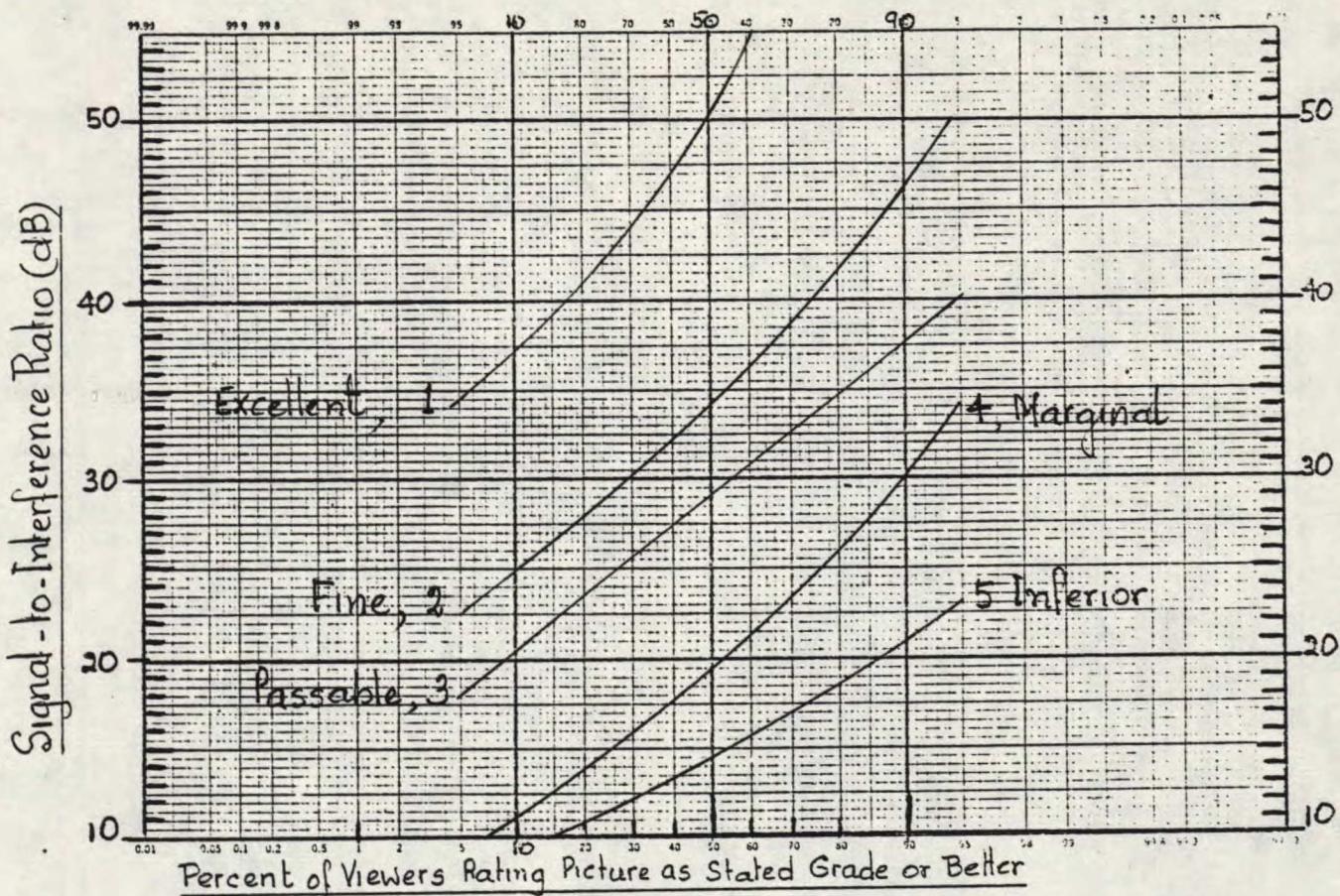


Figure 5B: AM-VSB Co-channel (offset = 20,000Hz) Protection Ratio Rating

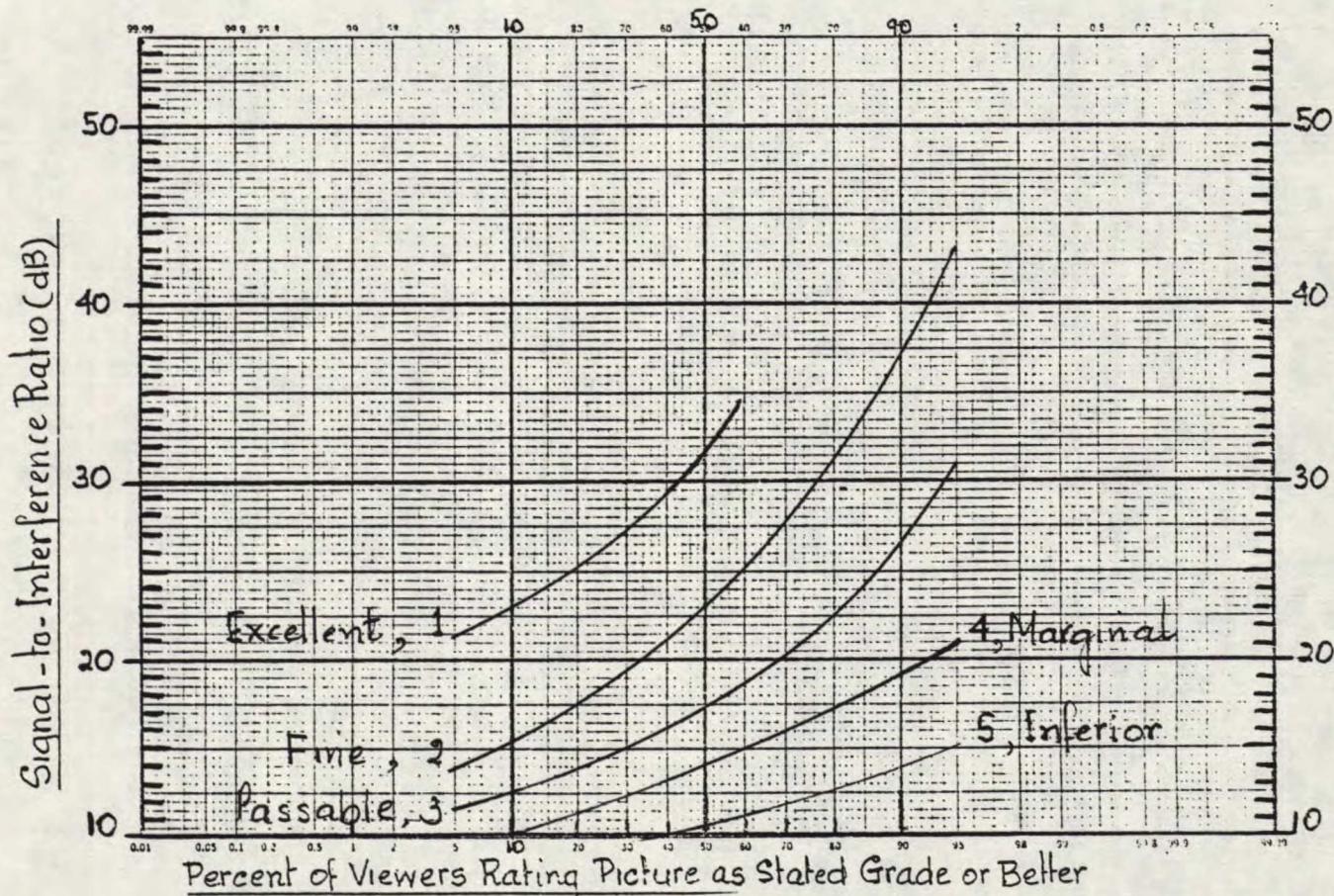


Figure 6A: AM-VSB Upper Adjacent Channel Protection Ratio Rating

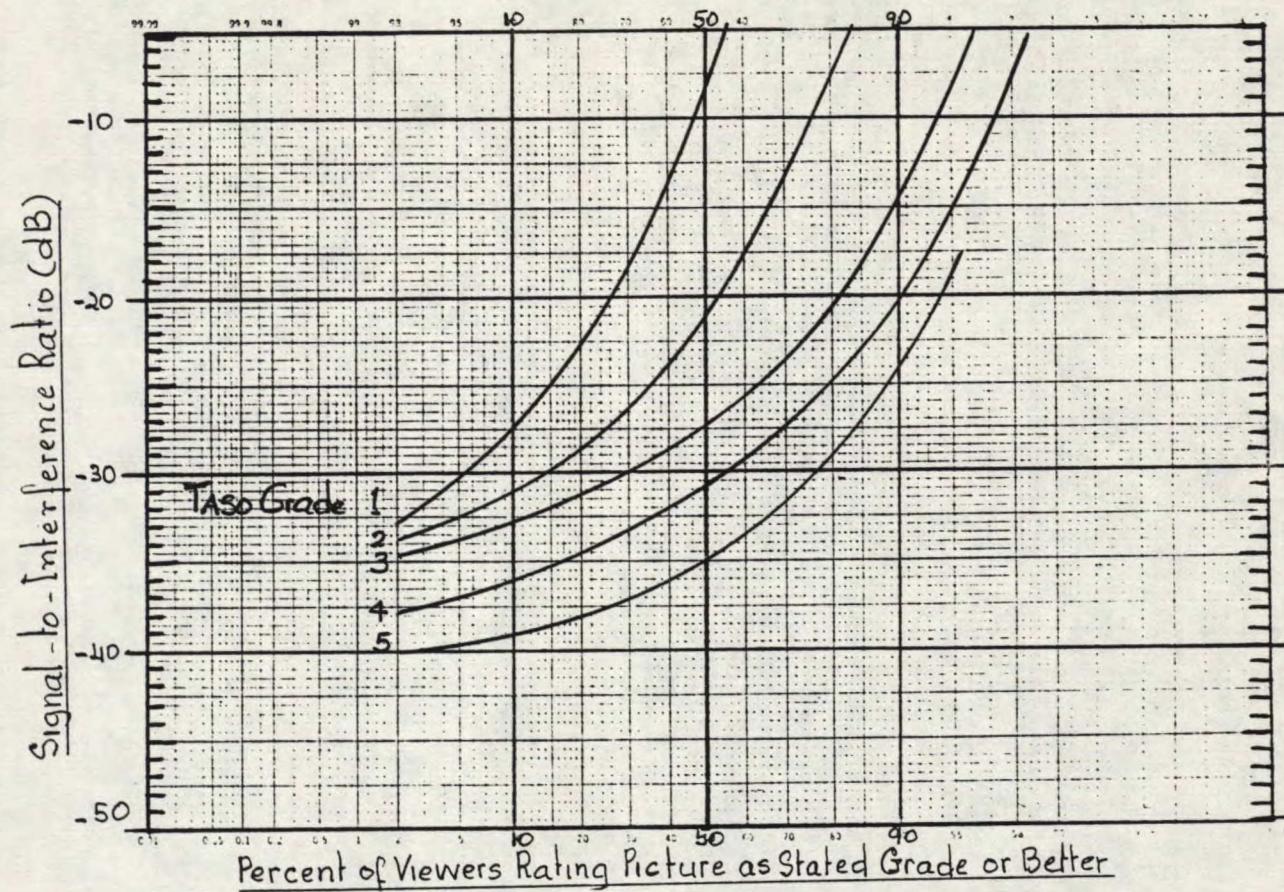


Figure 6B: AM-VSB Lower Adjacent Channel Protection Ratio Rating

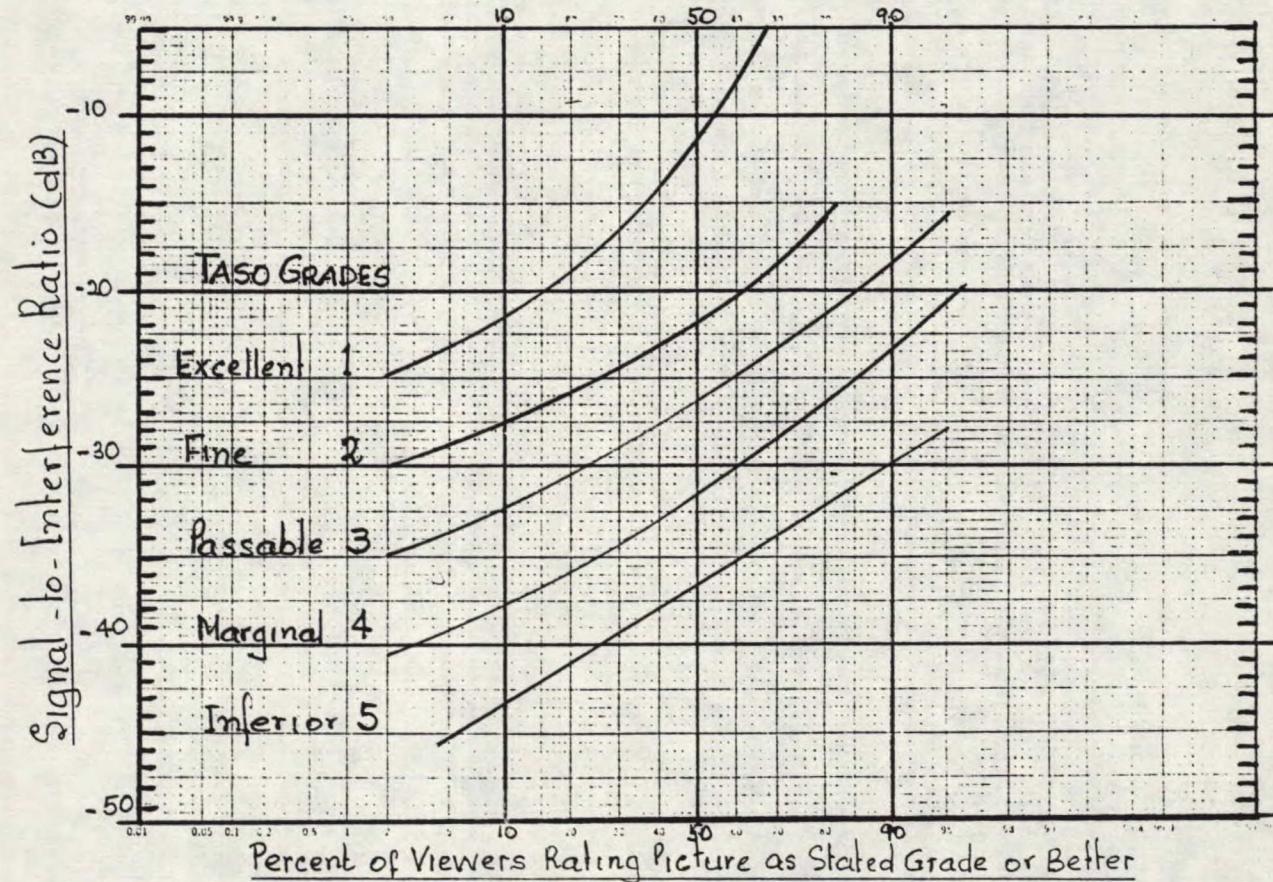


Figure 7: AM-VSB - Picture Quality vs Degradation from Random Noise

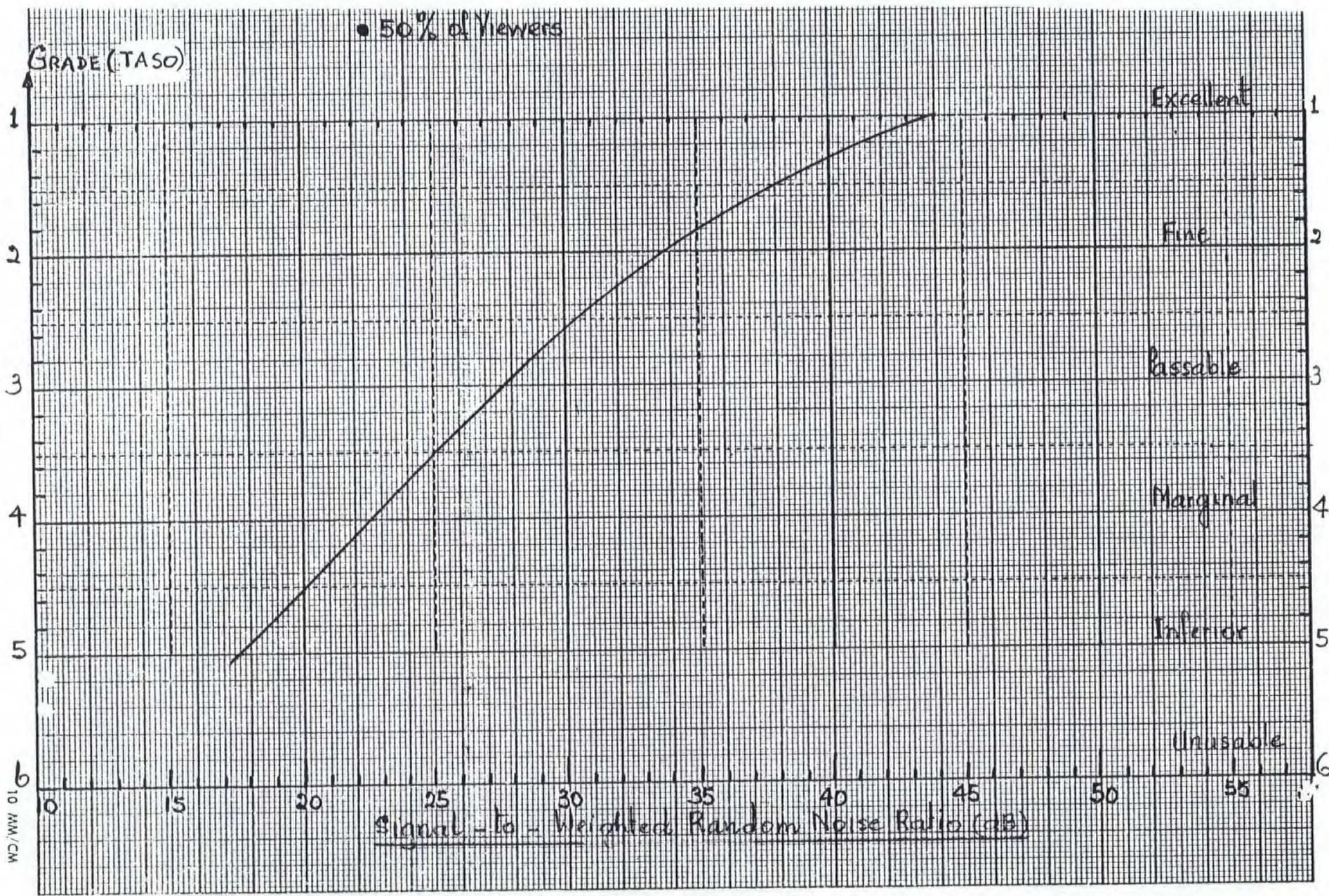


Figure 8: AM-VSB Picture Quality vs Co-channel Interference from AM-VSB

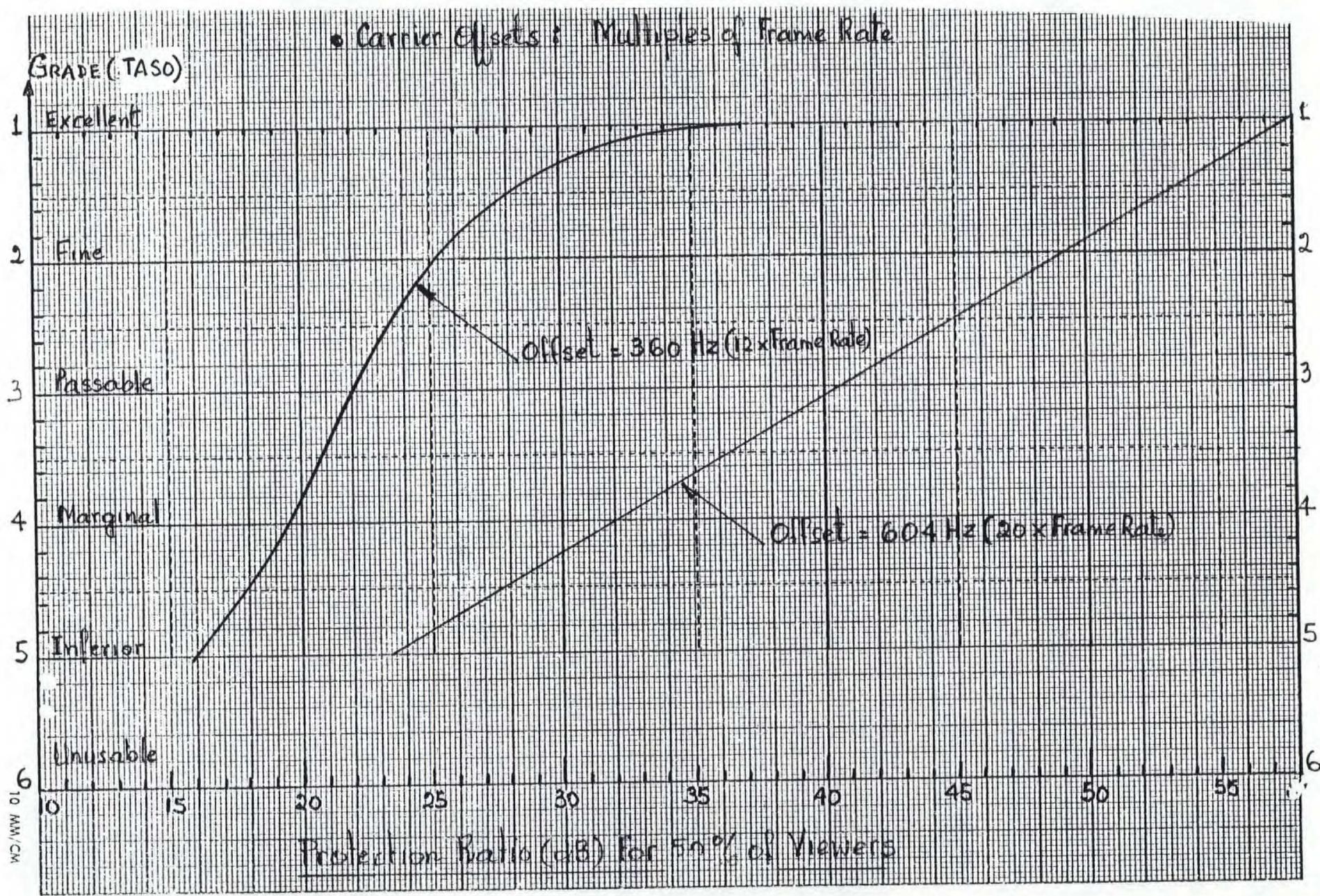


Figure 9: AM-VSB Picture Quality vs Co-channel Interference from AM-VSB

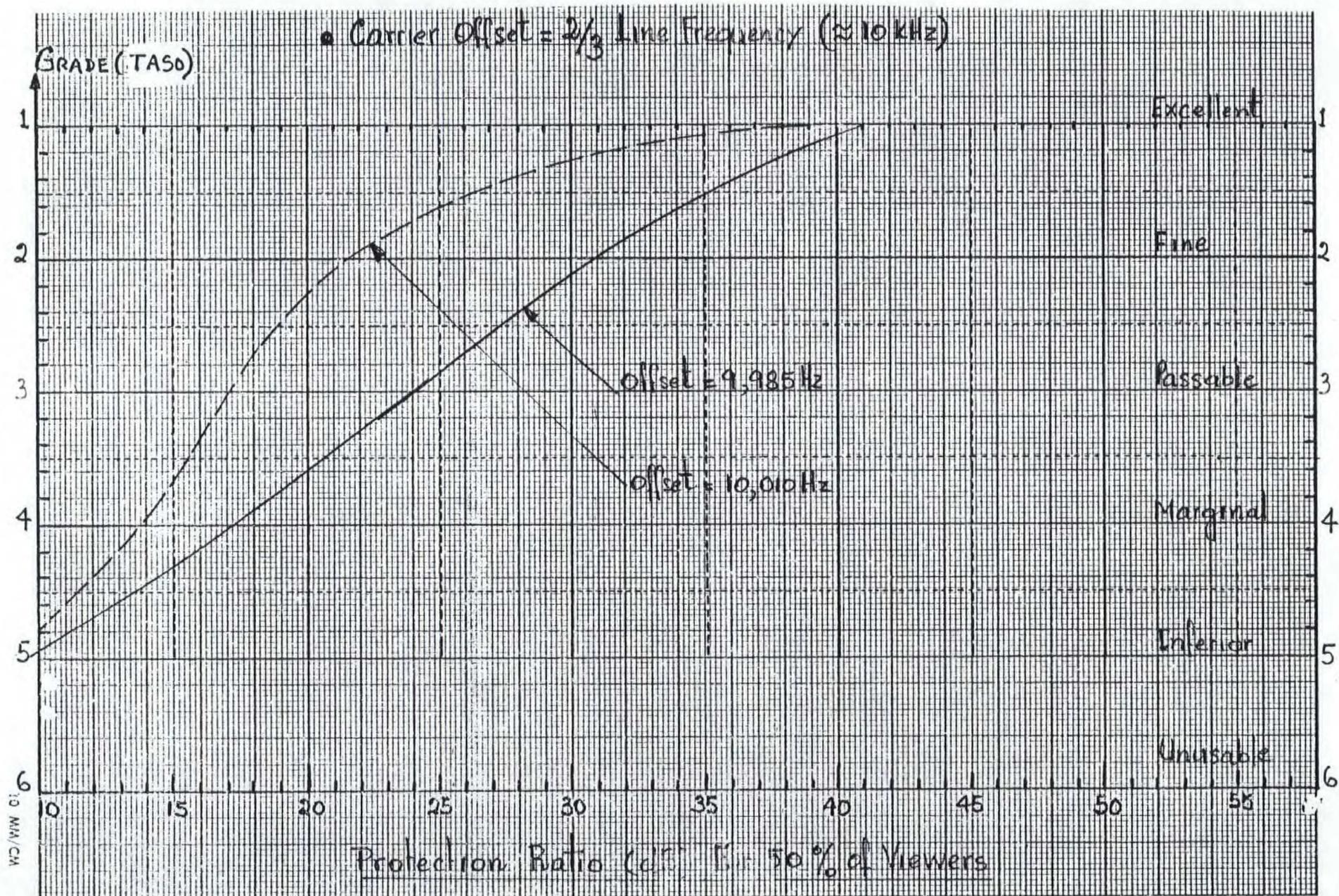


Figure 10: AM-VSB Picture Quality vs Co-channel Interference from AM-VSB

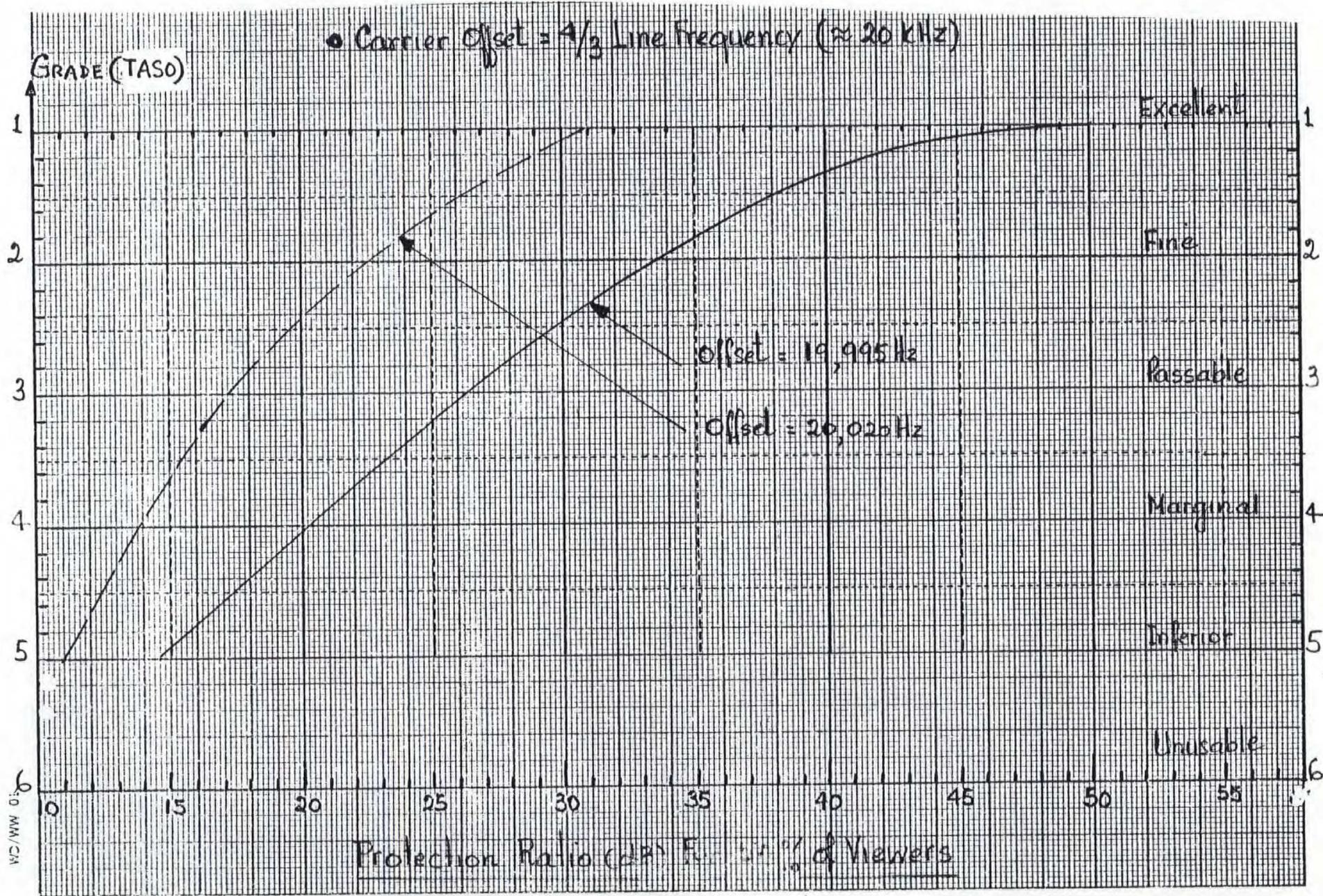
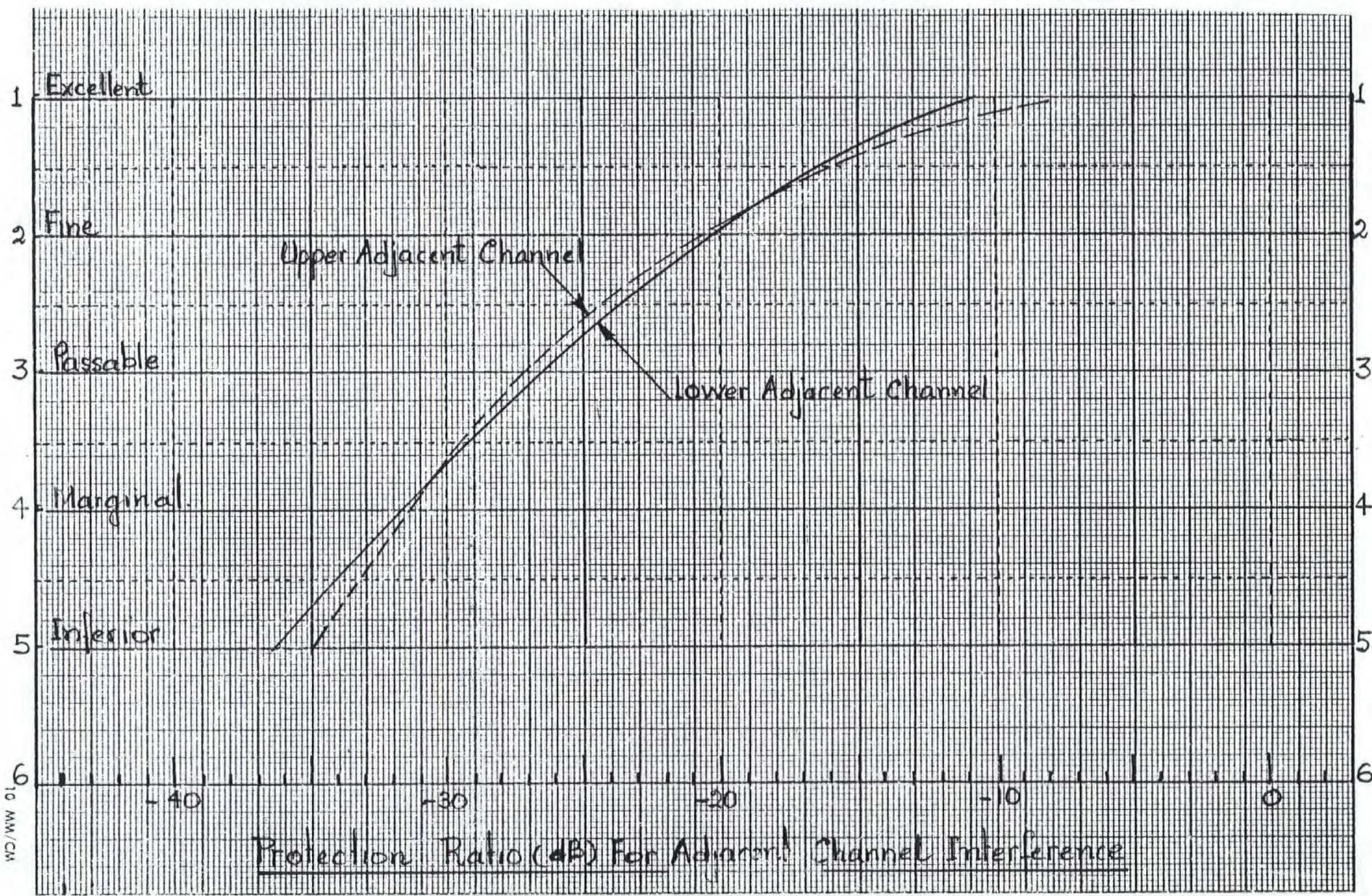


Figure 11: AM-VSB Picture Quality Impairment vs Adjacent Channel Interference



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to evaluate the performance of very
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