E.W. HORRIGAN & ASSOCIATES LIMITED

REPORT No.1

TELEVISION GHOSTING and FM. MULTIPATH DISTORTION INVESTIGATION

TELEVISION PICTURE IMPAIRMENT and FM-RADIO DISTORTION

DSS.CONTRACT: 36100-7-0615

Prepared for: The Department of Communications
Journal North Building,
300 Slater Street,
Ottawa, Ontario.

Prepared by: E.W.Horrigan & Associates Ltd.,
Consulting Engineers,
4800 Leslie Street, Suite 310,
Willowdale, Ontario.

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The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Department of Communications of the Government of Canada.

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Summary of Report

This section of the study was undertaken to ascertain the subjective effects of ghosts in television pictures and the effects of multipath propagation on FM reception. The test material, which was pre-recorded, was generated using normal transmission and reception equipment interconnected by means of a multipath RF cable matrix. The echo or delayed radio path was varied over the range 0.5 u.Sec. to 5.0 u.Sec. relative to the direct reception path. These paths were also varied in amplitude in 5 dB increments between -10 dB and -40 dB and, in addition, the instantaneous RF phase was adjusted to provide both positive and negative echoes.

The TV program material was selected to provide both critical and non-critical test sequences. Typical mixed program sequences formed the basic material used to derive the TV ghost subjective grading equations.

A small group of 'Expert' viewers evaluated the test material initially and the results were subsequently used for control purposes.

The major TV subjective tests utilized predominantly non-expert observers who were considered to be more typical of average viewers.

The intial FM subjective tests indicated that little subjective impairment resulted at echo levels and delays which caused major impairment to TV reception. Therefore, an objective test phase was substituted to obtain the required FM grading equation.

The new television test material provided in excess of 5,000 data pairs and the resulting statistical analysis exhibits a high degree of confidence. The results of the regression analysis phases were reduced by non-linear slope fitting techniques to two basic grading equations for the 'Expert' observer group and the 'Typical' observer group.

These equations together with the objective FM impairment equations have been prepared as a software package for the T.I. SR-59 Calculator/Printer. The results are also shown graphically in Figures 19, 20 and 29 of the Appendix to this Report.

It is intended to incorporate the FM and TV impairment equations into the ghost prediction study which is now in process. Recommendations regarding 'Standards' and 'Procedures' relating to ghost or multipath impairment are contained in this report.

E. W. Horrigan, P. Eng.

TV & FM MULTIPATH INVESTIGATION

1.0 Introduction

This study program was commissioned by the Department of Communications under DSS Contract No. 36100-7-0615 to:

a) assess the validity of existing criteria and methods of evaluation, predicting and computing multipath distortion on TV and FM transmissions;

b) to set up, conduct and analyse subjective assessments of impaired transmissions;

c) to make recommendations which will assist the Department to establish 'Standards' and 'Procedures' in respect to television and FM radio multipath impairment.

This first report deals specifically with the subjective and objective test program and analysis of television 'ghost' and FM multipath distortions.

The results of the subjective television ghost phase have been condensed to two easily applied

equations covering the 'Typical Viewer' and 'Expert Viewer' opinions.

The Appendix to this report contains the graphs, histograms, tables of results and methods of calculation.

2.0 Method

2.1 Observers

The judges were selected to ensure, as far as possible, that they were typical of the viewing public and included engineers, engineering technicians, factory and office workers, administrators, teachers and students. About 25% of the judges were women. A total of 162 subjects took part in the test series and 792 'Test Series' ballots containing over 5,000 data-pairs were analysed.

2.2 Grading Scale - Television Ghosts

Ballot forms were prepared using a five point, quality scale based on the CCIR Recommendation No. 500 (Geneva 1974) Figure 1 of the Appendix.

2.3 Ghost Generation - Television

It was a requirement of this study program that the television 'ghost' impairments be fully

representative of situations which could result from the location of radio towers in proximity to existing television stations. Therefore, provision was made to provide single and multiple RF echoes in the amplitude range of 1% to 32% (-40 to -10 dB) at delays between 500 ft. and 5,000 ft. (0.5 uS to 5 uS) relative to the direct signal. In the TV study program this was accomplished by using a low-power TV transmitter operating at Channel 6 feeding a RF delay matrix consisting of various lengths of high quality co-axial cables. These various paths were recombined via RF attenuators and phase shifters to provide the desired 'ghost' parameters at the input to a Channel 6 demodulator.

A block diagram of the system is shown in Figure 2 of the Appendix.

2.4 Test Material - Television

The low-power television transmitter was modulated by master program tapes prepared by the Ontario Educational Television Authority using excerpts from three days of normal production material.

These first generation masters contained sports activities (Olympic Running, Polo Games, etc.), Studio Shows, Drama, Cartoons, Outdoor Scenes and Captions, etc.

The ghost impaired demodulated test signals obtained via the co-axial delay matrix were edited and re-recorded on 3/4" video tape for use in the subjective test phase.

Test Tape No. 1 used a mixed program format consisting of Sports (Olympic Track Running), Captions, Studio Interview and Cartoon Clips with an individual test duration of 90 seconds. This short program mix was repeated for each of the Test Series 1A-F to 5A-G. Test Tape No. 2 contained Test Series 6A-F to 10 A-G and also used 90 second duration format. However, this group of tests used specific master tape program activities as follows:

Test Series 6 - Polo Game;
Test Series 7 - Drama;
Test Series 8 - Outdoor Colour Stills;
Test Series 9 - Studio Show;
Test Series 10 - Colour Outdoor Scenes and some B/W Stills which were judged to be of a very non-critical nature.

Each Test Series used a fixed ghost delay as follows:

Test Series	1	- 5 uSec;
Test Series	2	- 1 uSec;
Test Series	3	- 2 uSec;
Test Series	4	- 0.5 uSec;
Test Series	5	- Three Ghosts at 1, 2 & 5 uSec;
Test Series	6, 7 & 8	- 5 uSec;
Test Series	9	- 3 uSec;
Test Series	10	- 2 uSec.

The ghost polarity was discretely switched from a full positive to a full negative format during each test program. The ghost ratio was changed for each test in each specific series in a non-sequential manner. This avoided anticipation effects and also acted as a confidence check on voting patterns. Ghost levels based on 5 dB increments were used for this test program. Test Tape No. 3 was an objective ghost test tape using composite test waveform material.

2.5 Multipath Signal Generation - FM

A similar technique to that described in Paragraph 2.3 was used to generate the FM multipath distortions. The television modulator/demodulator

combination was, in this case, replaced by a FM exciter and high quality FM monitor receiver system. A block diagram of this system is shown in Figure 3 of the Appendix.

2.6 Test Method - FM Radio

A subjective stereo test tape was made containing material judged to be susceptible to multipath interference. (Clear Male Singer with Guitar and Orchestral Accompaniment.) This material was used to modulate the FM transmitter and the results were re-recorded for various delays and echo ratios. However, within the amplitude and delay range of interest the impairment was judged by the investigators to be too insignificant to solicit a positive listener reaction. Therefore, the FM subjective test program was replaced by an objective single tone evaluation of harmonic distortion, channel separation, SCA distortion, and cross-talk under multipath conditions.

2.7 Viewing Conditions - Television

The subjective test program was arranged as relatively small group sessions (approximately 10 observers to a group). In some cases up to six colour monitors were fed from the same V.T.R.

This arrangement ensured that, in general, viewing distances were typical of the 'home' environment with a picture height to distance ratio range of 6 - 8. Subdued lighting was used in the viewing area but no measurements of average intensity were made. However, in all cases adequate picture contrast was available while maintaining sufficient ambient illumination for ease of ballot marking.

2.8 Test Procedures

Twelve separate subjective test sessions were held with a total attendance of 162 observers.

The purpose of the tests were explained to the observers prior to the start of these sessions and a demonstration test was run showing the unimpaired program and also large (-15 dB) negative and positive ghosts impressed on the same material. The 'Grading' system and the ballot forms were discussed and any questions answered before the running of the test tapes. The viewers were requested not to identify themselves on the ballots. No attempt was made to evaluate the differential between positive and negative 'ghosts' which were alternated at suitable intervals during each test. Therefore,

the subjective assessment would tend to the worst case.

2.9 Control Tests - Television

In order to achieve a 'control' standard for the television subjective test series a small group of 'expert' television engineering staff (9) were selected from the viewing population. These subjects were well acquainted with picture quality assessment and therefore it was considered that they could provide a more critical analysis of television ghosting which could be used for reference purposes. The results of this test series were classified as "Expert Grades".

3.0 Results

3.1 Analysis of Primary Data - Television

The primary data for each test series were grouped in histogram form (Figures 4 - 8) and a mean score was calculated for each picture condition as shown in Table 1.

The distributed data for each test series was also processed in conventional manner to obtain least squares fit linear regression lines;

product-moment co-efficients of correlation; and standard estimates of error. These characteristics are also shown in Table 1 and graphically in Figures 9 - 18 of the Appendix.

The linear regression equations for the various echo delays provide a Grade versus Ghost (dB) relationship of the form:-

$$\text{Grade} = -mx + b$$

where m & b are constants

and x = Ghost (dB)

for each ghost delay value.

These various regression equations were then fitted by a slope search technique to a logistic curve of the form:-

$$\frac{m'x + b'}{}$$ where

$$m' = 0.143\, e^{\frac{-0.637}{td}}$$ td = echo delay in uSec.

$$b' = 6.65\, e^{\frac{-0.475}{td}}$$ x = Ghost (dB)

The experts' ballots were analysed in a similar manner and fitted to a logistic curve of the form:-

$m'x + b'$ where

$$m' = 0.152\ e^{-\frac{0.490}{td}}$$

$$b' = 7.03\ e^{-\frac{0.40}{td}}$$

x = Ghost (dB)

td = Delay (uS)

Working equations were assembled for use in computer or calculator programs where the ghost amplitude and delay are known or can be computed.

General Equations:-

Viewing Population Sample:-

$$\text{Grade} = (0.143\ e^{-\frac{0.637}{td}})\ (\text{Ghost dB}) - (6.65\ e^{-\frac{0.475}{td}})$$

Expert Viewer Sample:-

$$\text{Grade} = (0.152\ ^{-\frac{0.490}{td}})\ (\text{Ghost dB}) - (7.03\ e^{-\frac{0.40}{td}})$$

These equations are shown graphically for several 'Grades' of impairment in Figures 19 & 20. For comparison purposes the group mean value scores are shown on the regression lines in Figures 9 - 18 of the Appendix.

3.2 Accuracy of Results

'Null Hypothesis' tests using the 'Chi-square' distribution conducted on the primary grouped data indicates a very strong dependance between the ghost levels and the subjective grading $>$ 99%.

The 5 uSecond delay mixed program linear regression line used as a base for the general ghost equation was tested for 'Goodness of Fit' relative to the grouped means using the 'Chi-square' distribution. This gave a 'fit' figure exceeding 95%.

The product-moment correlation co-efficients for the various derived regression lines are shown in Table 1.

The co-efficients for the distributed primary raw data range from r =-0.89 for the 5 uSecond data to r =-0.45 for the 0.5 uSecond data. The correlation co-efficients for the grouped means relative to the various regression lines are also shown in Table 1. These range from =-0.99 for the 5 uSec. regression line to =-0.95 for the 0.5 uSec. regression line.

3.3 FM Multipath Measurements

The impaired stereo subjective test tapes were found to exhibit little, if any, apparent distortion at ghost levels of -15 dB or greater within the delay range 0.5 uSec. to 5.0 uSec.

Similar tests made by the BBC Research Department indicate that multipath is not a problem at delays of less than 25 seconds.[1]

In view of the apparent lack of subjective reaction to multipath interference within the amplitude and delay range of interest it was decided to substitute an objective and theoretical evaluation program for the subjective test program originally envisaged.

The results of the objective measurement program are contained in Table II of the Appendix to this report. These results are also shown graphically in Figures 21 - 31.

A theoretical analysis is covered in Section 3.4 of this report.

1. R. V. Harvey, IEE Paper No. 3221, March 1960

3.4 FM Distortion Caused by a Delayed Signal

In 1959, R. V. Harvey of the BBC investigated FM multipath propagation distortion and published an appraisal of its subjective effects in Paper No. 3221 dated March 1960 of the Institution of Electrical Engineers. The Harvey investigation dealt with echo delays considerably longer than those of current interest and not representative of re-radiation problems from structures adjacent to FM transmitting antennas. However, the general approach is applicable to the current study program and will be used to obtain theoretical values of total harmonic distortion for comparison purposes. A similar theoretical analysis of multipath distortion is given by P. F. Panter in "Modulation, Noise and Spectral Analysis" published by McGraw-Hill in 1965.

A delayed echo produces unwanted amplitude and phase modulation of the received FM signal, as shown in Figure A. The direct signal is considered to have unit amplitude and the echo signal(a) will add

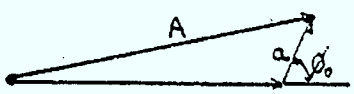


Figure A, Unmodulated Carrier

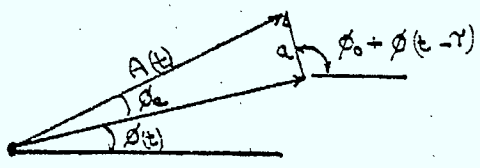


Figure B, Modulated Carrier

vectorially giving a resultant total amplitude A dependent upon the relative phase and amplitude of the echo signal. When the FM carrier is modulated the vector diagram takes the form of Figure B. The modulation component of the direct signal can be represented at the phase deviation $\phi(t)$ where Figure B shows the vector relationships for the time instant (t). The echo signal has been delayed by the time τ and consequently has changed in phase by $\phi(t-\tau)$. Therefore, the angle ϕe can be considered as the phase error or phase distortion of the composite received signal.

Where $a \ll 1$, a quasi-stationary approximation results in:-

$$A(t) = 1 + a \cos\left[\phi_o + \phi(t-\tau) - \phi_t\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$\phi_e(t) = a \sin\left[\phi_o + \phi(t-\tau) - \phi_t\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The distortion appearing at the output of the FM discriminator will be proportioned to $d/dt\ \phi_e(t)$ which is defined as the distortion term $\omega_e(t)$

$$\omega_e(t) = a \cos\left[\phi_o + \phi(t-\tau) - \phi_t\right] \times \left[\omega(t-\tau) - \omega(t)\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

This assumes that sufficient AM limiting exists in the demodulator to exclude AM contributions to the distortion process.

The above equations are general in respect to modulation waveform. However, these calculations are being made for comparison purposes in respect to distortion measurements made using a single simple sine-wave modulation of the FM carrier

Therefore:

$$\omega(t) = \omega_d \cos pt$$

$$\phi(t) = \phi_d \sin pt$$

Where $\phi_d = \omega_d / p$

p = angular modulation frequency

ω_d = angular peak deviation

For simple sine-wave modulation equation (1) becomes:

$$A(t) - 1 = a \cos \left[\phi_o - 2\phi_d \sin \tfrac{1}{2} p\tau \cos p(t - \tfrac{1}{2}\tau) \right]$$

$$= a \cos \left[\phi_o - {}^{2}/_{p} (\sin \tfrac{1}{2} p\tau) \omega (t - \tfrac{1}{2}\tau) \right] \quad \ldots\ldots\ldots\ldots\ldots (4)$$

The FM distortion term of equation (3) becomes $\omega_d \left[\cos p(t - \tau) - \cos pt \right]$

$$= 2\omega_d \sin \tfrac{1}{2} p\tau \sin p(t - \tfrac{1}{2}\tau) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

From equations (3) and (5) the peak amplitude of the distortion can be derived. At some instant (t) these equations reduce to:

$$\omega_{e(t)} = 2a\omega_d \sin \tfrac{1}{2} p\tau$$

The average percentage distortion of this sine-wave modulation can be expressed as follows:

$$\text{Distortion (\%)} = \frac{\sqrt{2}\, a\omega_d \sin \tfrac{1}{2} p\tau}{\omega_d} \times 100 = \quad \%$$

$$= 141.4\, a \sin \tfrac{1}{2} p\tau$$

Table III and Figure 29 show the computed results for several echo levels and delays.

3.5 Comparison with Other Studies

It is not possible to make a direct comparison with previous studies because of major differences in program material, television standards, grading scales and types and number of observers, etc.

This study made no attempt to evaluate the obvious differential effects of ghost image polarity as this was considered to be of academic interest only. The viewer has no control over the ghost polarity which is dependent upon differences in direct and reflected RF signal phase at the reception point. Therefore, both polarities were used in all tests to obtain a worst case assessment.

The work of Allnatt and Presser[1]·1965, Lessman[2]·1972 and Corbett and Allnatt[3]·1974 were studied. The Lessman study[2]·used a 7 point grading scale and still colour pictures for the subjective test program. The Allnatt and Presser study used a 5 point grading scale similar to that used in the study and 625 line still colour pictures. The Corbett and Allnatt[3]·study also used a 5 point grading scale and 625 line still colour pictures.

The mid-opinion (Grade 3) results of our tests at 2 uSec. delay were found to be 21.0 dB for the program mixture test (Test No. 3). The Corbett and Allnatt figures for a mid-opinion negative echo at 2 uSec. was 19.7 dB and 21.1 dB for a positive echo of similar delay.

The mid-opinion average picture grade given in the Allnatt and Presser study for a 2 uSec. delay is given in 21 dB for colour stills. Lessman's mid-opinion values for a 2 u.Sec. delay are 22.7 dB and 25.5 dB respectively for negative and positive echoes.

At echo delays that are less than 2.0 uSec. the results of this study show greater differences with decreasing delay indicating that the observers used were less critical than those used in previous above-mentioned tests. A comparison with the Christopher results, which are assumed to be based on the threshold of visibility, and the similar impairment condition herein defined as Grade No. 1.5 indicates reasonable correlation exists.

A similar comparison was made with the averaged results of the Corbett and Allnatt, 1972, 1/8 imp grade impairment. This 1/8 imp curve falls between limits set by the 'Expert' Grades 2 - 2.5 over the delay range 0.5 to 5.0 u.Sec.

The short echo delay ($<$ 2 uSec.) results obtained with the 'typical viewer' samples are much more tolerant to impairment than the 'expert' opinions cited above. This is very possibly the result of prior conditioning of urban area viewers who normally see a multitude of short delay echoes on their pictures which are possibly a product of their high-rise, big-city environment and mediocre receiving systems.

4.0 Conclusions

4.1 General

This study has shown that "typical viewer" and "expert viewer" subjective opinions of ghost-impaired television reception can be objectively related to mathematical expressions or graphs suitable for incorporation into 'Standards' and 'Procedures' concerning antenna towers adjacent to television radiators.

It has also shown that typical urban area viewers are more tolerant to short delayed ghosts than was anticipated from a study of 'expert' opinions. This study has also provided data relating to multiple ghosting impairment, grading scales, program material effects and the need for more accurate objective measurement techniques for ghost level evaluations in the field.

The results of the FM multipath study show that echo levels and delays typical of those anticipated from antenna towers adjacent to FM radiators are very unlikely to cause any listener reaction. Tests made even at unrealistic echo levels produced no 'expert-listener' reaction within the delay range investigated. Discussions with the BBC and IBA staff indicate that large echoes at delays of several kilometers are required to invoke a positive listener reaction. The conditions required for such multipath signals are more related to aircraft flutter or large topographical obstructions than to adjacent towers. Therefore, an objective FM multipath distortion measurement program was substituted for the subjective

test program originally envisaged. The objective test results indicate that FM radio is little troubled by ghost levels which would be considered intolerable in TV reception. The objective test results in respect to indicated total harmonic distortion at higher modulating frequencies $\geqslant$ 5 KHz are not a true measure of harmonic distortion. The harmonic spectrum of typical multipath distortion has been shown by Harvey[1] to favour the higher order harmonics; therefore, above 5 KHz the band-limited audio response of typical receivers and measuring instruments would reject these components. Consequently, the results obtained in this objective program are extraneous non-fundamental components within the 15 KHz passband which are either impulse spikes[2] or intermodulation components and not true harmonics.

The measured noise and/or distortion results in the main channel are very similar to those calculated by Harvey's equations allowing 7 - 8 dB discrimination due to the emphasis/pre-emphasis

1. R.V.Harvey, IEE Paper No. 3221 March 1960

2. P.F.Panter, Modulation, Noise, and Spectral Analysis Fig.11-3 McGraw-Hill, 1965

characteristics. The noise and/or distortion measurements on the stereo channels appear to fit within the limits of the basic equation shown in Section 3-4. The results of the stereo tests indicate that the noise and/or distortion measured is not directly related to modulating frequency but is a function of echo delay and modulating frequency within the delay range investigated. However, it is considered that the basic FM equation for non-fundamental extraneous components has some validity in defining limiting values of echo amplitude in stereo FM applications.

4.2 'Typical Viewer' - 'Expert Viewer' Grading

The 'typical' versus 'expert' viewer grading results derived from the two best-fit logistic equations are shown in Table A. which follows.

For Impairment grades considered acceptable (1.5 - 2.0), insignificant differences exist at echo delays in excess of 1.0 u.Second; however, a considerable difference is indicated at delays in the range of 0.5 u.Sec. as shown in the following table:

TABLE A.

Delay u.Sec.	Grade No.	'Expert' Grade dB.	'Typical' Grade dB.	Difference dB.
5.0	1.5	36.21	36.02	-0.19
5.0	2.0	32.56	32.05	- 0.51
3.0	1.5	36.04	35.95	- 0.09
3.0	2.0	32.17	31.63	- 0.44
2.0	1.5	35.77	35.75	- 0.02
2.0	2.0	31.57	30.94	- 0.63
1.0	1.5	34.50	34.03	- 0.47
1.0	2.0	29.13	27.70	- 1.43
0.5	1.5	29.01	25.52	- 3.49
0.5	2.0	20.31	13.02	- 7.29

4.3 Multiple Ghost Grading

The multiple ghost tests showed that in all cases the ghost of longest delay (5 u.Sec.) was the governing factor in subjective grading.

The ghost polarities and amplitudes were all varied in a non-sequential, non-coherent manner for the three ghosts used in this test series. The correlation coefficients obtained from the subjective test ballots approached one (1) for the more delayed

5.0 u.Sec. ghost and zero for the 2.0 u.Sec. and 1.0 u.Sec. ghosts regardless of amplitude or phase. Therefore, as expected the more delayed and distinct ghosts are the most objectionable. However, the multiple ghost grades were slightly more critical than similarly ghost-impaired single ghost grades. The difference being about -1.5dB at Grade 2 and - 0.75 dB at Grade 1.5.

4.4 Program Material Grading

As anticipated, sports activities were more degraded by ghost impairments than were studio shows, plays or still outdoor scenes, as shown in Figure 14 and 16.

At ghost impairments levels considered acceptable (Grade 1.5 - 2.0) the difference between general program material and sports activities do not exceed about 1.0 dB on average.

4.5 Grading Scales

It is considered that the CCIR 5 level grading scale is too coarse a scale to provide an adequate assessment of picture quality impairment. It was found necessary to use half grades for the analysis of the

subjective data and to provide meaningful recommendations for its use.

4.6 Objective Ghost Measurement Techniques

Objective TV ghost measurements using the pulse and bar or window signal only provide a valid ghost level evaluation when the direct signal/ghost signal RF phase relationship is approximately 0° or 180°.

This limitation did not cause any problem during the ghost generation phase of this study because complete control of ghost signal RF phase was available and furthermore, the direct and ghost signals could be measured independently. However, in field measurement programs where the two signals cannot be separated this method of ghost measurement will yield erroneous results in the majority of situations. Assuming that a ghost RF phase of $0^{\circ} \pm 15$ and $180^{\circ} \pm 15^{\circ}$ relative to the direct RF can be considered as either a full positive or full negative ghost and consequently a valid measurement standard, it can easily be shown that invalid results (underestimations) will occur in $\sim$ 83% of the situations so measured.

4.7 Luminance and Chromanance Effects

The echo delays of interest to this study program (0.5 u.Sec. to 5.0 u.Sec.) ensure that distortions occur in the back-porch colour-burst reference signal. The added echo signal then level shifts and/or phase shifts this reference signal dependent upon the relative RF amplitude and phases of the direct and reflected signals.

It was found possible to so adjust the phase of a large echo signal so as to almost completely cancel the step signal (luminance change) caused by the echo (echo phase $\sim 90^{\circ}$ relative to direct signal). Monochrome transmissions made under these conditions were found to be quite tolerable with only a faint outline visible in the ghost area. However, colour transmissions under the same conditions were found to be unacceptable because a considerable hue and saturation effect produced a very visible ghost. This would appear to suggest that ghosting can produce significant overall colour shift on a viewer's receiver even when the actual ghost level is tolerable.

It would also indicate that ghosting will have more effect on the NTSC system than on the PAL system which should cancel out moderate hue shifts caused by multipath reception.

4.8 FM Multipath

This study program has shown that FM multipath interference is a minor impairment to FM reception in the echo delay and amplitude range representative of towers adjacent to the FM radiator.

Objective measurements indicate that echoes more than 15 dB below the direct signal will have negligible effects on FM reception.

5.0 Recommendations

5.1 Acceptable Television Ghost Impairment Grades (Standards)

It is considered that this study has produced an easily applied unified method of specifying ghost levels which can be incorporated into 'Standards' and 'Procedures' and/or 'Notices to Broadcast Consultants'.

It is recommended that the following proposed-minimum standards be considered for promulgation by the Department of Communications:-

a) Major Television Stations

i) Minimum "Standard":- ≤Grade 1.5 Impairment for 75% of Population covered by Service Contours.

ii) Minimum "Standard":- ≤Grade 2.0 Impairment for 25% of Population covered by service contours.

b) Limited or Drop-In Stations

i) Minimum "Standard":- ≤Grade 1.5 Impairment for 50% of Population covered by Service Contours.

ii) Minimum "Standard":- ≤Grade 2.0 Impairment for 50% of Population covered by Service Contours.

c) Low-Power Television Stations

i) Minimum "Standard":- ≤Grade 2.0 Impairment for 75% of Population covered by Service Contours.

ii) Minimum "Standard":- ≤Grade 2.5 Impairment for 25% of Population covered by Service Contours.

d) Mini-TV Stations

i) Minimum "Standard":- ≤Grade 2.5 Impairment for 100% of Population covered by Service Contours.

5.2 Method of Calculation (Procedure)

i) Ghost Prediction:-

The echo amplitude and delay will be calculated by a method acceptable or specified by the Department of Communications.

ii) The Impairment Grade will be computed by means of Figure 19 or by use of the 'Typical Viewer' equation:-

$$\text{Grade} = \left[(0.143\, e^{-\frac{0.637}{td}})(G) - (6.65\, e^{-\frac{0.0475}{td}})\right]$$

Where td = Ghost delay in μ. Seconds

G = Ghost level in dB

5.3 Acceptable FM Multipath Levels

i) Procedure:-

Echo amplitudes and delays will be calculated by a method acceptable or specified by the Department of Communications.

ii) Minimum Standard:-

≤ 2% noise and/or distortion calculated by means of Figure 29 or as follows:

$$\text{Ghost (dB)} = 20\ \text{Log}_{10}\ \left[\frac{2\,(\%)}{141.4\ \sin(1.8td)}\right]$$

Where td = delay (u.Sec.)

6.0 Areas for Further Study

6.1 Prediction Methods

This area of the study program is currently under investigation and it is anticipated that a report and computer soft wave program will be made available in the near future.

In the interim period it is recommended that the BBC Knight/Hill methods be used for calculation purposes.

6.2 Ghost Measurement Techniques

It is recommended that a thorough study be made of objective measurement techniques for 'Ghost' evaluations under field conditions.

The use of bar or window signals in test transmissions will yield results which will in all probability grossly under-estimate the true ghost situation. Consequently such surveys should incorporate an associated subjective assessment which is undesirable for objective or enforcement purposes.

'K' rating methods have potential for ghost evaluation purposes as have two frequency test signals and colour burst spectrum response techniques.

7.0 ACKNOWLEDGEMENTS

The author wishes to acknowledge the co-operation and assistance provided by the numerous persons and organizations including those listed below which contributed greatly to the success of this phase of the project: Mr.K.Easton, P.Eng., of Cable Consulting Services Ltd., who designed and set-up the RF delay matrix system; Mr. R.Carnovale,P.Eng.,of the Ontario Educational Communications Authority, and Mr. R.Turnpenny of Rogers Radio Broadcasting Ltd., who provided the 'Master' TV and Radio program tapes; Applied Electronics Ltd.,M.S.C. Electronics Ltd., Rogers Radio, and RF Communications Ltd., who provided electronic equipment; The Jerrold Division of General Instrument of Canada who provided the test facilities and assistance during the ghost generation phase of the project;The Canadian Broadcasting Corporation,EHQ.,Canadian General Electric,Radio College of Canada, Metro Cable TV, Rogers Cable TV, and many others who provided both 'expert' and 'typical' viewers for the subjective tests; and for the useful suggestions and assistance provided by my colleagues.

8.0 ENGINEERING SEAL & SIGNATURE

SEAL 

SIGNATURE _____ P.Eng

Edwin W. Horrigan,
Principal Investigator.

September 15th, 1978

9.0 APPENDIX

TABLE I

TV GHOST STUDY - SUBJECTIVE TEST ANALYSIS

Test Series	Test 1		Test 2		Test 3		Test 4	
Type of Observers	Typical Viewers	Experts	Typical Viewers	Experts	Typical Viewers	Experts	Typical Viewers	Experts
Echo Delay	5 u.Sec	5 u.Sec	1 u.Sec	1 u.Sec	2 u.Sec	2 u.Sec	0.5 u.Sec	0.5 u.Sec
Echo Level								
-40 dB	1.13	1.11	1.13	1.0	1.14	1.11	1.11	1.11
-35 dB	1.58	1.49	1.42	1.49	1.45	1.49	1.38	1.22
-30 dB	2.18	2.44	1.64	1.88	1.77	2.11	1.43	1.49
-25 dB	2.85	2.88	2.11	2.44	2.25	2.77	1.6	1.88
-20 dB	3.51	4.0	2.58	2.77	3.16	3.22	1.66	2.0
-15 dB	4.41	4.33	3.21	3.33	3.87	4.11	2.1	2.44
N = Data Pairs	552	53	552	53	552	53	552	53
No. of Observers	92	9	92	9	92	9	92	9
Test Material	Program Mix							
No. of Ghosts	1	1	1	1	1	1	1	1
Coefficient of Correlation (Raw)	-0.89		-0.78		-0.86		-0.45	
Coefficient of Correlation (Means)	-0.995	-0.99	-0.984	-0.998	-0.986	-0.994	-0.958	-0.986
Slope (m)	-0.126	-0.1375	-0.076	-0.092	-0.106	-0.1191	-0.04	-0.0536
Intercept (b)	6.05	6.49	4.00	4.67	5.23	5.74	2.60	3.16
(Sx) Raw Data	3.9 dB							
(Sx) Means	0.85 dB							
Null Hypothesis χ^2	> 99%							
Group Mean Fit χ^2	> 95%							

Group Mean Scores X

TABLE I

TV GHOST STUDY - SUBJECTIVE TEST ANALYSIS (cont/d.)

Test Series	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Type of Observers	Typical Viewers	Typical Viewers	Typical Viewers	Typical Viewers	Typical Viewers	Typical Viewers
Echo Delay	1,2,5	5 u.Sec	5 u.Sec	5 u.Sec	3 u.Sec	2 u.Sec
Echo Level						
-40 dB	-	1.13	1.12	1.17	1.13	1.1
-35 dB	1.71	1.47	1.59	-	1.73	1.28
-30 dB	2.51	2.14	1.97	1.88	2.23	1.5
-25 dB	3.43	3.16	2.51	2.37	2.76	2.02
-20 dB	3.91	3.89	3.48	2.84	3.63	2.51
-15 dB	4.8	4.63	4.24	3.57	4.27	3.24
N = Data Pairs	268	408	408	340	408	408
No. of Observers	67	68	68	68	68	68
Test Material	Program Mix	Polo Game	Drama Show	Still Colour Landscapes	Studio Show	Non-critical Outdoor & B/W
No. of Ghosts	3	1	1	1	1	1
Coefficient of Correlation (Raw)	-0.89				-0.90	
Coefficient of Correlation (Means)	-0.992	-0.152	-0.985	-0.989	-0.997	-0.972
Slope (m)	-0.150	-0.152	-0.1283	-0.0953	-0.1256	-0.0866
Intercept (b)	7.03	6.94	6.02	4.84	6.03	4.36

Group Mean Scores X

F.M. Multipath Delay Test Program

Test No.: 1A - I

Objective Test Series

Date: May 1978

TABLE II

Audio Test Frequency Hertz	Ghost Level dB	Ghost Delay μ Sec	Monaural Distortion & Noise %	Stereo Distortion & NOISE % RIGHT	Stereo Distortion & NOISE % LEFT	S.C.A. Distortion & Noise %	Stereo Separation dB	System Crosstalk dB	Additional Remarks or Observations
100	No Ghost	5.0	0.5	0.8	0.8		31		The observed percentage of distortion was the sum of all extraneous products in the band 25 - 15,000 Hz.
	-40		0.5	0.8	0.8		31		
	-30		0.5	0.8	0.8		31		
	-25		0.5	0.85	0.85		31		
	-20		0.5	2.2	2.3		31		
	-15		0.5	3.8	3.8		30		
	-10		0.5	6.2	6.3		28		
	-5		0.5	12.0	13.0		22		
	0		0.55	18.0	18.0		18		
1,000	No Ghost	5.0	0.55	0.5	0.5	2.0	32	45	
	-40		0.55	0.5	0.5	2.0	32	45	
	-30		0.55	0.5	0.5	2.0	32	44	
	-25		0.55	1.25	1.25	2.0	32	44	
	-20		0.6	2.0	2.0	2.2	31	43	
	-15		0.7	3.2	3.25	2.2	30	43	
	-10		0.7	5.8	6.0	2.3	29	41	
	-5		0.7	12.0	12.0	2.5	23	40	
	0		0.75	20.0	20.0	3.0	19	30	
5,000	No Ghost	5.0	0.8	0.6	0.6		31		
	-40		0.8	0.6	0.6		31		
	-30		0.9	0.6	0.6		31		
	-25		0.9	0.9	0.9		31		
	-20		1.2	1.2	1.2		31		
	-15		1.7	1.85	1.9		30		
	-10		2.0	3.4	3.5		28		
	-5		3.2	7.2	7.5		25		
	0		3.9	16.0	16.0		20		
10,000	No Ghost	5.0	0.8	0.8	0.8		31		
	-40		0.8	1.0	1.0		31		
	-30		0.9	1.5	1.5		31		
	-25		0.9	1.8	1.8		31		
	-20		1.2	2.0	2.0		30		
	-15		1.75	2.8	3.0		29		
	-10		2.2	4.3	4.5		25		
	-5		4.5	10.5	11.0		20		
	0		6.4	20.0	20.0		11		

F.M. Multipath Delay Test Program

Test No.: 2A - I

Objective Test Series

Date: May 1978

TABLE II (cont/d.)

Audio Test Frequency Hertz	Ghost Level dB	Ghost Delay u.Sec	Monaural Distortion & Noise %	Stereo Distortion & Noise % RIGHT	Stereo Distortion & Noise % LEFT	S.C.A. Distortion & Noise %	Stereo Separation dB	System Crosstalk dB	Additional Remarks or Observations
100	No Ghost	2.0	0.5	0.8	0.8		31		Distortion measurements include all noise and extraneous products in band 25 - 15,000 Hz.
	-40		0.5	0.8	0.8		31		
	-30		0.5	0.8	0.8		31		
	-25		0.5	0.8	0.8		31		
	-20		0.5	1.0	1.0		31		
	-15		0.5	2.2	2.0		31		
	-10		0.5	3.0	3.0		30		
	-5		0.5	4.5	4.5		29		
	0								
1,000	No Ghost	2.0	0.5	0.5	0.5	2.0	32	45	
	-40		0.5	0.5	0.5	2.0	32	45	
	-30		0.5	0.5	0.5	2.0	32	45	
	-25		0.5	0.65	0.7	2.0	32	45	
	-20		0.55	0.75	0.75	2.0	32	45	
	-15		0.55	0.85	0.85	2.0	31	44	
	-10		0.55	1.5	1.5	2.0	30	44	
	-5		0.6	3.0	3.0	2.0	29	43	
	0								
5,000	No Ghost	2.0	0.8	0.6	0.6		31		
	-40		0.8	0.6	0.6		31		
	-30		0.8	0.6	0.6		31		
	-25		0.8	0.9	0.9		31		
	-20		0.8	1.2	1.2		31		
	-15		0.9	1.5	1.5		31		
	-10		1.0	2.0	2.0		30		
	-5		1.5	3.53	3.5		28		
	0								
10,000	No Ghost	2.0	0.8	0.8	0.8		31		
	-40		0.8	0.8	0.8		31		
	-30		0.8	0.8	0.8		31		
	-25		0.8	1.2	1.2		31		
	-20		0.9	1.7	1.7		31		
	-15		1.0	2.25	2.25		30		
	-10		1.2	3.9	4.0		29		
	-5		2.2	7.0	7.0		25		
	0								

TABLE III

CALCULATED FM MULTIPATH DISTORTIONS

1. Echo Delays: 5 u.Sec., 3 u.Sec., 2 u.Sec., 1 u.Sec.
2. Echo Amplitudes: 30 dB, 20 dB, 10 dB
3. Modulation Frequencies: 1 KHz, 5 KHz, 10 KHz

Modulation Frequency	Delay u.Sec.	Ghost dB	Main Channel with Pre-Emphasis Equiv.* dB	Distortion %
1 KHz	5	30	22	0.07
1 KHz	5	20	12	0.22
1 KHz	5	10	2	0.7
5 KHz	5	30	22	0.35
5 KHz	5	20	12	1.1
5 KHz	5	10	2	3.5
10 KHz	5	30	22	0.7
10 KHz	5	20	12	2.21
10 KHz	5	10	2	7.0
1 KHz	3	30	22	0.04
1 KHz	3	20	12	0.13
1 KHz	3	10	2	0.42
5 KHz	3	30	22	0.2
5 KHz	3	20	12	0.7
5 KHz	3	10	2	2.1
10 KHz	3	30	22	0.42
10 KHz	3	20	12	1.33
10 KHz	3	10	2	4.2

... cont'd.

TABLE III (cont'd.)

Modulation Frequency	Delay u.Sec.	Ghost dB	Main Channel with Pre-Emphasis Equiv.* dB	Distortion %
1 KHz	2	30	22	0.03
1 KHz	2	20	12	0.09
1 KHz	2	10	2	0.3
5 KHz	2	30	22	0.14
5 KHz	2	20	12	0.44
5 KHz	2	10	2	0.4
10 KHz	2	30	22	0.28
10 KHz	2	20	12	0.9
10 KHz	2	10	2	2.80
1 KHz	1	30	22	0.014
1 KHz	1	20	12	0.044
1 KHz	1	10	2	0.14
5 KHz	1	30	22	0.07
5 KHz	1	20	12	0.22
5 KHz	1	10	2	0.7
10 KHz	1	30	22	0.14
10 KHz	1	20	12	0.44
10 KHz	1	10	2	1.4

* Correction for Pre-emphasis/De-emphasis characteristics - Main Channel

STATISTICAL ANALYSIS DETAILS

The following equations were used to analyse the raw data obtained from the television ghosting subjective tests:-

Mean of x array ($\bar{x}$) = $\frac{\sum x}{N}$ Where N = Data Input Units

Mean of y array ($\bar{y}$) = $\frac{\sum y}{N}$

Standard Deviation of x array (σx) = $\left[\frac{\sum x^2 - \frac{(\sum x)^2}{N}}{N-1}\right]^{\frac{1}{2}}$

Standard Deviation of y array (σy) = $\left[\frac{\sum y^2 - \frac{(\sum y)^2}{N}}{N-1}\right]^{\frac{1}{2}}$

Variance of x array ($\sigma^2 x$) = $\frac{\sum x^2}{N} - \bar{x}^2$

Variation of y array ($\sigma^2 y$) = $\frac{\sum y^2}{N} - \bar{y}^2$

Slope of Linear Regression Line (m) = $\frac{\sum xy - \frac{\sum x \sum y}{N}}{\sum x^2 - \frac{(\sum x)^2}{N}}$

y-Intercept (b) = $\frac{\sum y - m \sum x}{N}$

Correlation Coefficient (r) = $m \frac{\sigma x}{\sigma y}$

Standard Error of (r) = $\frac{1 - r^2}{N^{\frac{1}{2}}}$

Standard Error of (x) (Sx) = $\sigma x \, (1-r^2)^{\frac{1}{2}}$

Test of Hypotheses

Analysis of r by k array

Null Hypotheses

$$e_{ij} = n(n_i/n)(n_j/n) = \frac{(n_i)(n_j)}{n}$$

Where n_{ij} = observed cell freq.
e_{ij} = estimated cell freq.

Degrees of freedom
= (r-1)(k-1)

$$\chi^2 = \sum \frac{(n_{ij} - e_{ij})^2}{e_{ij}}$$

Goodness of Fit

$$\chi^2 = \sum \frac{(n_i - e_i)^2}{e_i}$$

Where: degrees of freedom = k-3

Television 'Ghost' Subjective Tests

Introduction

These tests are being made to ascertain the subjective effects of 'ghosts' in television pictures.

Ghosting is a form of picture impairment in which an echo of the original picture appears displaced on the right hand side of the tube. The position and brightness of the echo or 'ghost' image can adversely affect the viewing pleasure of television. Therefore, we are attempting to find an acceptable level of ghosting based on your reactions to the deliberately impaired pictures we shall now present.

The ballot forms have 'Check Boxes' against five different descriptions of impairment ranging from "No Visible Ghost" to "Not Worth Viewing". Your task is to view a test run and then tick the box which most closely describes your reaction to the deliberate 'ghost' impairment we have added to the test program.

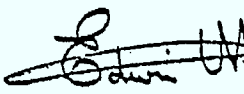
The tests will be identified on your screen so that you can relate your ballot to its corresponding test run. The "finish" of each test will also be shown on the tube and a subsequent brief interval will allow time for you to mark your ballot before the start of the next test.

The first test run is not to be marked as it is only a preview of the program you will be judging.

Please note that in different tests the ghosts will not always appear at the same distance from the original picture and furthermore they will vary in their degee of severity and appearance. Just record your general reaction to these various ghost impairments in accordance with the descriptions on your ballots.

If you have any questions please ask the demonstrator before we start the test program or during any of the marking pauses between the tests.

Thank you for your assistance in helping us to evaluate 'ghost' impairments in television pictures.



E. W. Horrigan, P.Eng.
Principal Investigator.

TELEVISION "GHOSTING" - SUBJECTIVE TEST FORM

FIGURE 1

DATE: _____

TEST SERIES 5 TEST # 5A

CHECK ONE ONLY	DESCRIPTION OF IMPAIRMENT	PICTURE RATING	GRADE	REMARKS OR COMMENTS	FOR OFFICIAL USE ONLY: VIDEO TAPE PROGRAM MATERIAL	FOR OFFICIAL USE ONLY: GHOST LEVELS dB
	No visible 'Ghost'	Excellent	1		TEST TAPE #2 Multiple Series	
	Faint 'Ghost'	Good	2			
	Obvious but not objectionable 'Ghost'.	Fair	3			
	Objectionable 'Ghost some viewing value	Poor	4			
	Picture is not worth viewing	Bad/Useless	5			

TEST # 5B

CHECK ONE ONLY	DESCRIPTION OF IMPAIRMENT	PICTURE RATING	GRADE	REMARKS OR COMMENTS	FOR OFFICIAL USE ONLY: VIDEO TAPE PROGRAM MATERIAL	FOR OFFICIAL USE ONLY: GHOST LEVELS dB
	No visible 'Ghost'	Excellent	1			
	Faint 'Ghost'	Good	2			
	Obvious but not objectionable 'Ghost'	Fair	3			
	Objectionable 'Ghost' some viewing value	Poor	4			
	Not worth viewing	Bad/Useless	5			

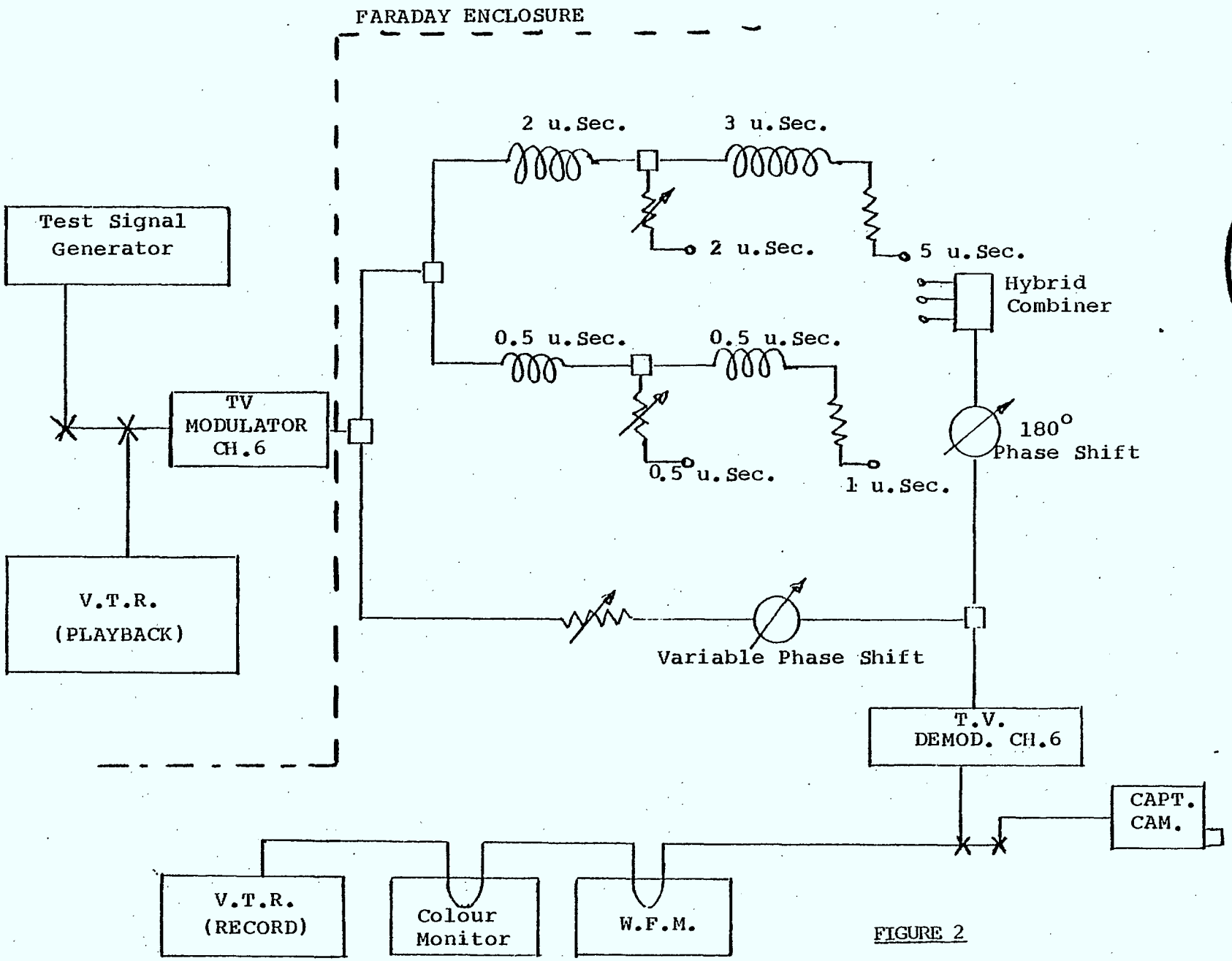


FIGURE 2

TV BLOCK DIAGRAM

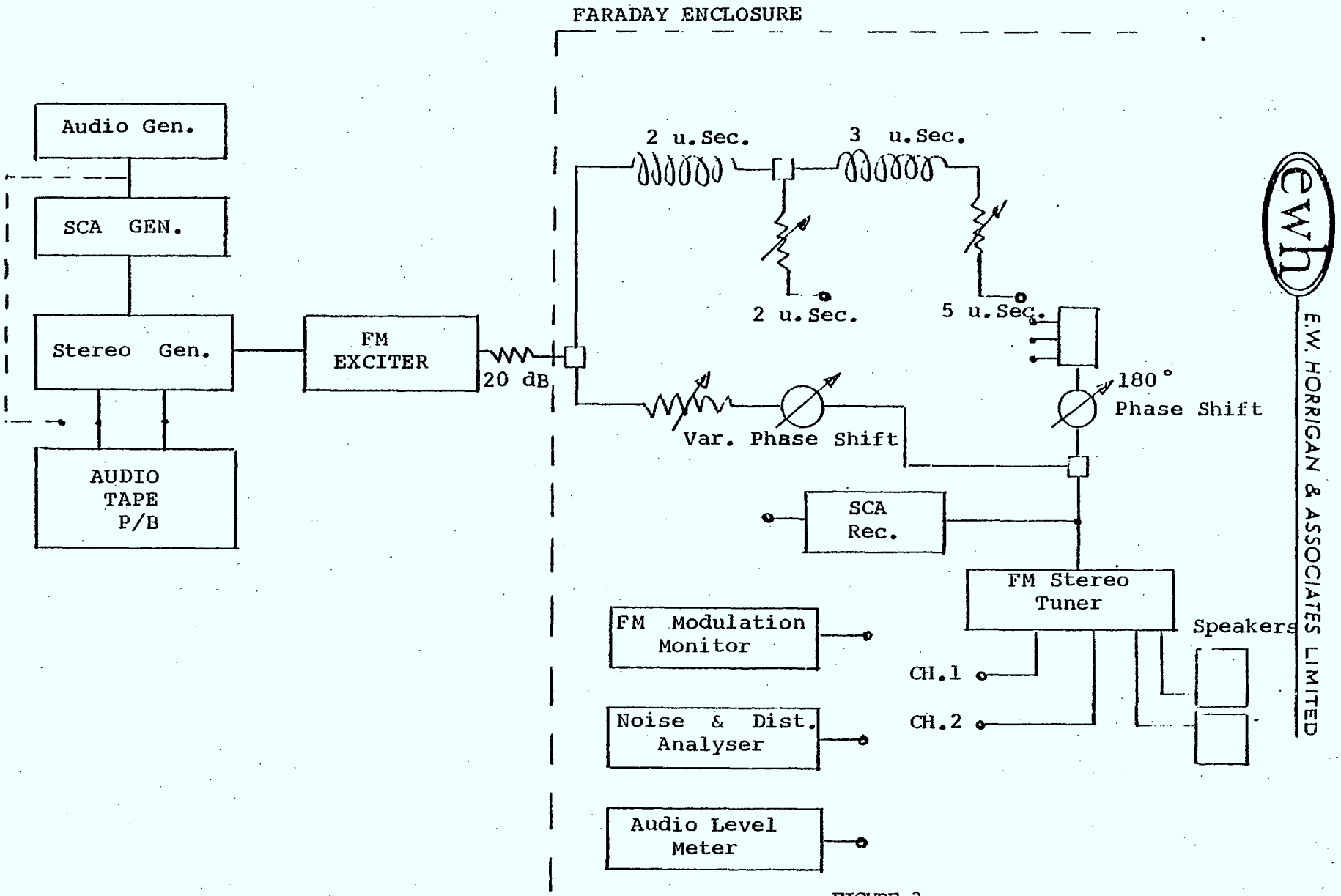


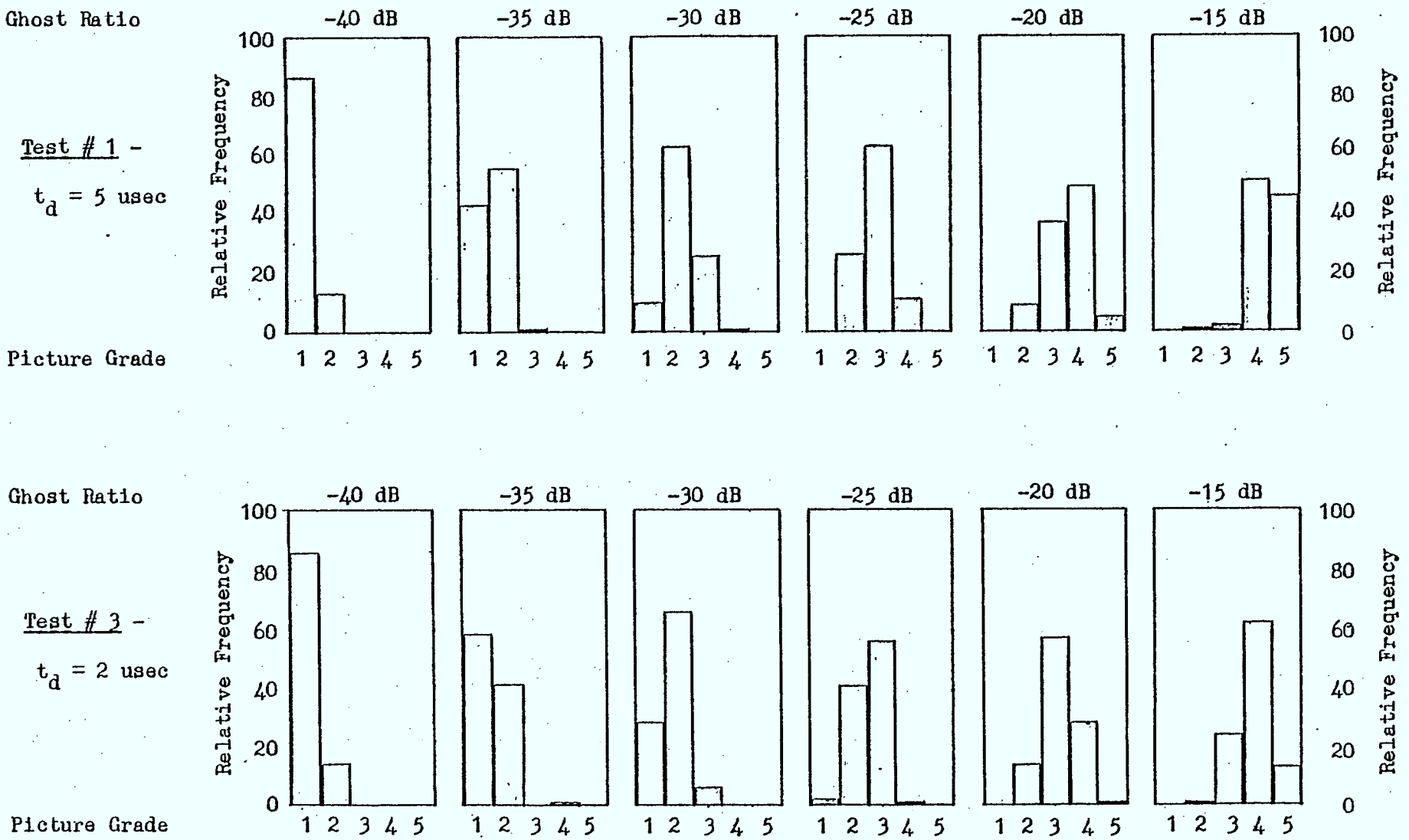
FIGURE 3

FM BLOCK DIAGRAM

TELEVISION GHOST INVESTIGATION

Evaluation of Subjective Test Results

FIGURE 4

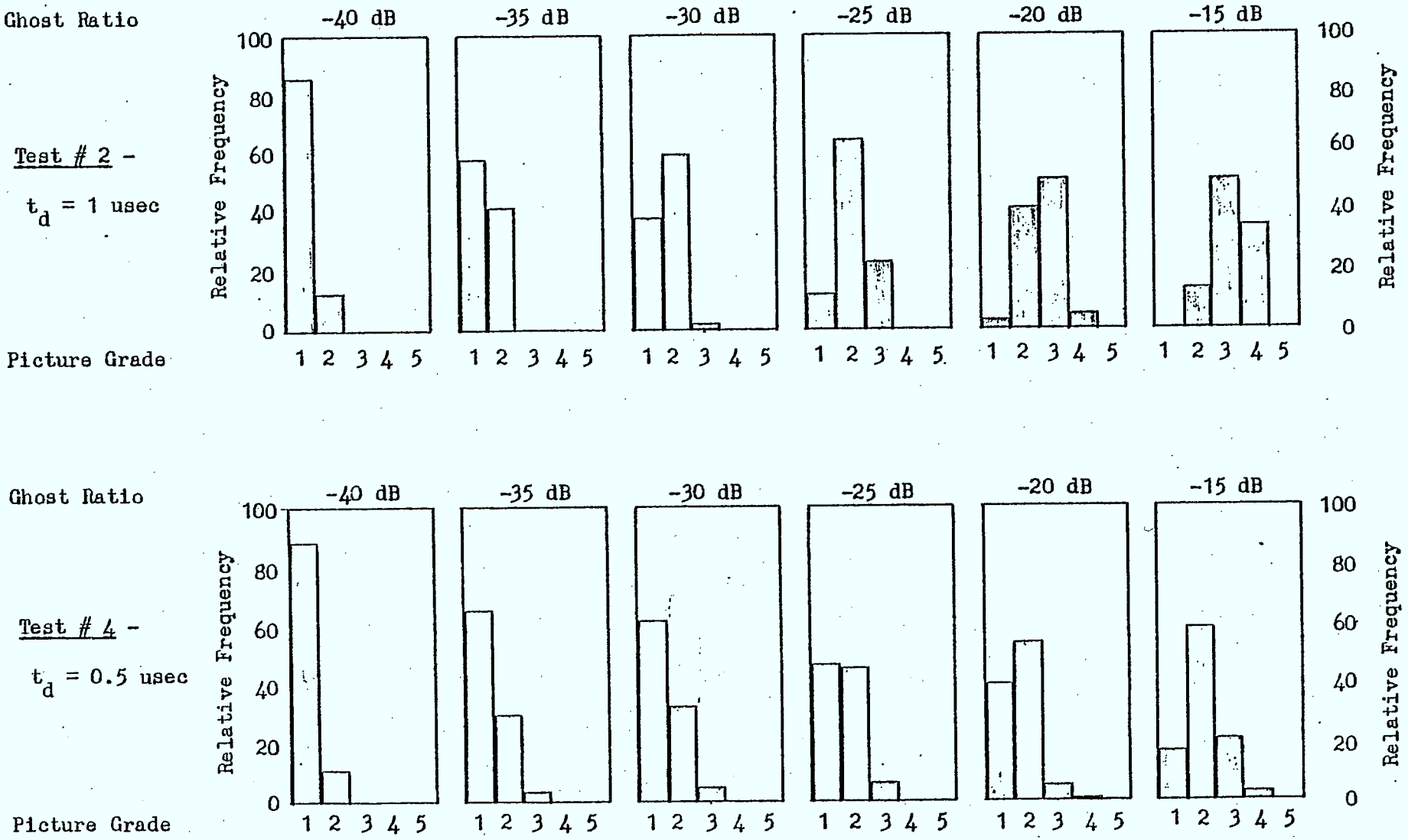


Relative Frequency Histograms

TELEVISION GHOST INVESTIGATION

Evaluation of Subjective Test Results

FIGURE 5

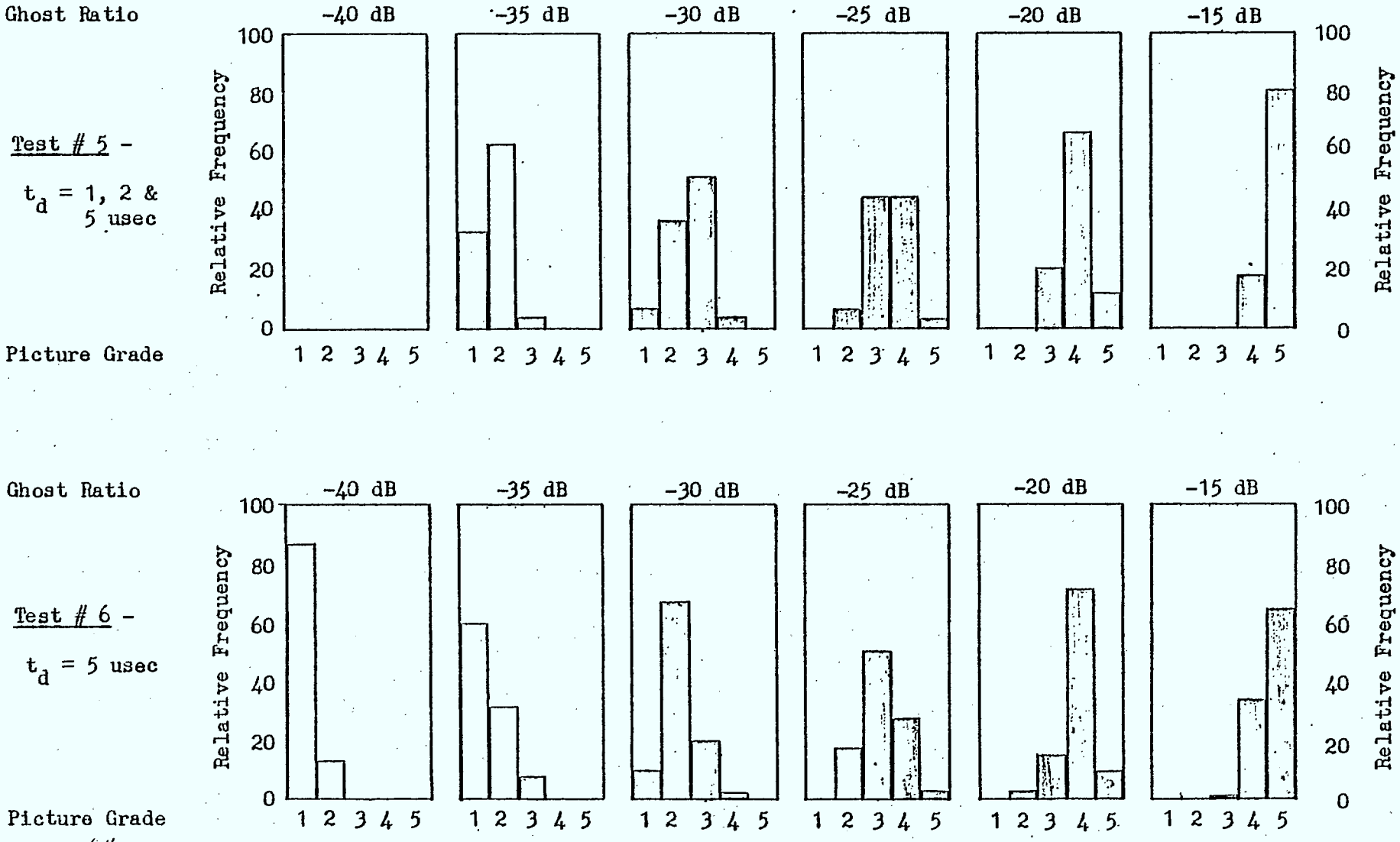


Relative Frequency Histograms

TELEVISION GHOST INVESTIGATION

Evaluation of Subjective Test Results

FIGURE 6

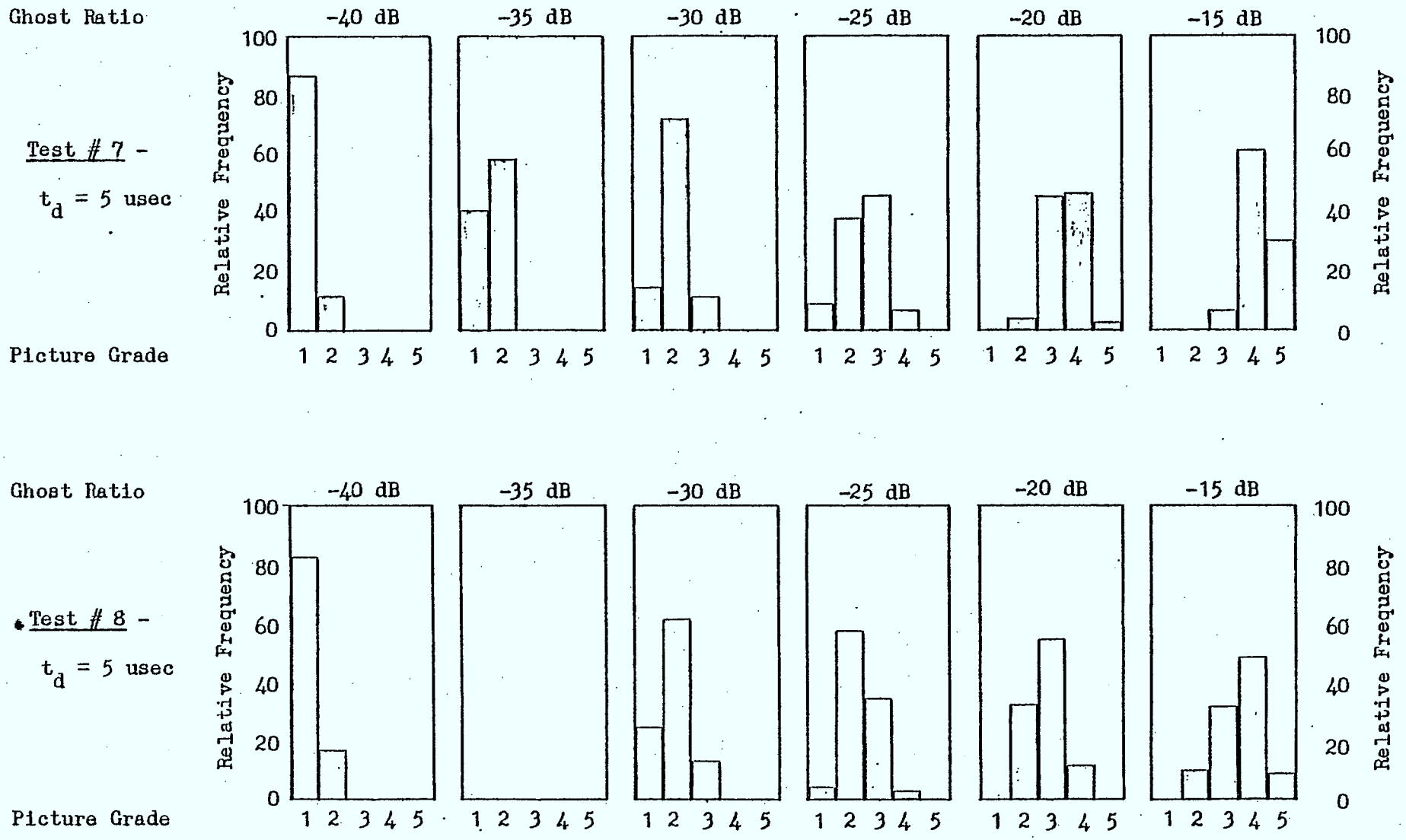


Relative Frequency Histograms

TELEVISION GHOST INVESTIGATION

Evaluation of Subjective Test Results

FIGURE 7

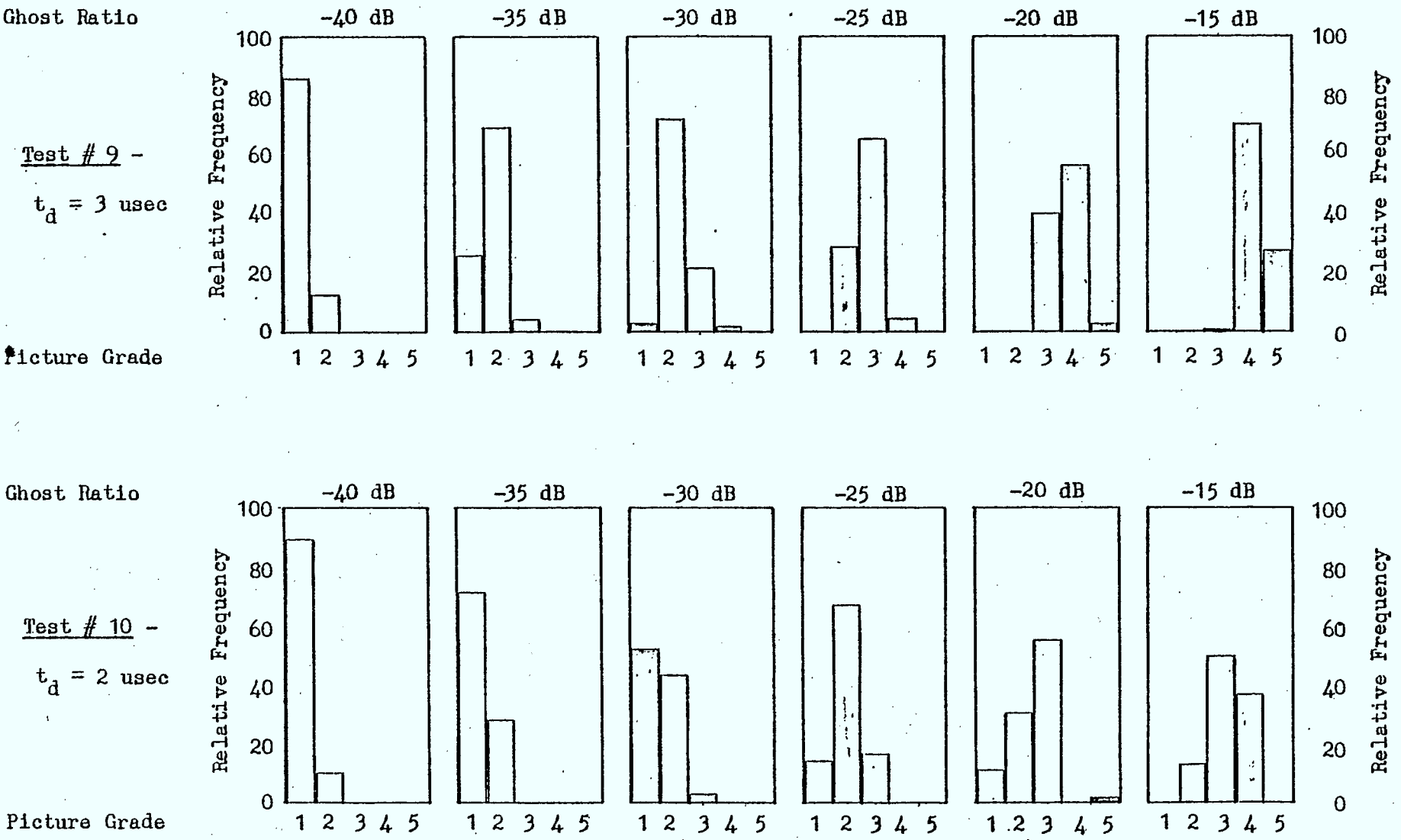


Relative Frequency Histograms

TELEVISION GHOST INVESTIGATION

Evaluation of Subjective Test Results

FIGURE 8



Relative Frequency Histograms

Typical Program Mix: Captions, Sports, Studio, Cartoon, etc.

TELEVISION GHOST INVESTIGATION

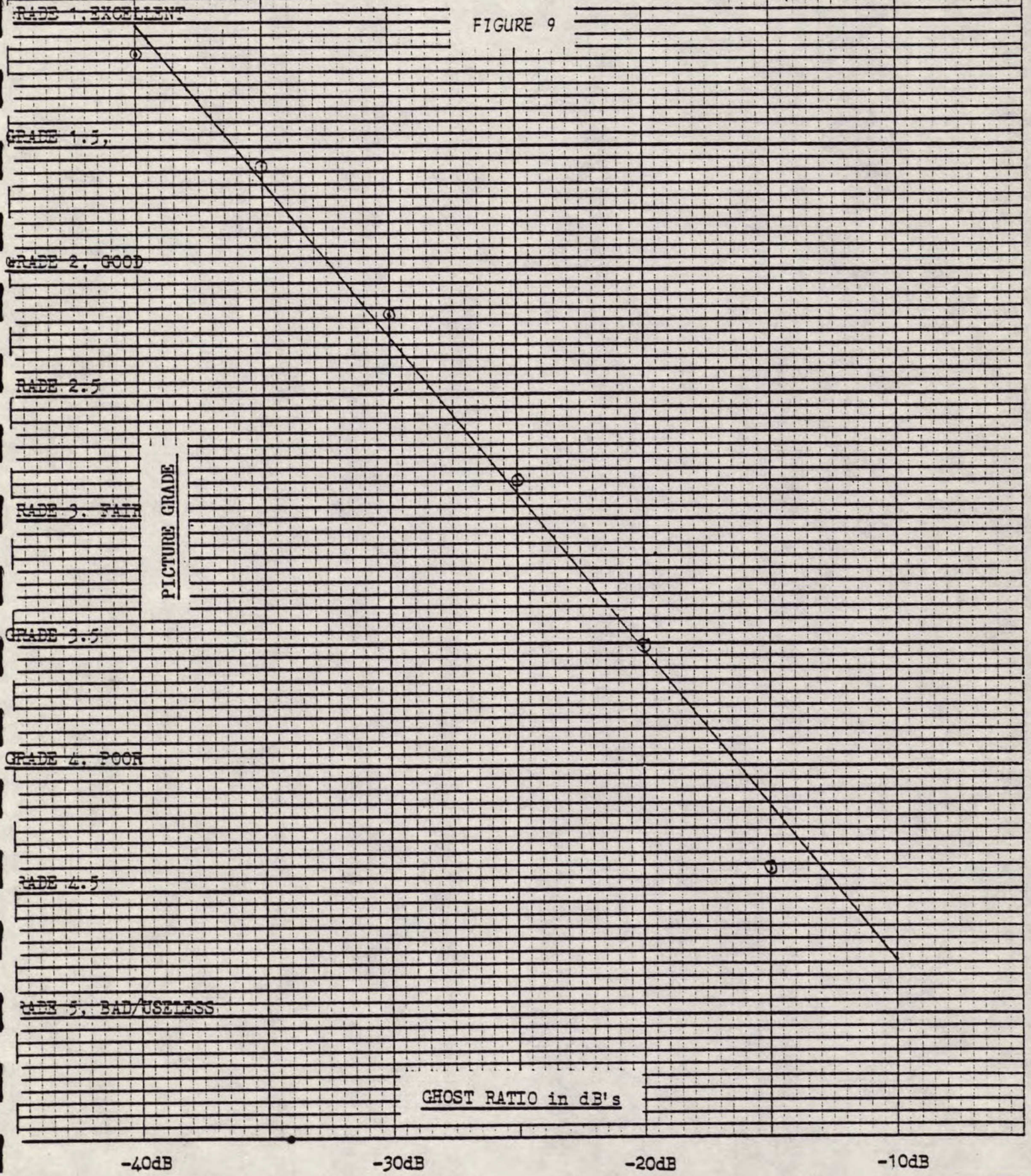
PICTURE GRADE versus GHOST LEVEL

FOR GIVEN PROGRAM MATERIAL

Echo Delay = 5.0 u.Secs.

TEST #1

FIGURE 9



TELEVISION GHOST INVESTIGATION

PICTURE GRADE versus GHOST LEVEL

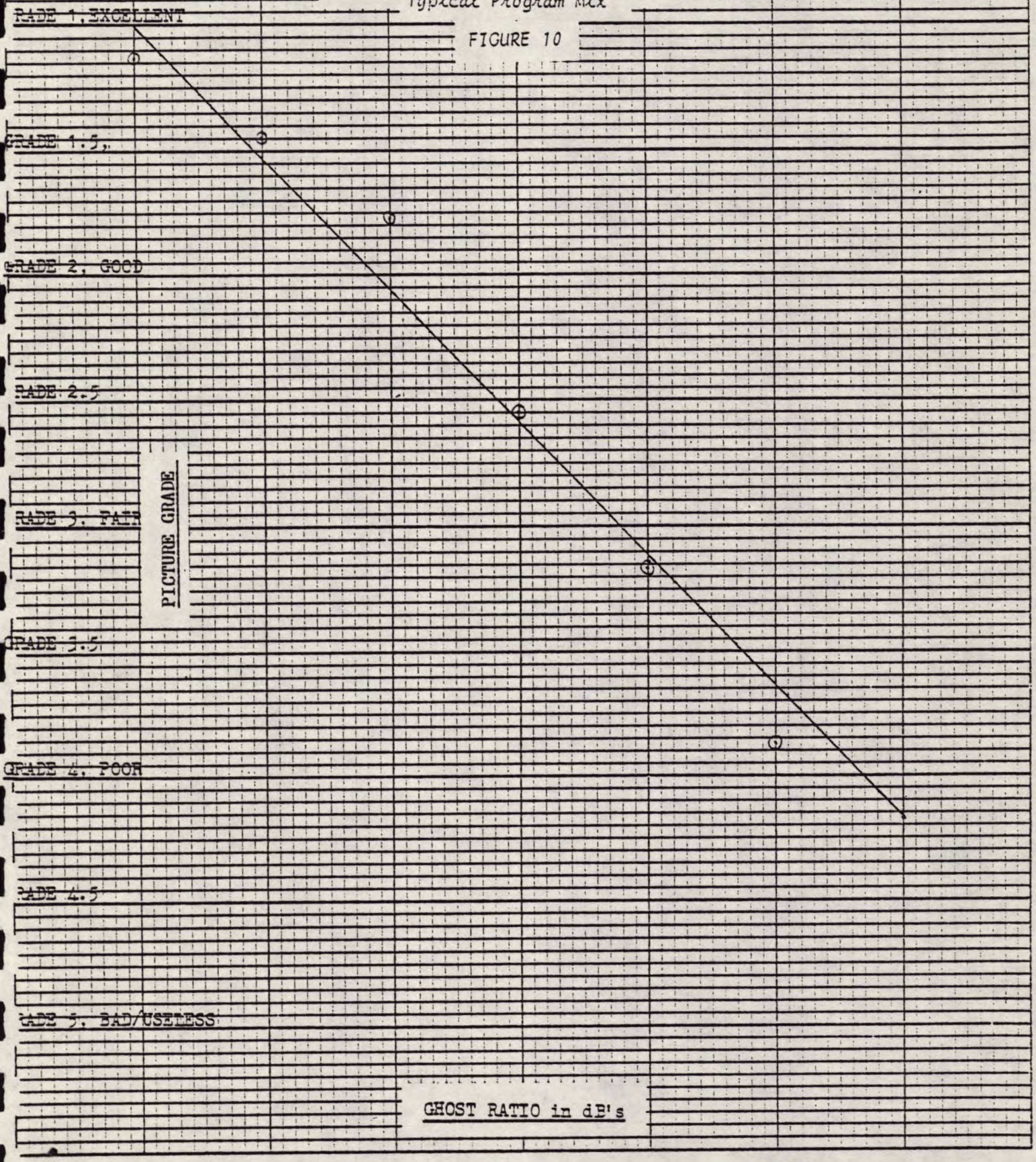
FOR GIVEN PROGRAM MATERIAL

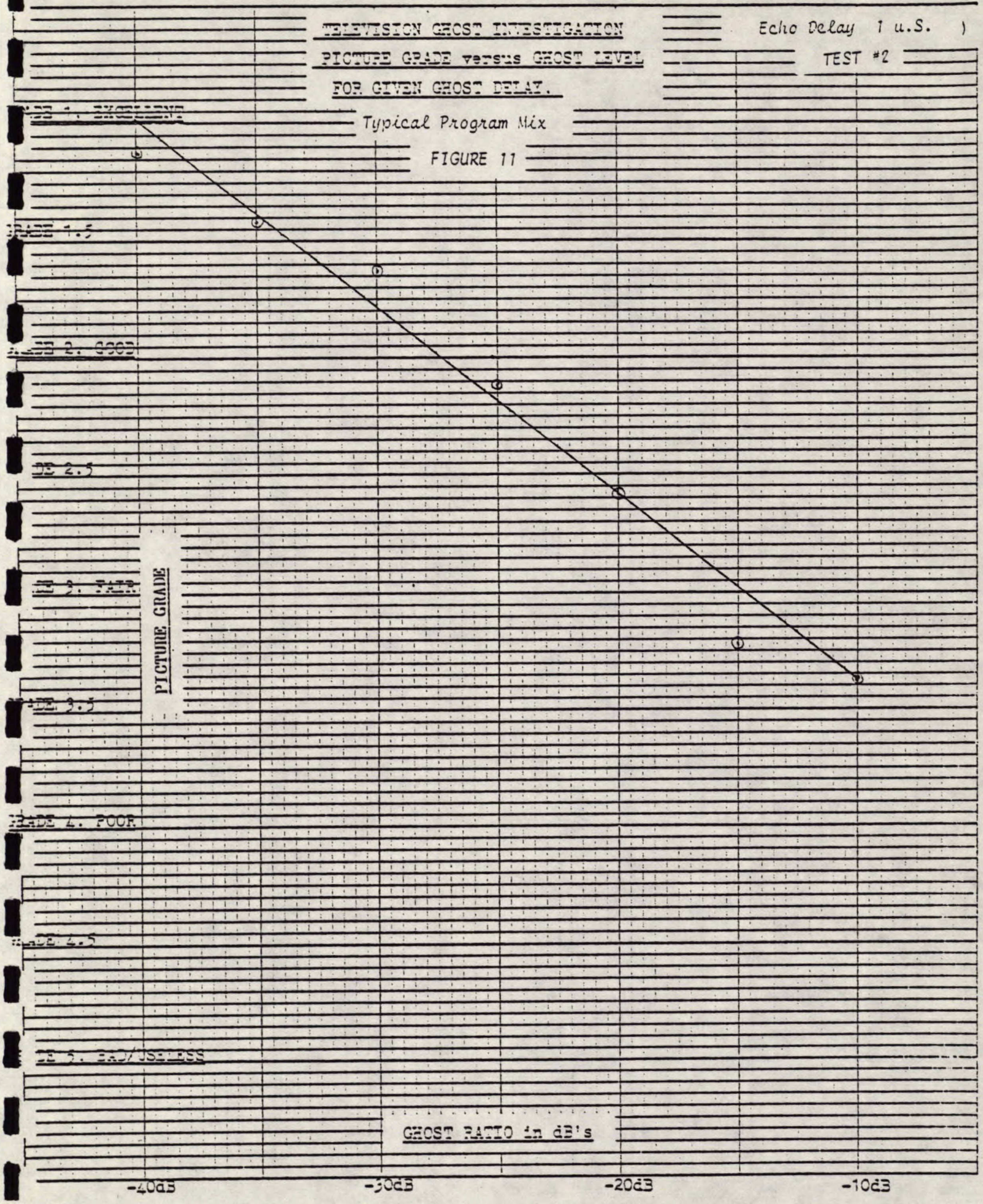
Typical Program Mix

Echo Delay 2 u.S.

TEST #3

FIGURE 10




TELEVISION GHOST INVESTIGATION
PICTURE GRADE versus GHOST LEVEL
FOR GIVEN GHOST DELAY.
Typical Program Mix
FIGURE 11
Echo Delay 1 u.S.)
TEST #2
PICTURE GRADE
GHOST RATIO in dB's
-40dB
-30dB
-20dB
-10dB

TELEVISION GHOST INVESTIGATION

PICTURE GRADE versus GHOST LEVEL

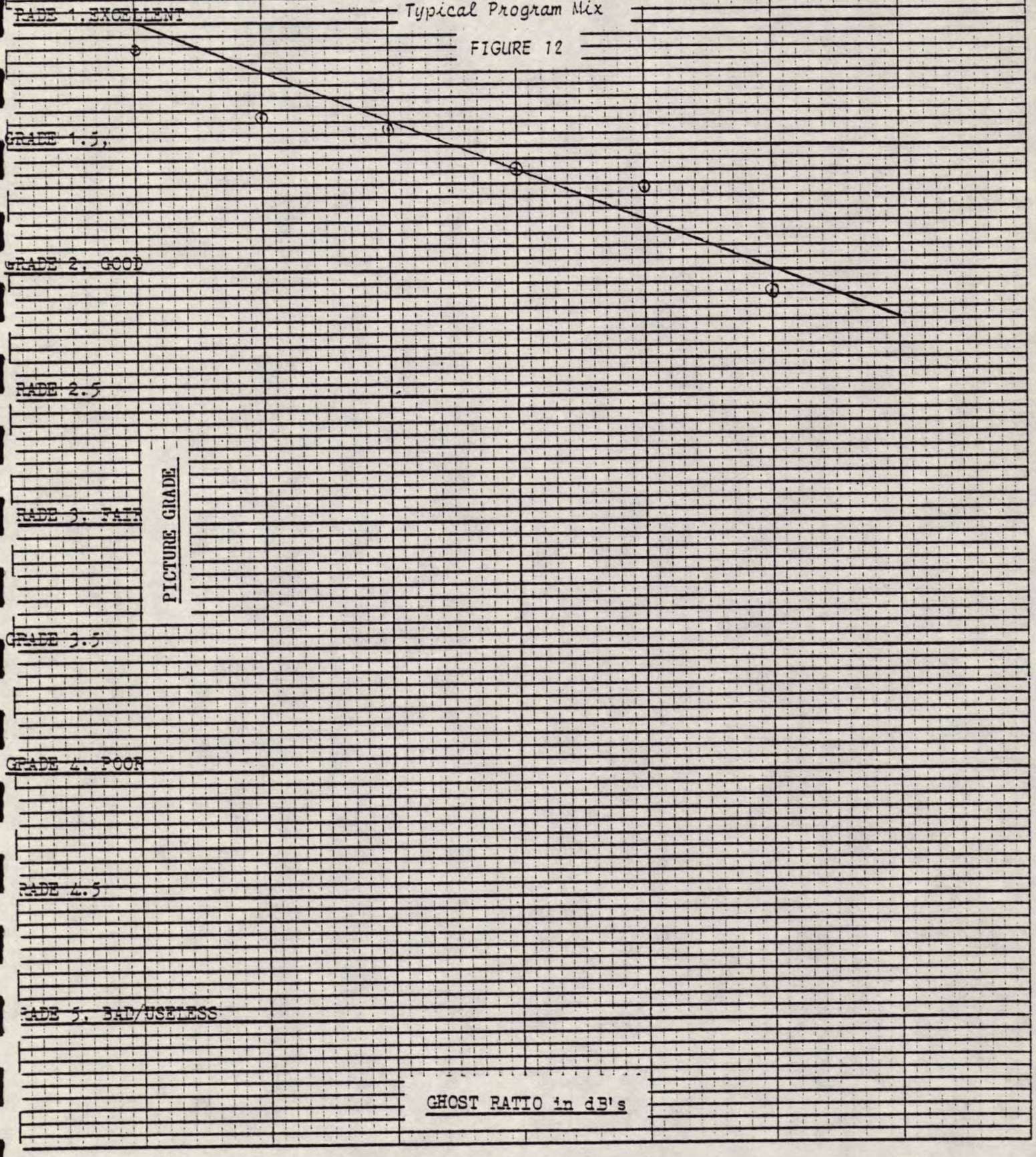
FOR GIVEN PROGRAM MATERIAL

Echo Delay 0.5 u.s.

TEST #4

Typical Program Mix

FIGURE 12



TELEVISION GHOST INVESTIGATION

PICTURE GRADE versus GHOST LEVEL

FOR GIVEN PROGRAM MATERIAL

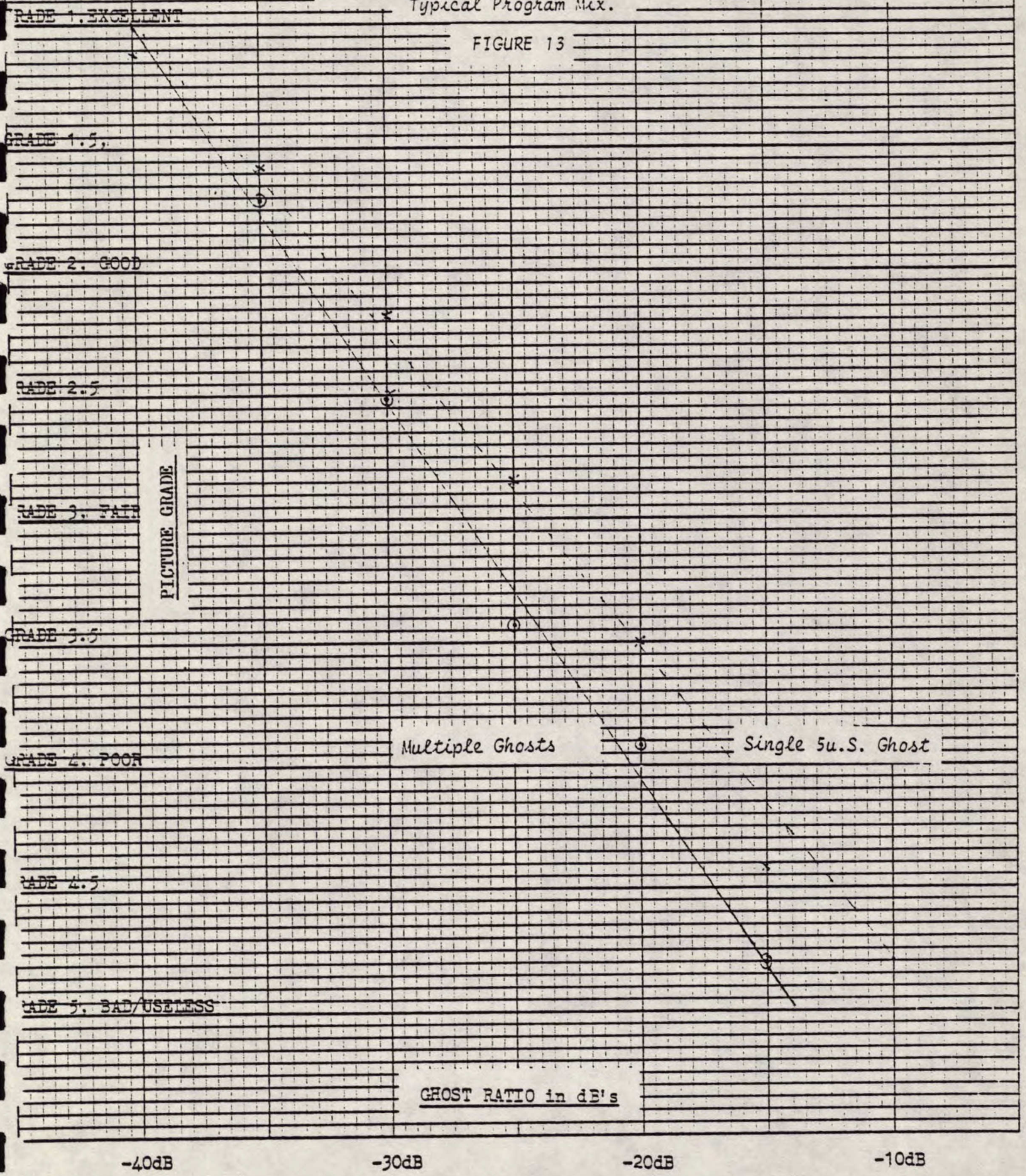
Typical Program Mix.

Multiple Ghosts

Echo Delay 1, 2, & 5u.S.

TEST #5

FIGURE 13



TELEVISION GHOST INVESTIGATION

PICTURE GRADE versus GHOST LEVEL

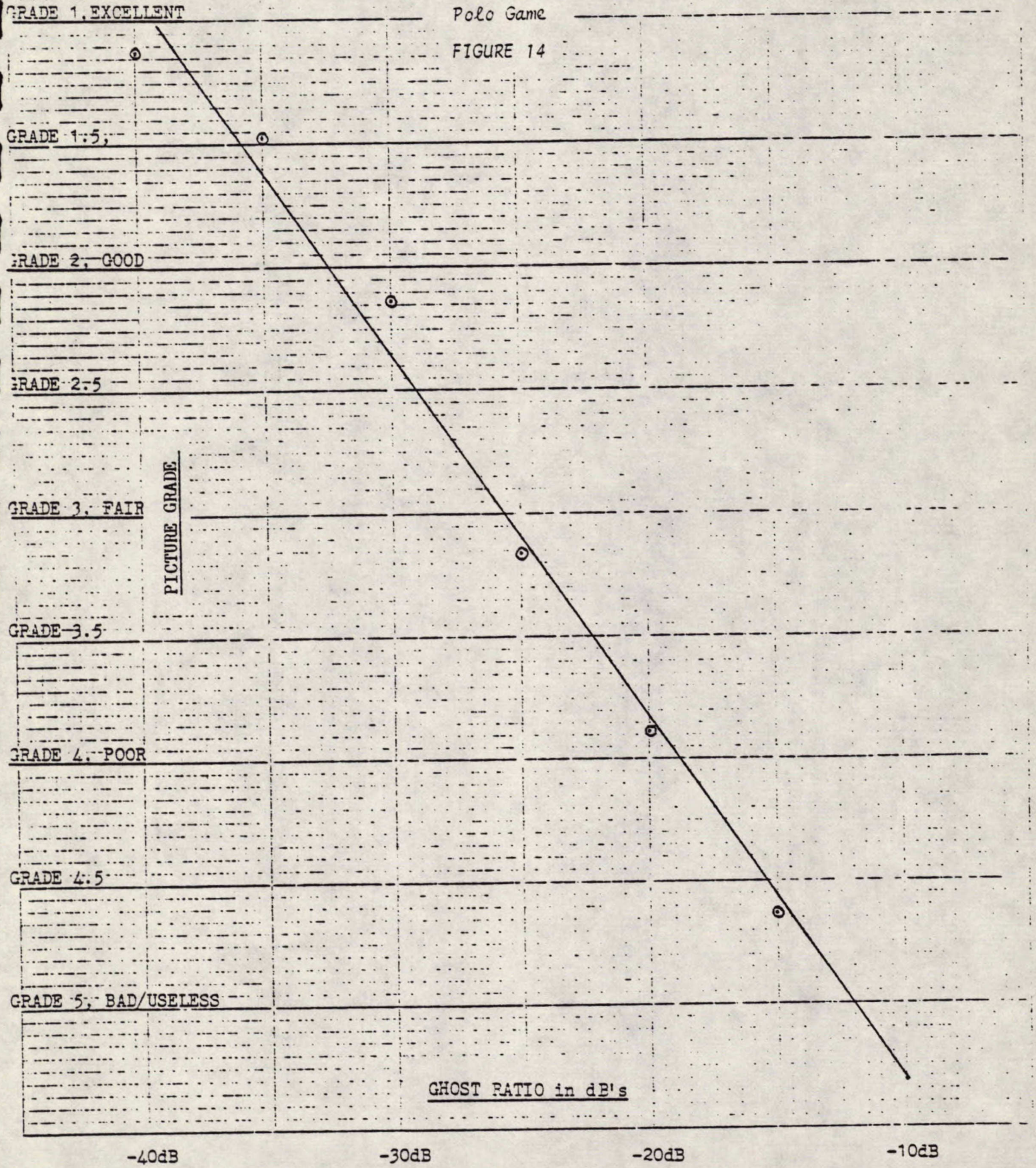
FOR GIVEN PROGRAM MATERIAL

Echo Delay = 5.0 u.Secs.

TEST #6

Polo Game

FIGURE 14



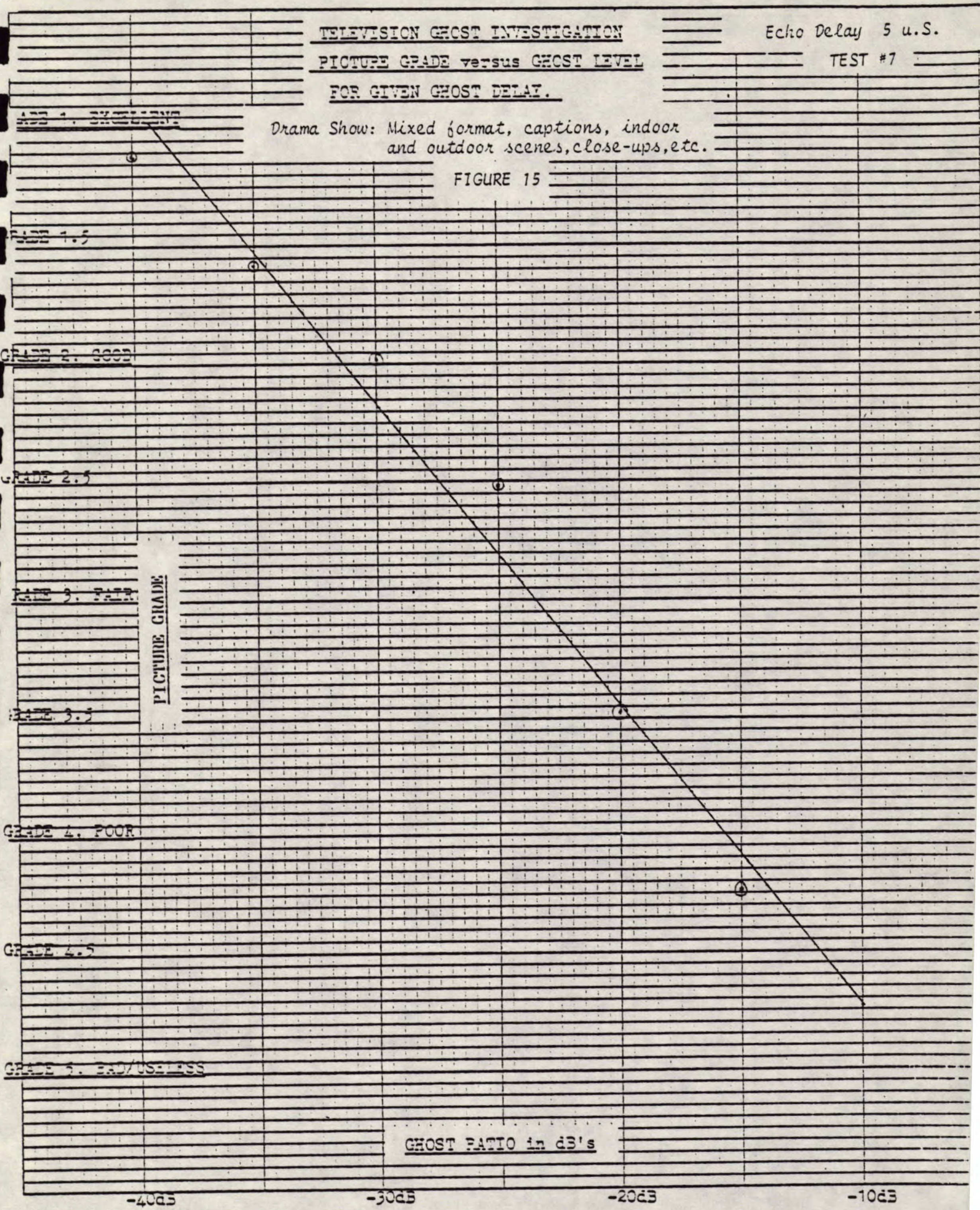

TELEVISION GHOST INVESTIGATION
PICTURE GRADE versus GHOST LEVEL
FOR GIVEN GHOST DELAY.
Echo Delay 5 u.S.
TEST #7
Drama Show: Mixed format, captions, indoor and outdoor scenes, close-ups, etc.
GRADE 1. EXCELLENT
GRADE 1.5
GRADE 2. GOOD
GRADE 2.5
GRADE 3. FAIR
GRADE 3.5
GRADE 4. POOR
GRADE 4.5
GRADE 5. BAD/USELESS
PICTURE GRADE
GHOST RATIO in dB's
-40dB
-30dB
-20dB
-10dB

FIGURE 15

TELEVISION GHOST INVESTIGATION

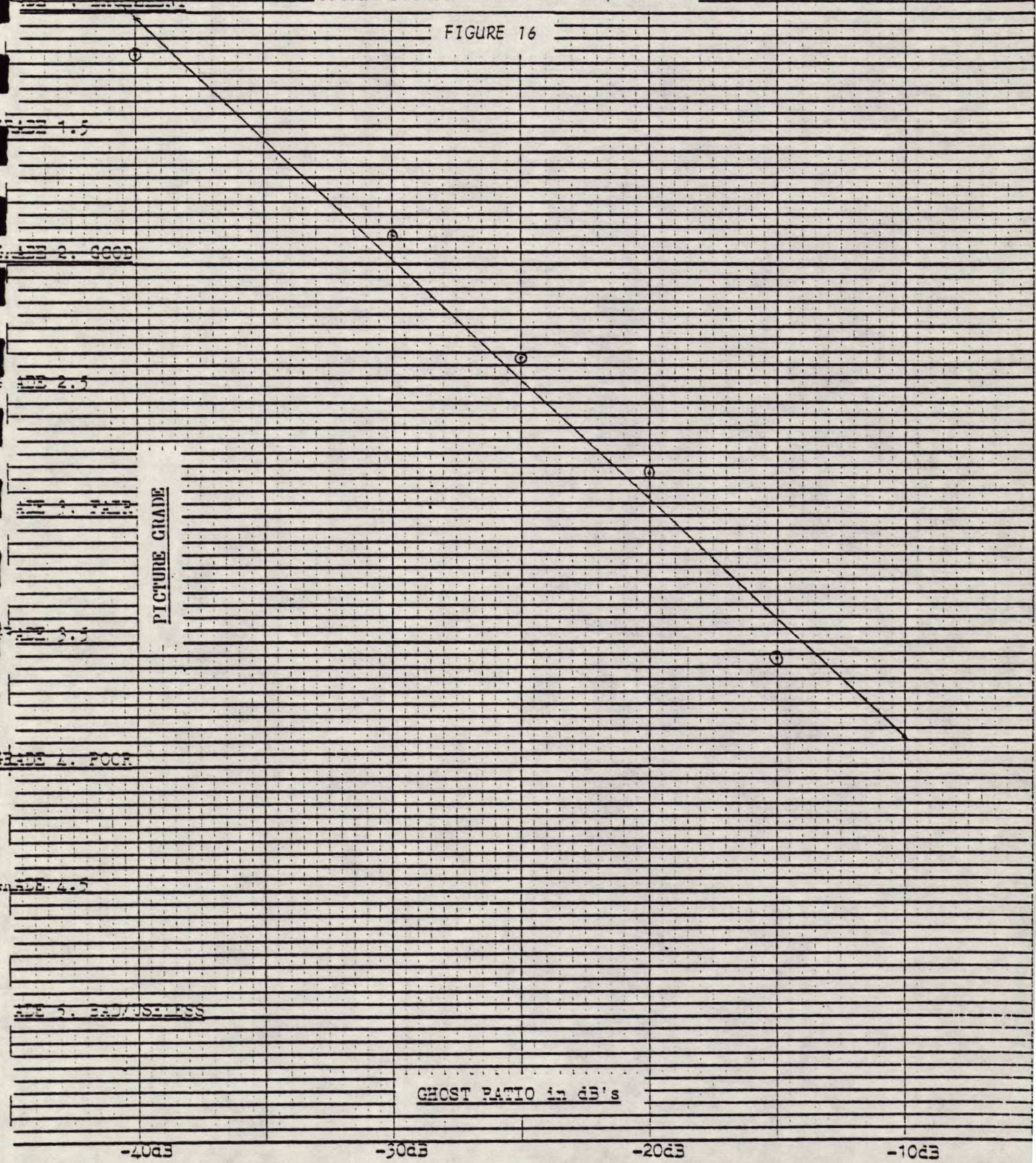
PICTURE GRADE versus GHOST LEVEL

Echo Delay 5 u.s.

TEST #8

Colour Stills: Mixed Landscapes, etc.

FIGURE 16



TELEVISION GHOST INVESTIGATION

PICTURE GRADE versus GHOST LEVEL

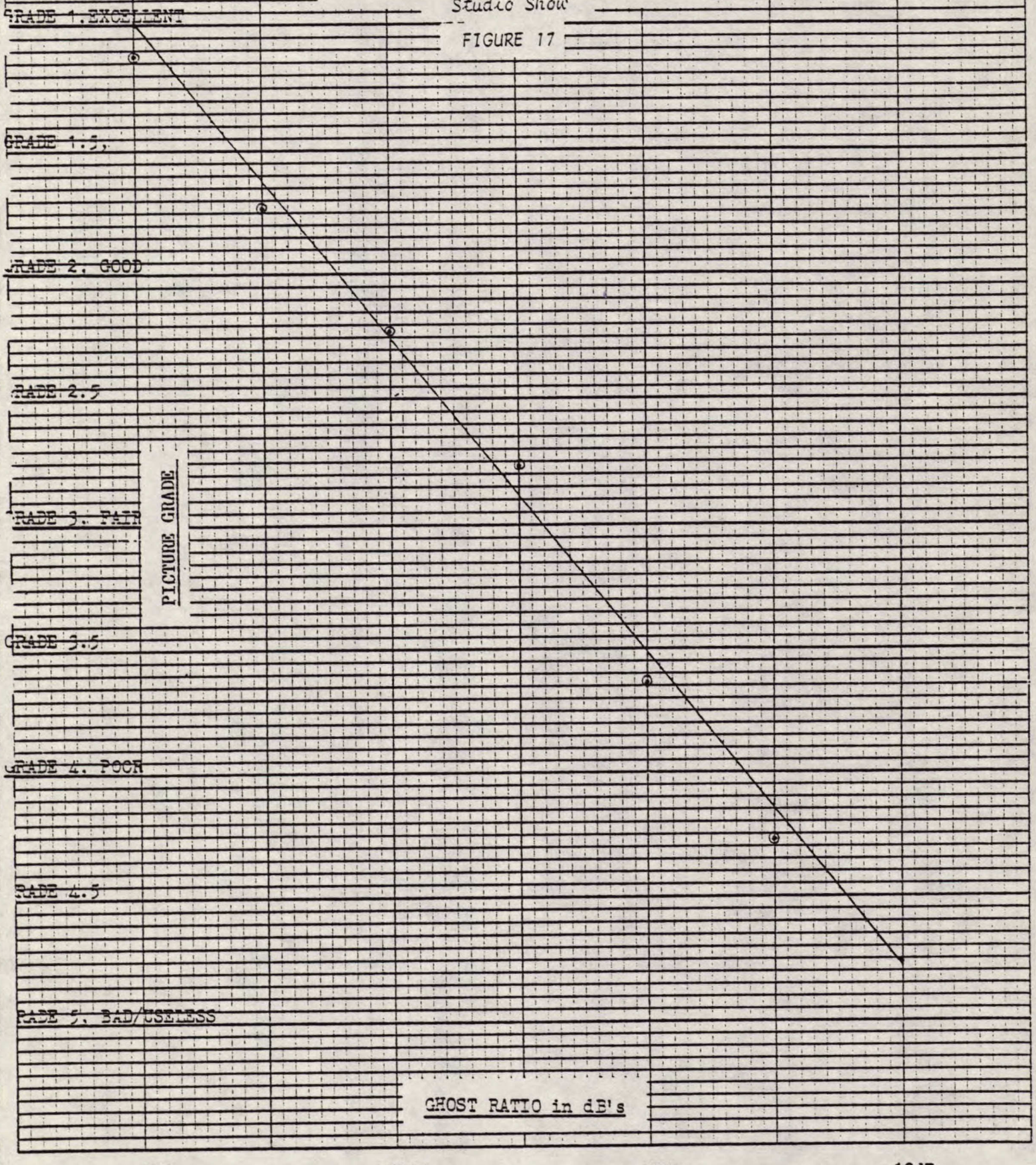
FOR GIVEN PROGRAM MATERIAL

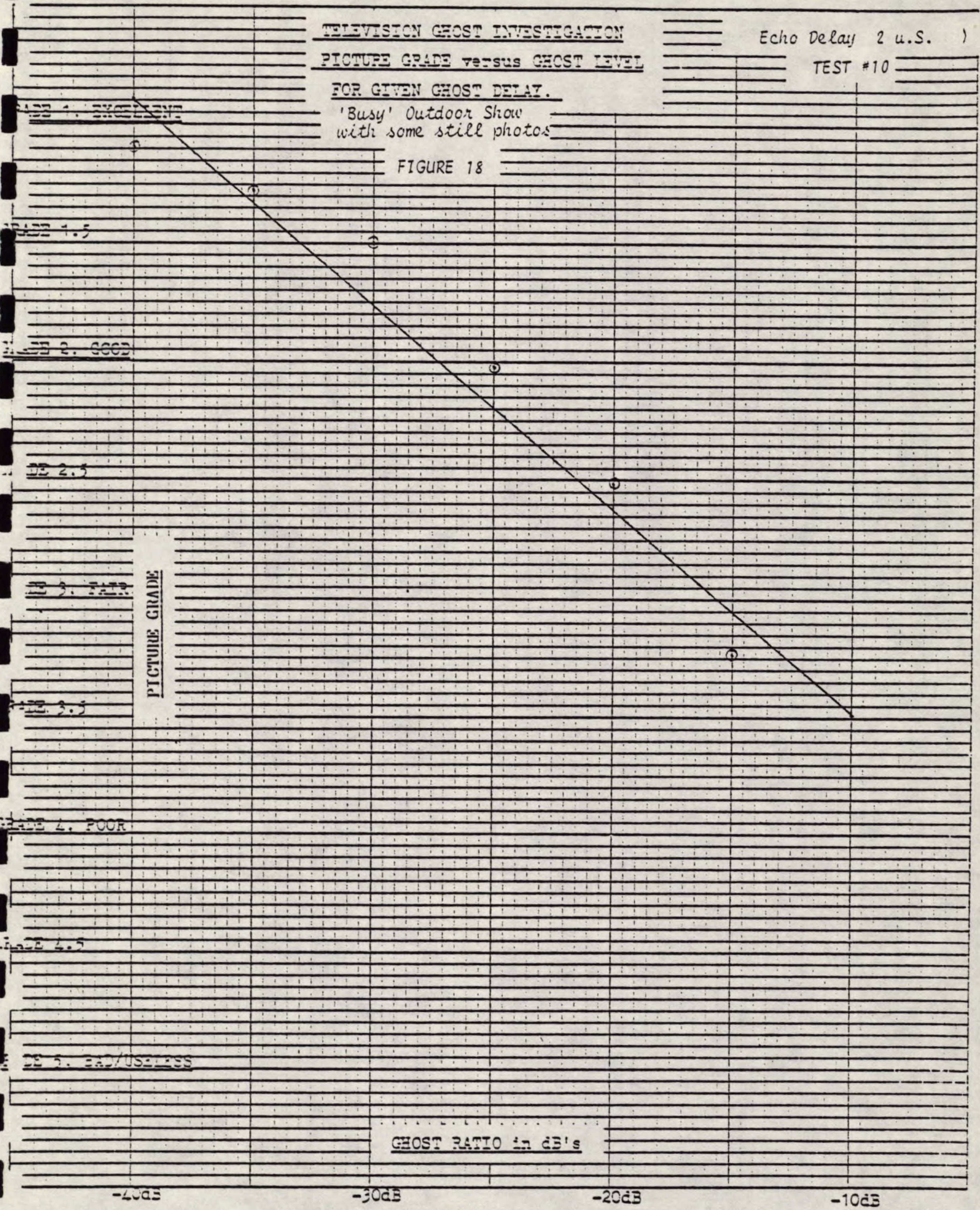
Studio Show

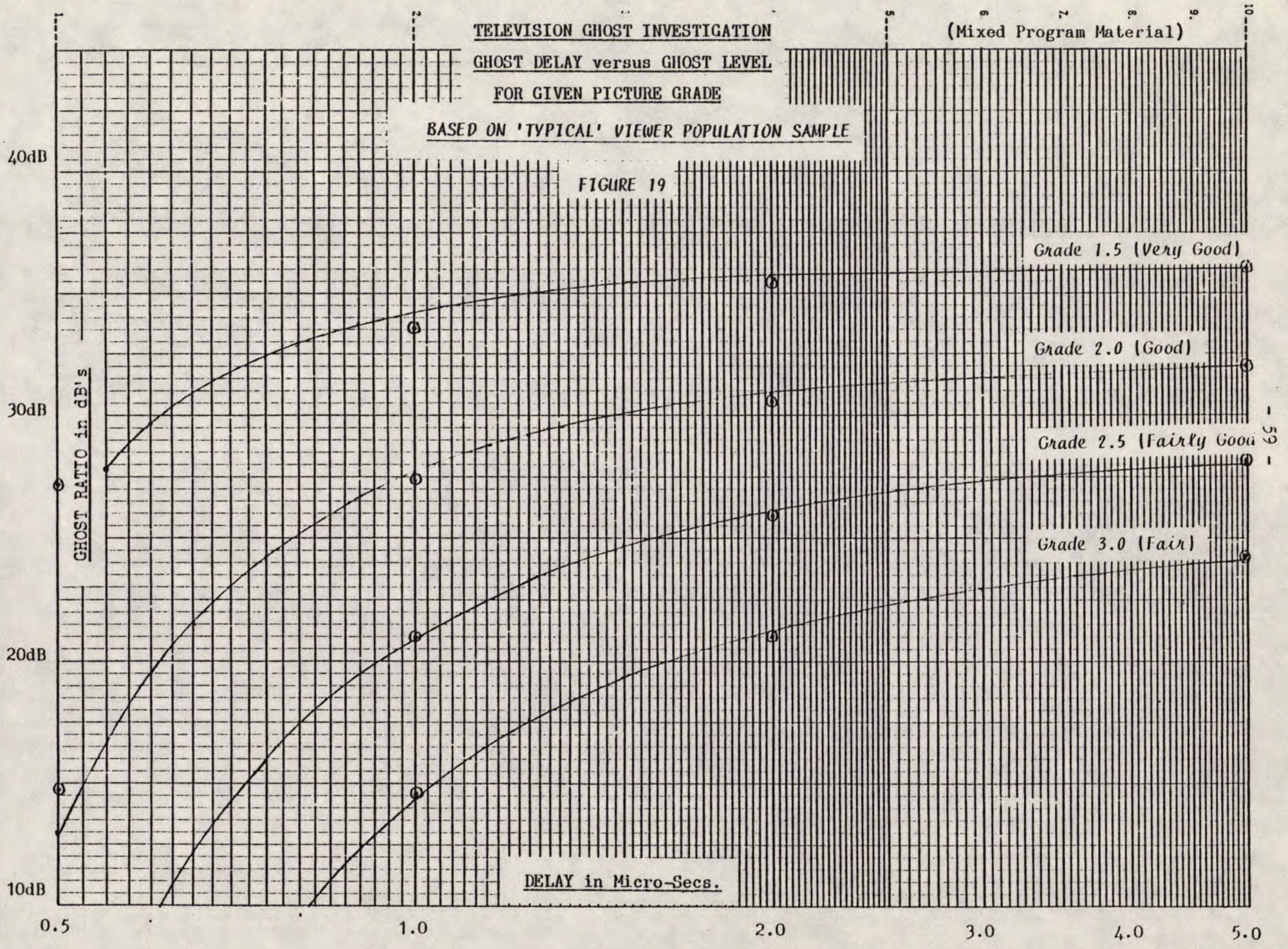
Echo Delay 3 u.s.

TEST #9

FIGURE 17




TELEVISION GHOST INVESTIGATION
PICTURE GRADE versus GHOST LEVEL
FOR GIVEN GHOST DELAY.
'Busy' Outdoor Show
with some still photos
Echo Delay 2 u.S.
TEST #10
FIGURE 18
PICTURE GRADE
GHOST RATIO in dB's
-40dB
-30dB
-20dB
-10dB



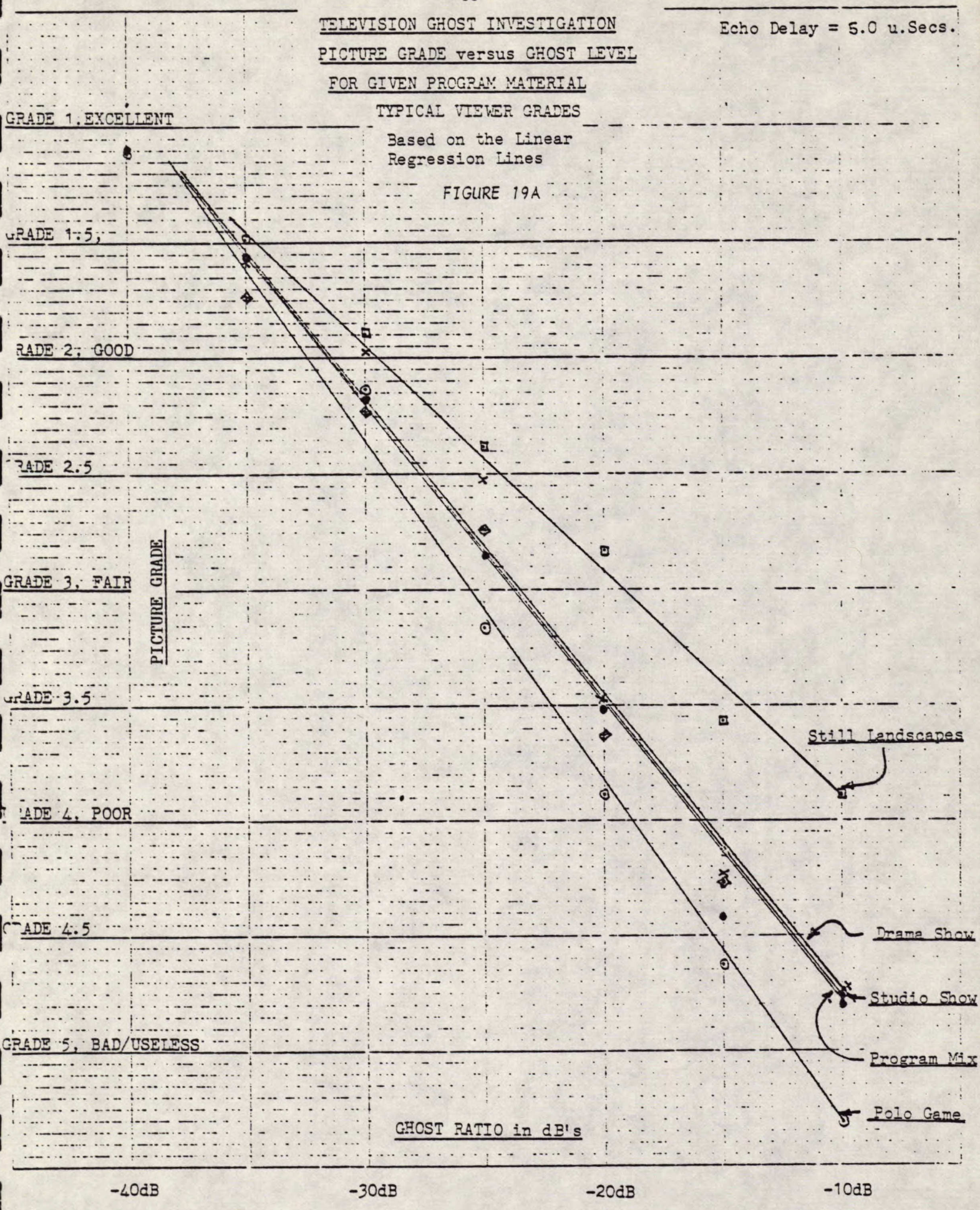
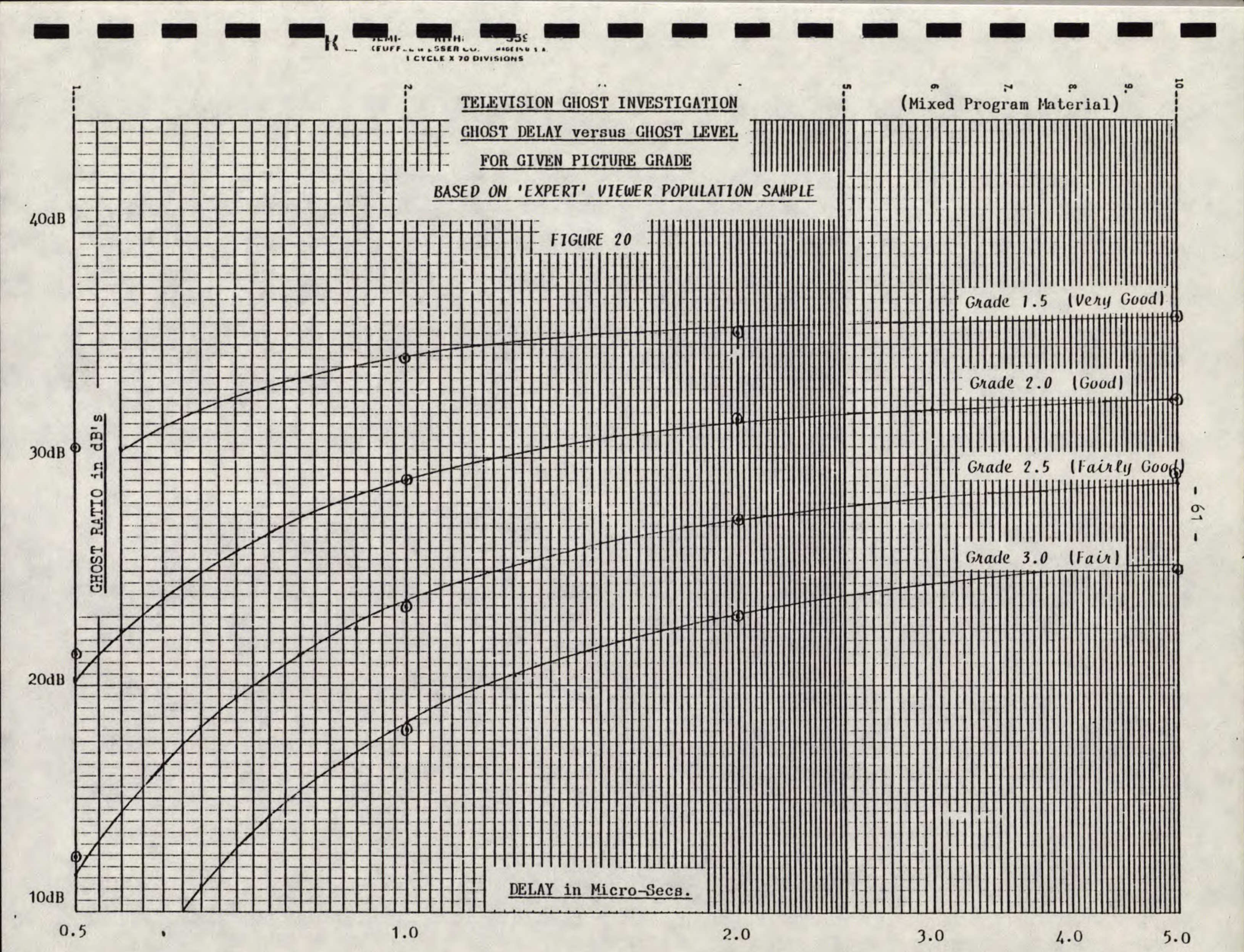
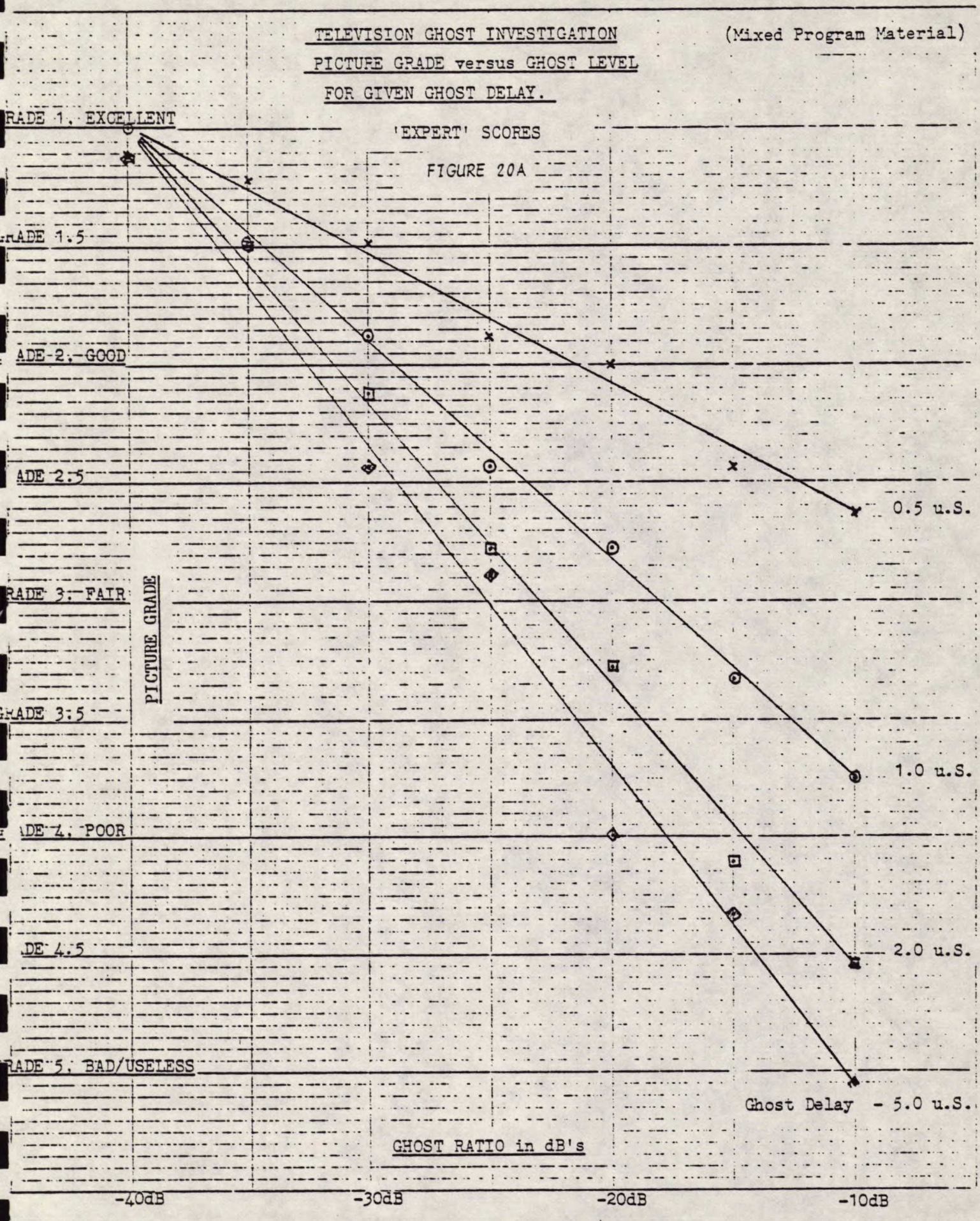

TELEVISION GHOST INVESTIGATION
PICTURE GRADE versus GHOST LEVEL
FOR GIVEN PROGRAM MATERIAL
TYPICAL VIEWER GRADES
Based on the Linear Regression Lines
Echo Delay = 5.0 u.Secs.
GRADE 1. EXCELLENT
GRADE 1.5,
RADE 2, GOOD
RADE 2.5
GRADE 3, FAIR
GRADE 3.5
ADE 4, POOR
ADE 4.5
GRADE 5, BAD/USELESS
PICTURE GRADE
Still Landscapes
Drama Show
Studio Show
Program Mix
Polo Game
GHOST RATIO in dB's
-40dB
-30dB
-20dB
-10dB

FIGURE 19A




TELEVISION GHOST INVESTIGATION
(Mixed Program Material)
PICTURE GRADE versus GHOST LEVEL
FOR GIVEN GHOST DELAY.
'EXPERT' SCORES
FIGURE 20A
RADE 1. EXCELLENT
GRADE 1.5
ADE 2. GOOD
ADE 2.5
RADE 3. FAIR
GRADE 3.5
DE 4. POOR
DE 4.5
RADE 5. BAD/USELESS
PICTURE GRADE
0.5 u.S.
1.0 u.S.
2.0 u.S.
Ghost Delay - 5.0 u.S.
GHOST RATIO in dB's
-40dB
-30dB
-20dB
-10dB

F.M. MULTIPATH DISTORTION INVESTIGATION.

NOISE & DISTORTION - MAIN CHANNEL

Echo Signal Delayed - 2 u.Sec.

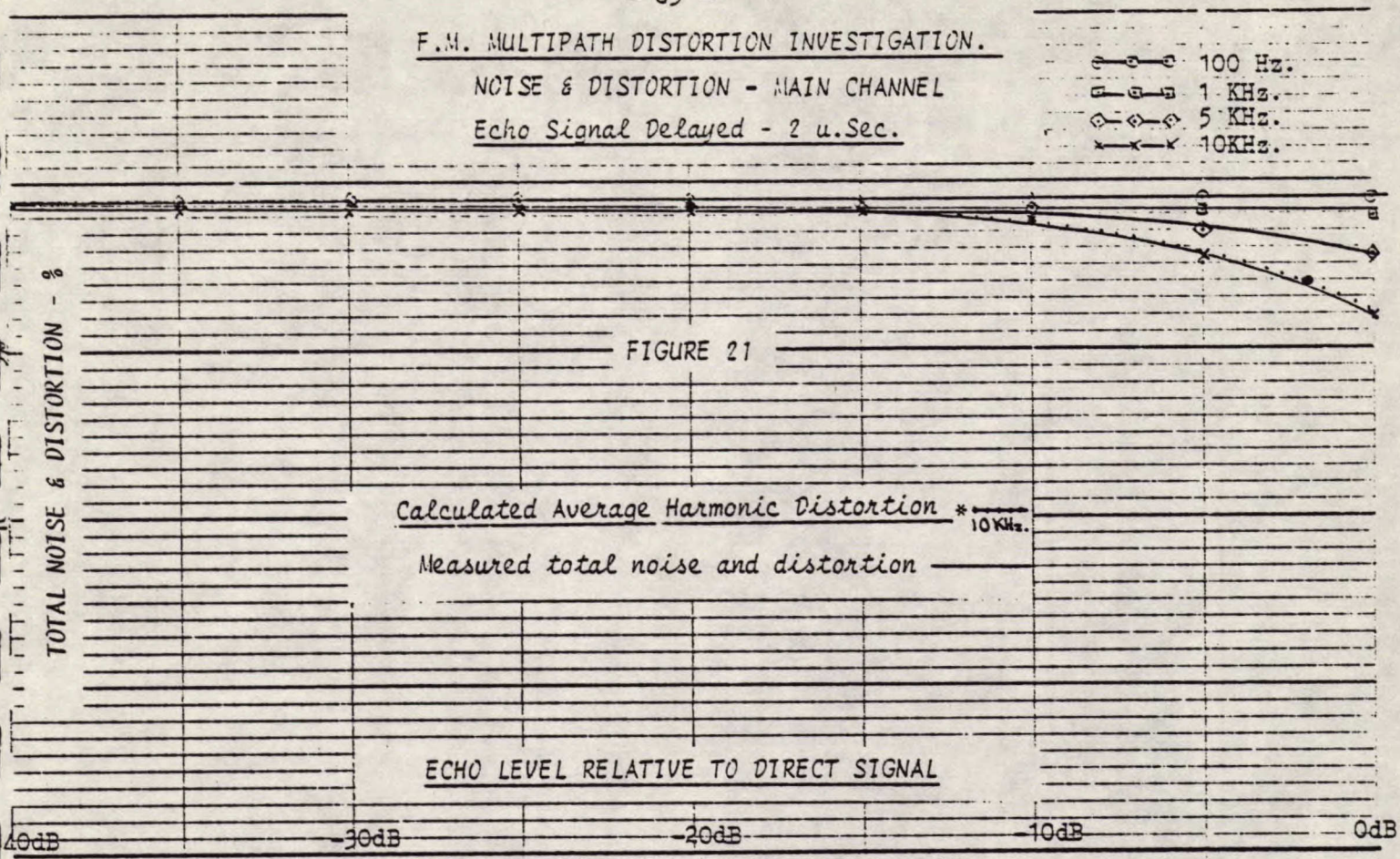


FIGURE 21

Calculated Average Harmonic Distortion * 10KHz.

Measured total noise and distortion

ECHO LEVEL RELATIVE TO DIRECT SIGNAL

F.M. MULTIPATH DISTORTION INVESTIGATION.

NOISE & DISTORTION - MAIN CHANNEL

Echo Signal Delayed - 5 u.Sec.

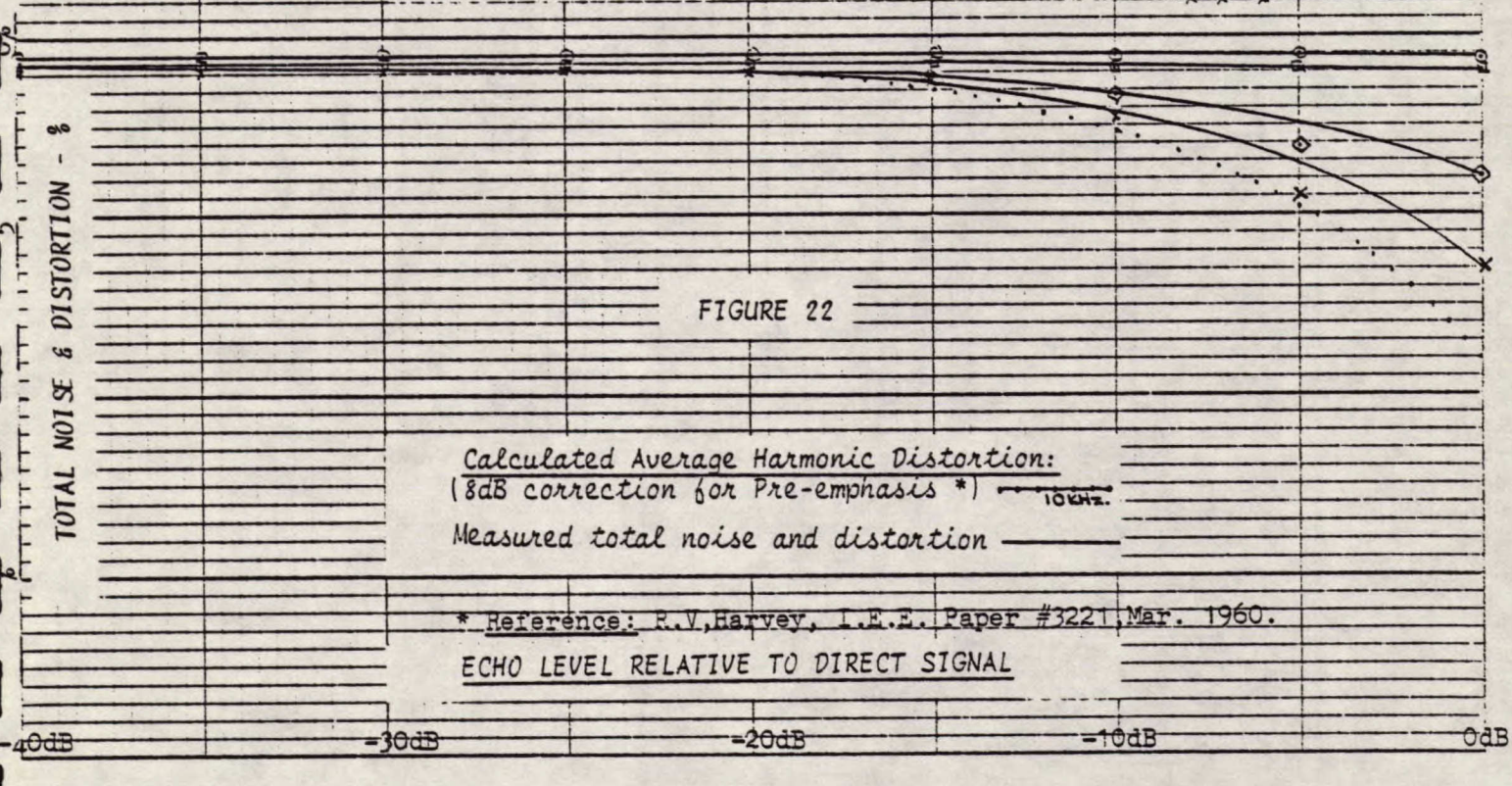


FIGURE 22

Calculated Average Harmonic Distortion:
(8dB correction for Pre-emphasis *) 10KHz.

Measured total noise and distortion

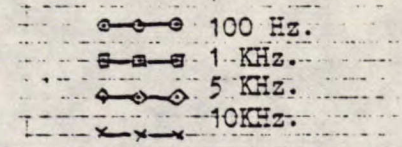
* Reference: R.V.Harvey, I.E.E. Paper #3221, Mar. 1960.

ECHO LEVEL RELATIVE TO DIRECT SIGNAL

F.M. MULTIPATH DISTORTION INVESTIGATION

NOISE & DISTORTION - STEREO CHANNEL

Echo Signal Delayed by 2 u.S.



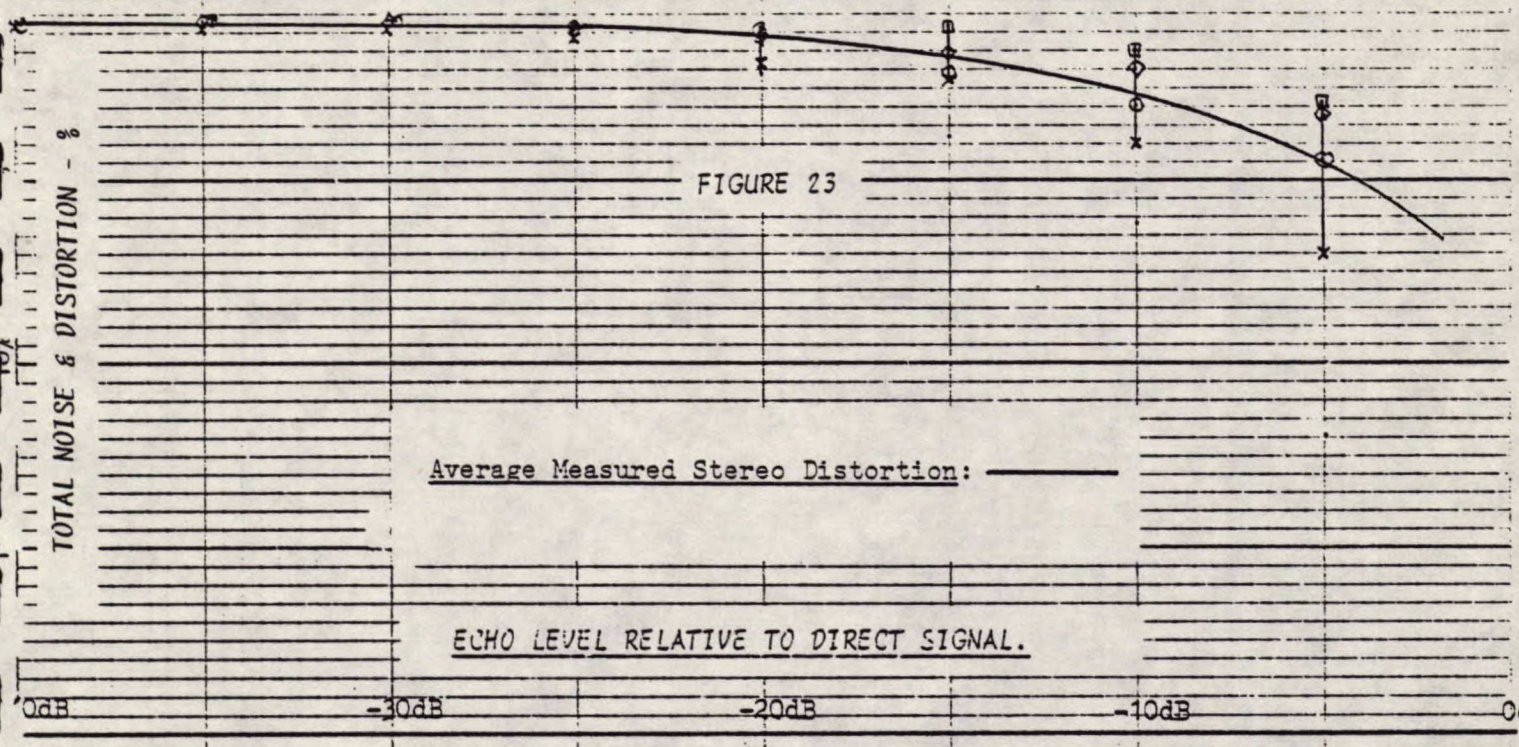


FIGURE 23

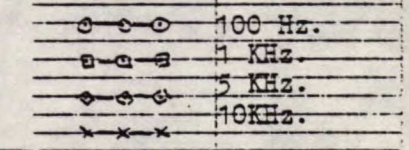
Average Measured Stereo Distortion: ———

ECHO LEVEL RELATIVE TO DIRECT SIGNAL.

F.M.MULTIPATH DISTORTION INVESTIGATION

NOISE & DISTORTION - STEREO CHANNEL

Echo Signal Delayed by 5 u.S.



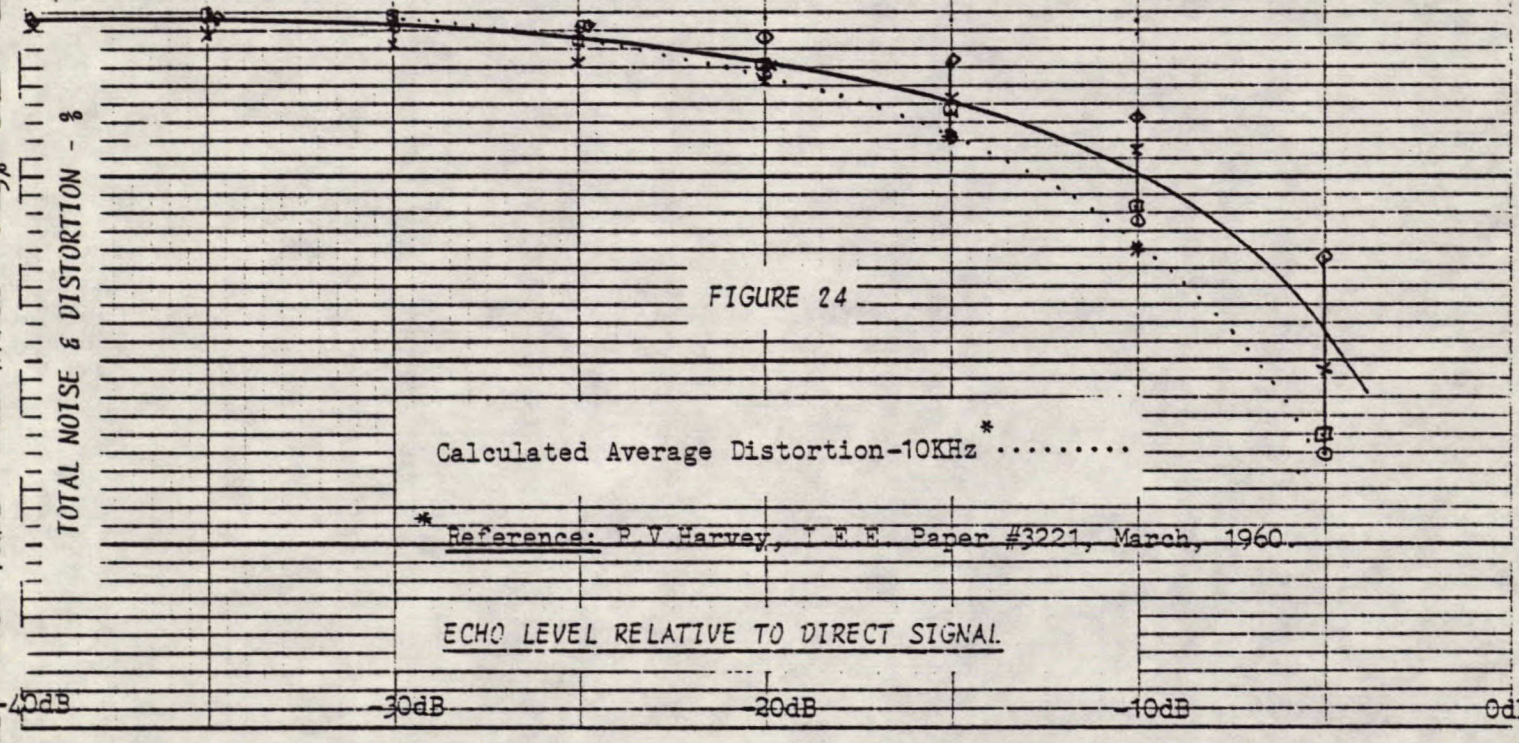


FIGURE 24

Calculated Average Distortion-10KHz* .....

* Reference: P.V.Harvey, I.E.E. Paper #3221, March, 1960.

ECHO LEVEL RELATIVE TO DIRECT SIGNAL

F.M. MULTIPATH DISTORTION INVESTIGATION

STEREO CHANNEL SEPARATION - LEFT/RIGHT

Echo Signal Delayed by 2 u.S.

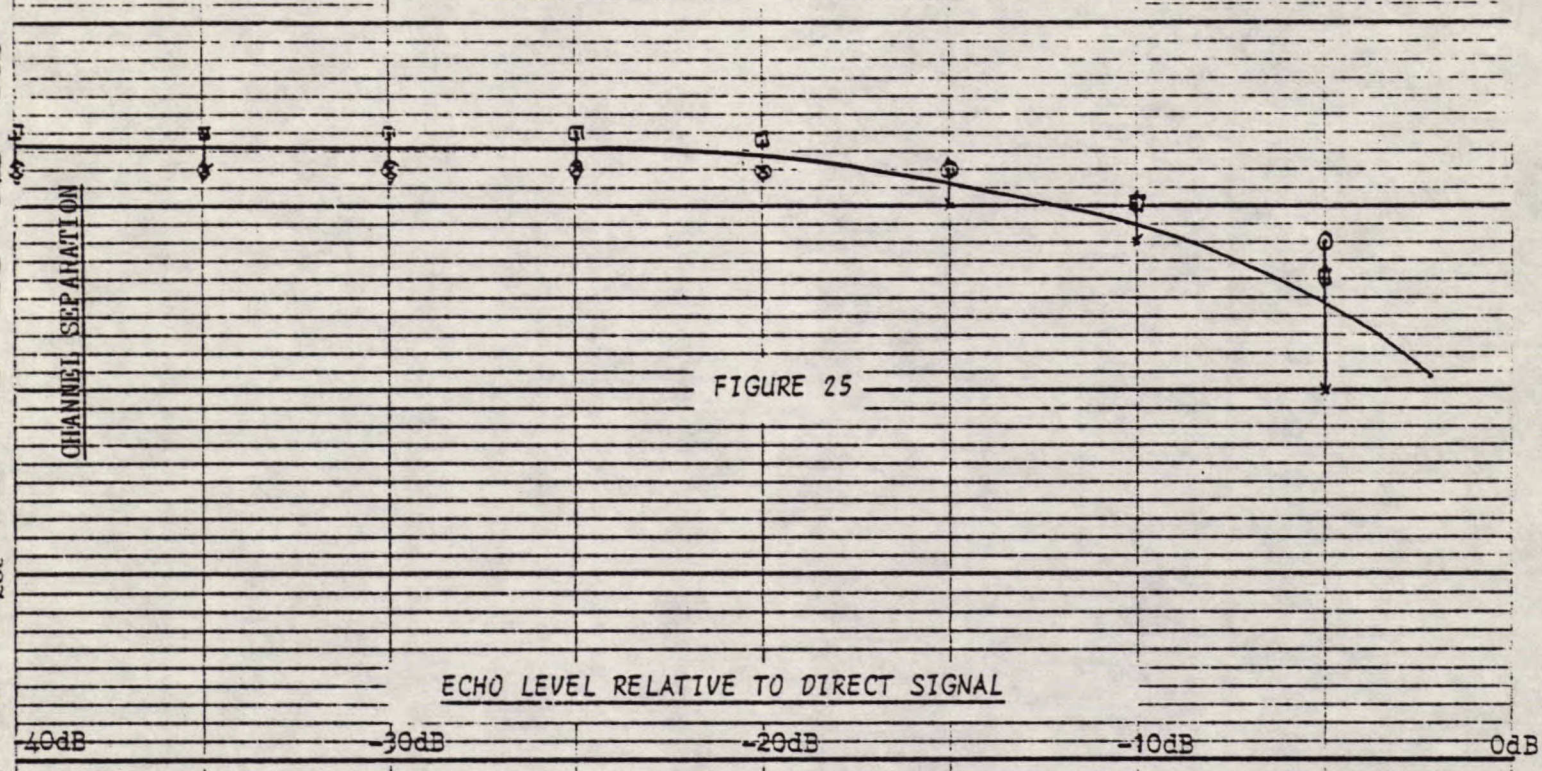


FIGURE 25

STEREO CHANNEL SEPARATION - LEFT/RIGHT

Echo Signal Delayed by 5 u.S.

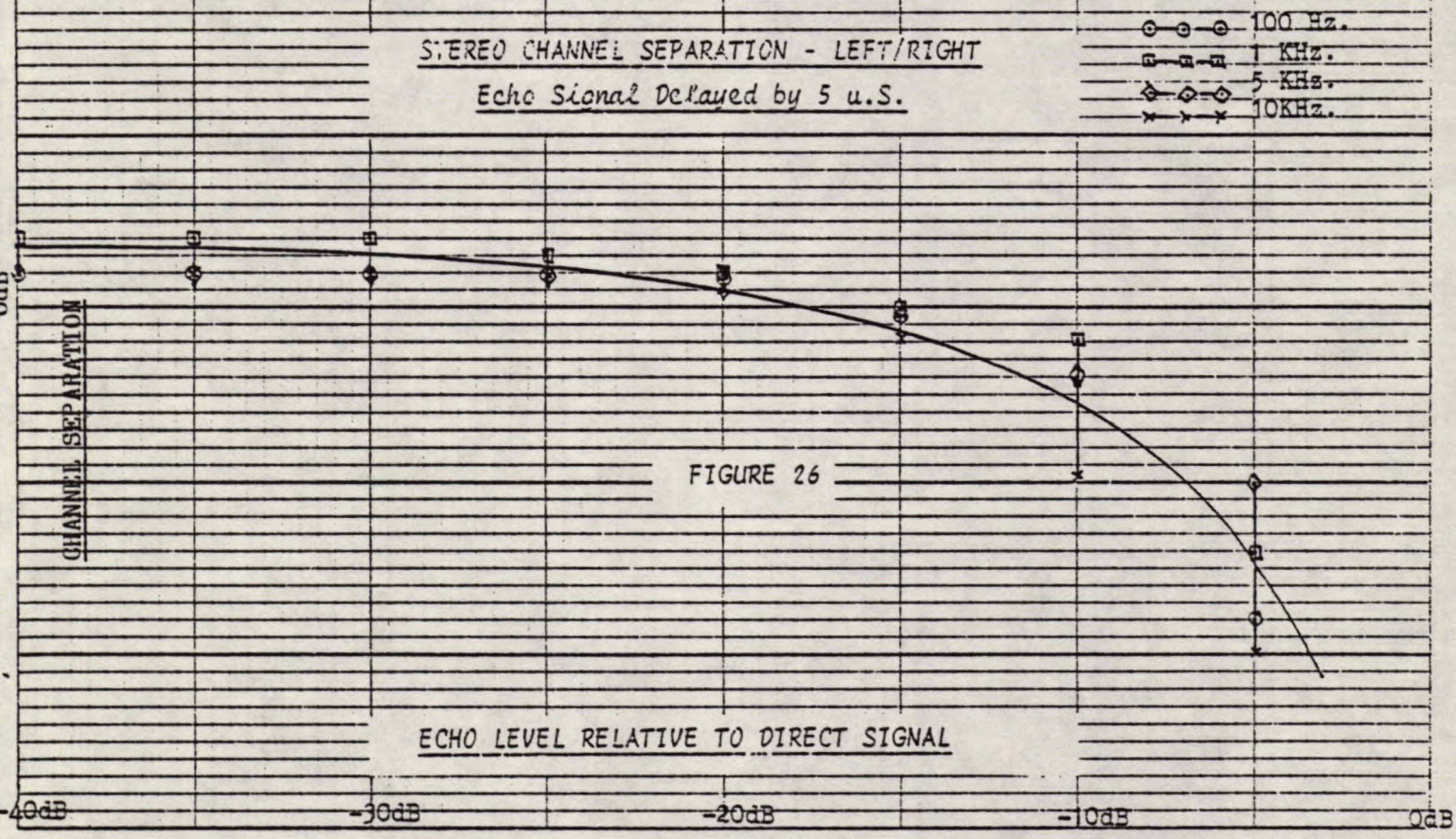


FIGURE 26

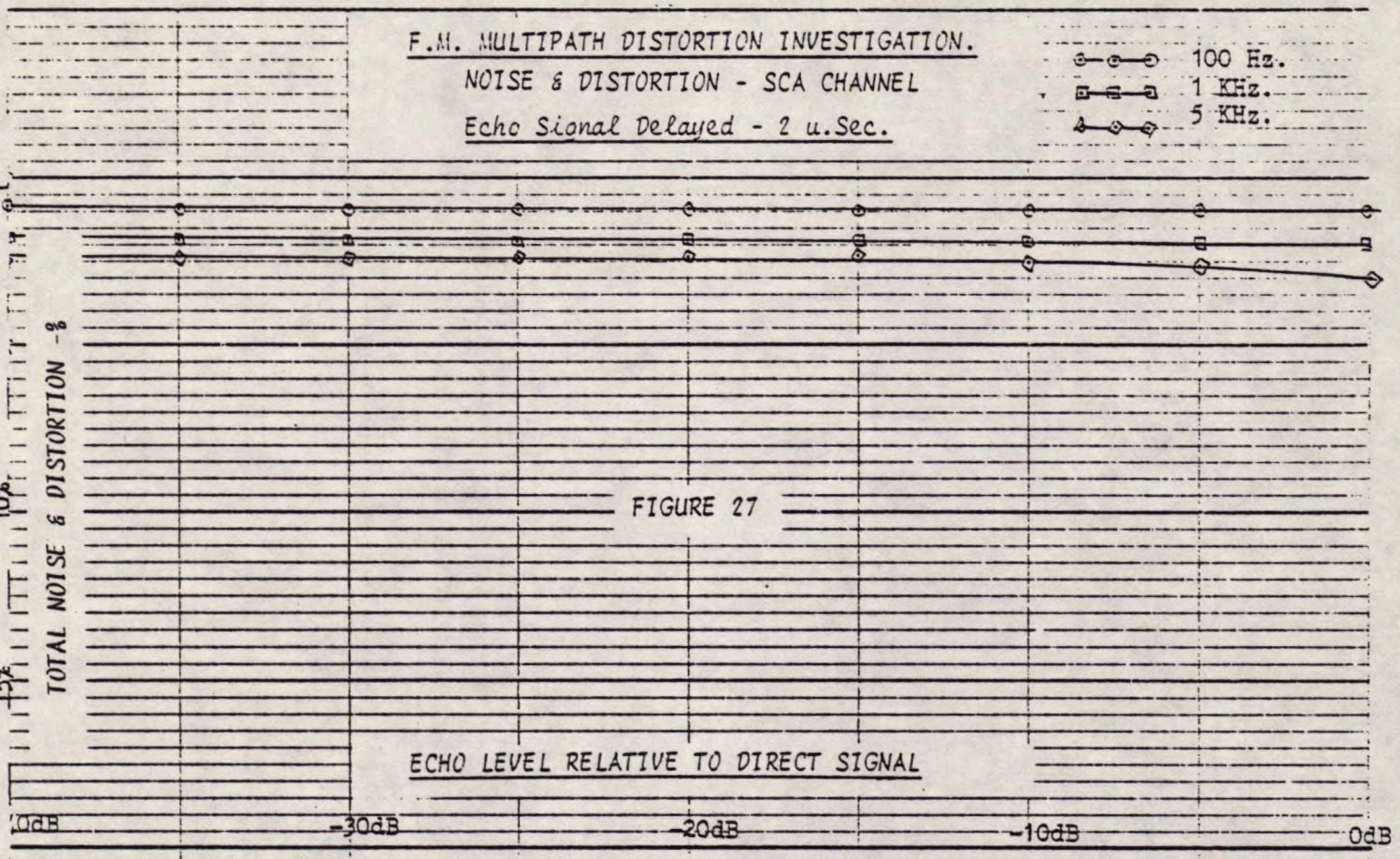
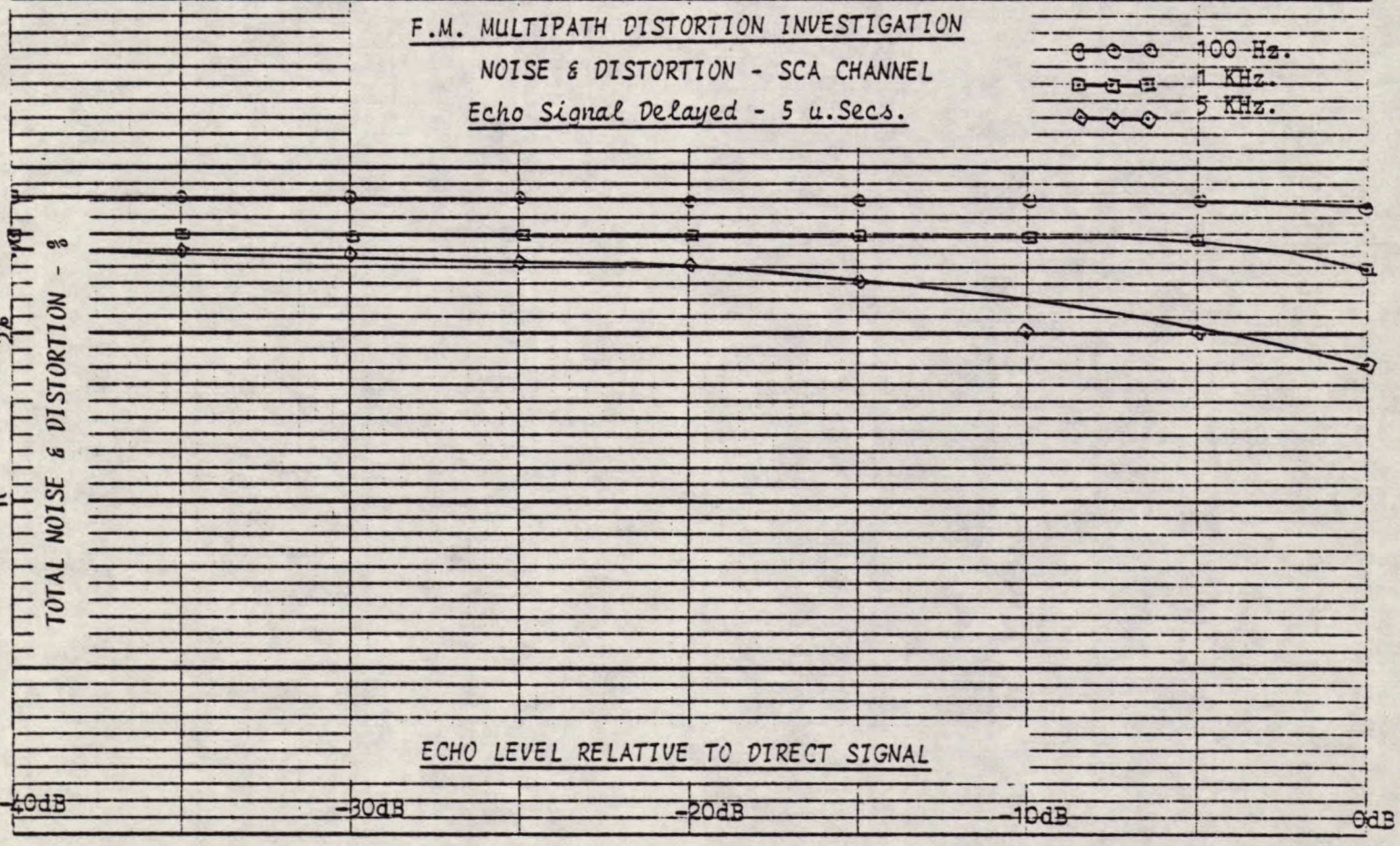

F.M. MULTIPATH DISTORTION INVESTIGATION.
NOISE & DISTORTION - SCA CHANNEL
Echo Signal Delayed - 2 u.Sec.
100 Hz.
1 KHz.
5 KHz.
TOTAL NOISE & DISTORTION - %
10%
15%
ECHO LEVEL RELATIVE TO DIRECT SIGNAL
-40dB
-30dB
-20dB
-10dB
0dB

FIGURE 27


F.M. MULTIPATH DISTORTION INVESTIGATION
NOISE & DISTORTION - SCA CHANNEL
Echo Signal Delayed - 5 u.Secs.
100 Hz.
1 KHz.
5 KHz.
TOTAL NOISE & DISTORTION - %
5%
ECHO LEVEL RELATIVE TO DIRECT SIGNAL
-40dB
-30dB
-20dB
-10dB
0dB

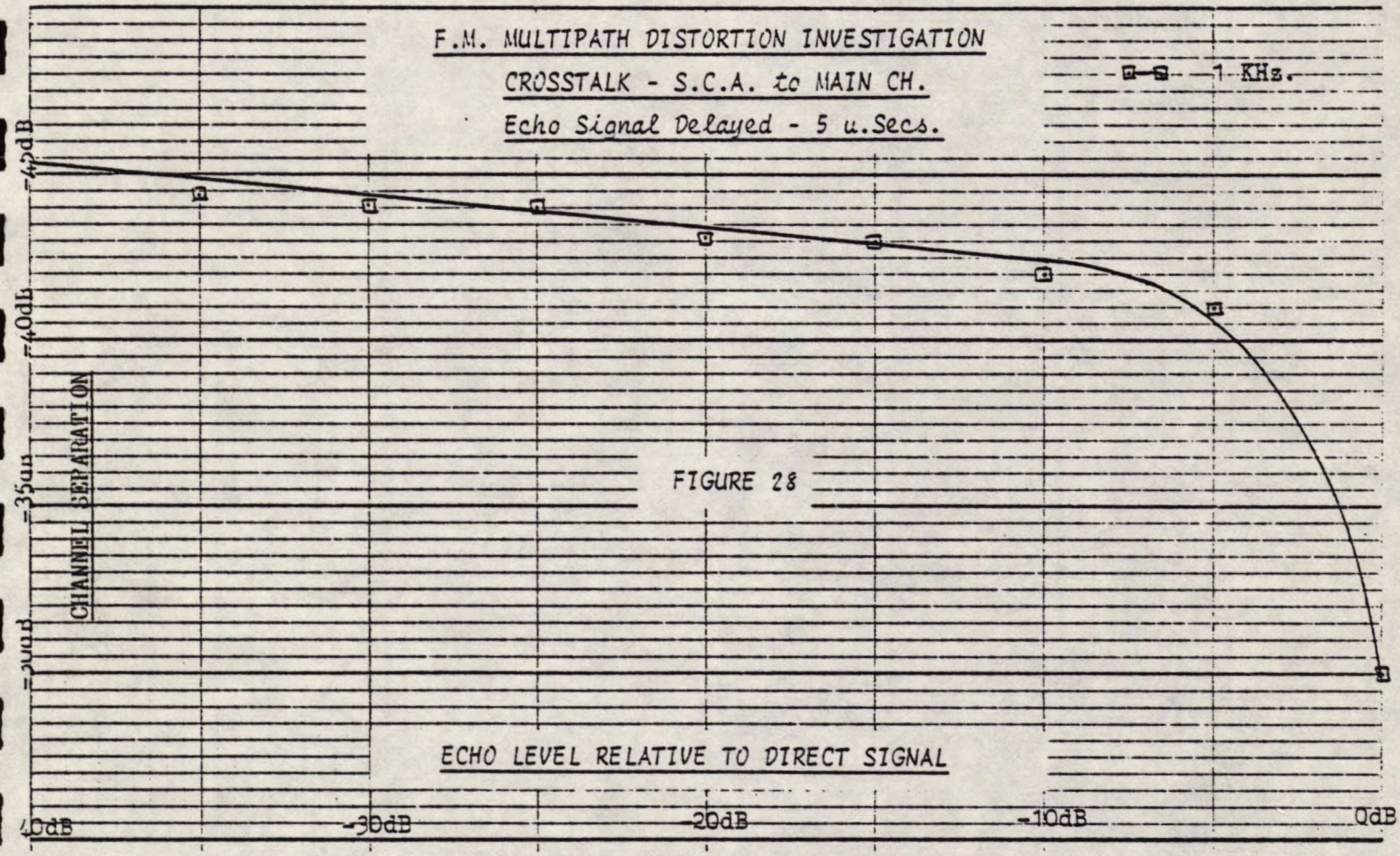

F.M. MULTIPATH DISTORTION INVESTIGATION
CROSSTALK - S.C.A. to MAIN CH.
Echo Signal Delayed - 5 u.Secs.
1 KHz.
-42dB
-40dB
-35dB
CHANNEL SEPARATION
-30dB
ECHO LEVEL RELATIVE TO DIRECT SIGNAL
-40dB
-30dB
-20dB
-10dB
0dB

FIGURE 28

Reference: - Single Tone 10 KHz.

F.M. MULTIPATH INVESTIGATION 1978

ECHO DELAY versus ECHO AMPLITUDE

FOR STATED % NOISE & DISTORTION

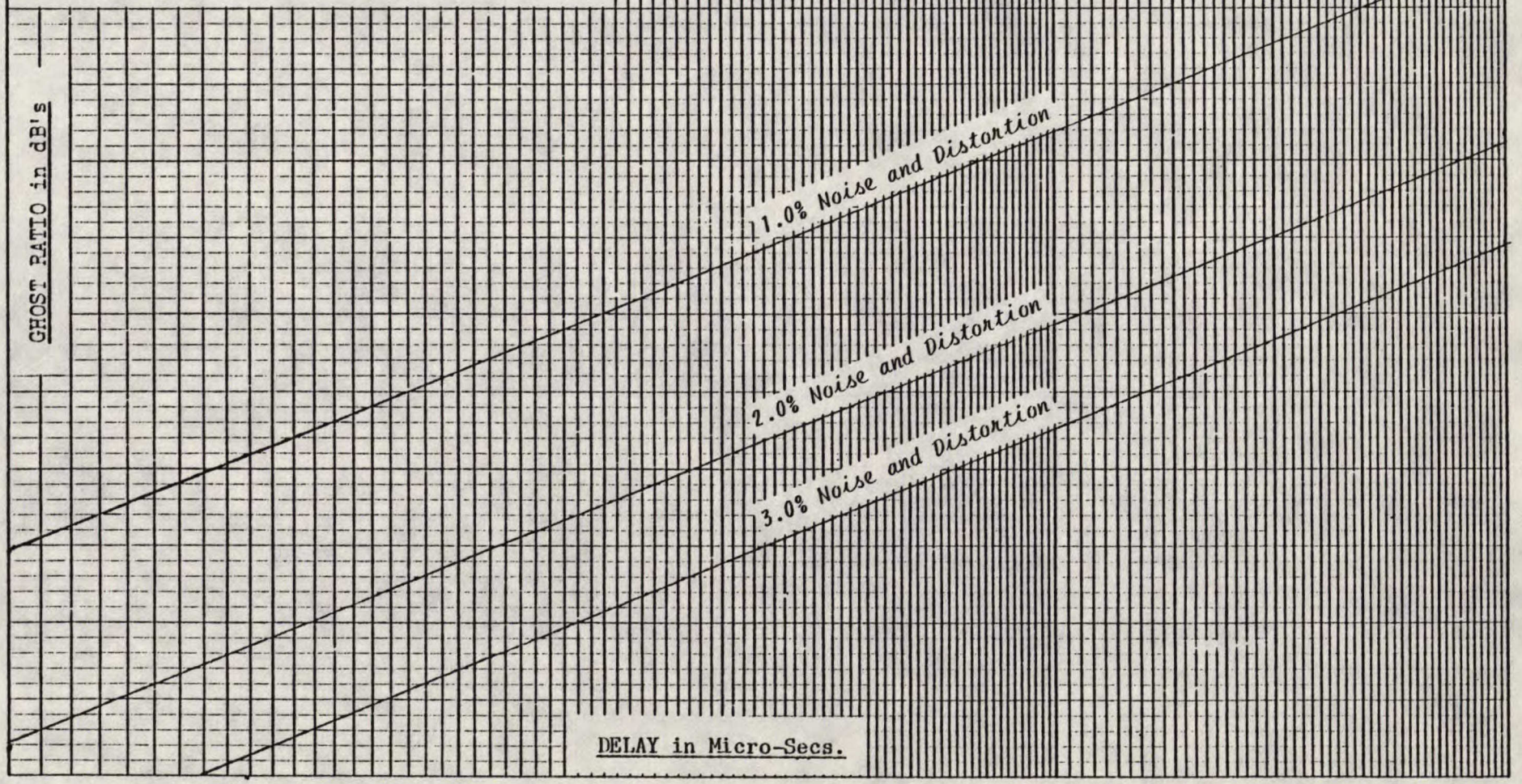
FIGURE 29

GRAPH CALCULATED FROM:

$$Echo(dB) = 20Log_{10}\left[\frac{\%\ Distortion}{141.4.\sin(1.8.t_d)}\right]$$

Where:

t_d = Echo Delay (u.Sec.)



Ghost (dB) for 'Typical Viewer' and for 'Expert Viewer'.

FIGURE 30

Given:- Echo Delay in u.s. and the Desired Impairment Grade No.

```
000  03  3
001  07  7
002  04  4
003  02  2
004  00  0
005  00  0
006  02  2
007  02  2
008  02  2
009  03  3
010  69  □P
011  01  01
012  03  3
013  02  2
014  03  3
015  06  6
016  03  3
017  07  7
018  00  0
019  00  0
020  01  1
021  03  3
022  69  □P
023  02  02
024  03  3
025  01  1
026  01  1
027  03  3
028  02  2
029  07  7
030  04  4
031  05  5
032  03  3
033  06  6
034  69  □P
035  03  03
036  02  2
037  04  4
038  03  3
039  06  6
040  00  0
041  00  0
042  00  0
043  00  0
044  00  0
045  00  0
046  69  □P
047  04  04
048  69  □P
049  05  05
050  98  ADV
051  69  □P
052  00  00
053  01  1
054  07  7
055  03  3
056  01  1
057  03  3
058  07  7
059  01  1
060  07  7
061  03  3
062  05  5
063  69  □P
064  01  01
065  00  0
066  00  0
067  02  2
068  02  2
069  03  3
070  05  5
071  01  1
072  03  3
073  01  1
074  06  6
075  69  □P
076  02  02
077  01  1
078  07  7
079  00  0
080  00  0
081  00  0
082  00  0
083  00  0
084  00  0
085  00  0
086  00  0
087  69  □P
088  03  03
089  69  □P
090  05  05
091  91  R/S
092  99  PRT
093  42  STO□
094  09  09
095  69  □P
096  00  00
097  01  1
098  07  7
099  03  3
100  01  1
101  03  3
102  07  7
103  01  1
104  07  7
105  03  3
106  05  5
107  69  □P
108  01  01
109  00  0
110  00  0
111  01  1
112  06  6
113  01  1
114  07  7
115  02  2
116  07  7
117  01  1
118  03  3
119  69  □P
120  02  02
121  04  4
122  05  5
123  00  0
124  00  0
125  04  4
126  01  1
127  04  4
128  00  0
129  03  3
130  06  6
131  69  □P
132  03  03
133  69  □P
134  05  05
135  91  R/S
136  99  PRT
137  42  STO□
138  08  08
139  53  (
140  93  .
141  06  6
142  03  3
143  07  7
144  55  ÷
145  43  RCL
146  08  08
147  95  =
148  94  +/-
149  22  INV
150  23  LNX
151  65  ×
152  93  .
153  01  1
154  04  4
155  03  3
156  54  )
157  42  STO□
158  07  07
159  53  (
160  93  .
```

```
161  04   4
162  08   8
163  05   5
164  55   ÷
165  43 RCL
166  08   08
167  95   =
168  94 +/-
169  22 INV
170  23 LNX
171  65   ×
172  06   6
173  93   .
174  06   6
175  05   5
176  54   )
177  75   -
178  43 RCL
179  09   09
180  95   =
181  55   ÷
182  43 RCL
183  07   07
184  95   =
185  99 PRT
186  69 □P
187  00   00
188  04   4
189  02   2
190  02   2
191  04   4
192  01   1
193  07   7
194  04   4
195  03   3
196  01   1
197  07   7
198  69 □P
199  01   01
200  03   3
201  05   5
202  00   0
203  00   0
204  01   1
205  06   6
206  01   1
207  04   4
208  00   0
209  00   0
210  69 □P
211  02   02
212  69 □P
213  05   05
214  98 ADV
```

```
215  93   .
216  04   4
217  09   9
218  00   0
219  55   ÷
220  43 RCL
221  08   08
222  95   =
223  94 +/-
224  22 INV
225  23 LNX
226  65   ×
227  93   .
228  01   1
229  05   5
230  02   2
231  95   =
232  42 STO
233  06   06
234  53   (
235  93   .
236  04   4
237  00   0
238  00   0
239  55   ÷
240  43 RCL
241  08   08
242  95   =
243  94 +/-
244  22 INV
245  23 LNX
246  65   ×
247  07   7
248  93   .
249  00   0
250  03   3
251  54   )
252  75   -
253  43 RCL
254  09   09
255  95   =
256  55   ÷
257  43 RCL
258  06   06
259  95   =
260  99 PRT
261  69 □P
262  00   00
263  01   1
264  07   7
265  04   4
266  04   4
267  03   3
268  03   3
```

```
269  01   1
270  07   7
271  03   3
272  05   5
273  69 □P
274  01   01
275  03   3
276  07   7
277  00   0
278  00   0
279  01   1
280  06   6
281  01   1
282  04   4
283  00   0
284  00   0
285  69 □P
286  02   02
287  69 □P
288  05   05
289  98 ADV
290  69 □P
291  00   00
292  03   3
293  01   1
294  01   1
295  07   7
296  04   4
297  03   3
298  00   0
299  00   0
300  01   1
301  06   6
302  69 □P
303  01   01
304  01   1
305  07   7
306  02   2
307  07   7
308  01   1
309  03   3
310  04   4
311  05   5
312  00   0
313  00   0
314  69 □P
315  02   02
316  06   6
317  04   4
318  00   0
319  00   0
320  03   3
321  05   5
322  06   6
```

```
323  03  3
324  03  3
325  06  6
326  69  DP
327  03  03
328  69  DP
329  05  05
330  98  ADV
331  69  DP
332  00  00
333  03  3
334  01  1
335  01  1
336  07  7
337  04  4
338  03  3
339  00  0
340  00  0
341  02  2
342  02  2
343  69  DP
344  01  01
345  03  3
346  05  5
347  01  1
348  03  3
349  01  1
350  06  6
351  01  1
352  07  7
353  00  0
354  00  0
355  69  DP
356  02  02
357  06  6
358  04  4
359  00  0
360  00  0
361  03  3
362  05  5
363  03  3
364  06  6
365  03  3
366  07  7
367  69  DP
368  03  03
369  69  DP
370  05  05
371  98  ADV
372  91  R/S
373  61  GTO
374  00  00
375  97  97
376  00  0
```

```
TV GHOST ANALYSIS

ENTER GRADE
          1.5
ENTER DELAY U.S
            5.
 36.02417689
VIEWER DB

 36.20553649
EXPERT DB

NEW DELAY = R/S

NEW GRADE = RST
```

Software Program for TI. 58/59 Calculator

FIGURE 31

Grade No. for 'Typical Viewer' and for 'Expert Viewer'

Given:- Echo Delay in u.S.
Echo Level in dB.

```
000  03   3
001  07   7
002  04   4
003  02   2
004  00   0
005  00   0
006  02   2
007  02   2
008  02   2
009  03   3
010  69  □P
011  01   01
012  03   3
013  02   2
014  03   3
015  06   6
016  03   3
017  07   7
018  00   0
019  00   0
020  01   1
021  03   3
022  69  □P
023  02   02
024  03   3
025  01   1
026  01   1
027  03   3
028  02   2
029  07   7
030  04   4
031  05   5
032  03   3
033  06   6
034  69  □P
035  03   03
036  02   2
037  04   4
038  03   3
039  06   6
040  00   0
041  00   0
042  00   0
043  00   0
044  00   0
045  00   0
046  69  □P
047  04   04
048  69  □P
049  05   05
050  98  ADV
051  69  □P
052  00   00
053  01   1
054  07   7
055  03   3
056  01   1
057  03   3
058  07   7
059  01   1
060  07   7
061  03   3
062  05   5
063  69  □P
064  01   01
065  00   0
066  00   0
067  02   2
068  02   2
069  02   2
070  03   3
071  03   3
072  02   2
073  03   3
074  06   6
075  69  □P
076  02   02
077  03   3
078  07   7
079  00   0
080  00   0
081  01   1
082  06   6
083  01   1
084  04   4
085  00   0
086  00   0
087  69  □P
088  03   03
089  69  □P
090  05   05
091  91  R/S
092  99  PRT
093  42  STO□
094  09   09
095  69  □P
096  00   00
097  01   1
098  07   7
099  03   3
100  01   1
101  03   3
102  07   7
103  01   1
104  07   7
105  03   3
106  05   5
107  69  □P
108  01   01
109  00   0
110  00   0
111  01   1
112  06   6
113  01   1
114  07   7
115  02   2
116  07   7
117  01   1
118  03   3
119  69  □P
120  02   02
121  04   4
122  05   5
123  00   0
124  00   0
125  04   4
126  01   1
127  04   4
128  00   0
129  03   3
130  06   6
131  69  □P
132  03   03
133  69  □P
134  05   05
135  91  R/S
136  99  PRT
137  42  STO□
138  08   08
139  53   (
140  93   .
141  06   6
142  03   3
143  07   7
144  55   ÷
145  43  RCL
```

```
146  08  08
147  95  =
148  94  +/-
149  22  INV
150  23  LNX
151  65  ×
152  93  .
153  01  1
154  04  4
155  03  3
156  54  )
157  65  ×
158  43  RCL
159  09  09
160  95  =
161  42  STO
162  07  07
163  53  (
164  93  .
165  04  4
166  08  8
167  05  5
168  55  ÷
169  43  RCL
170  08  08
171  95  =
172  94  +/-
173  22  INV
174  23  LNX
175  65  ×
176  06  6
177  93  .
178  06  6
179  05  5
180  54  )
181  75  -
182  43  RCL
183  07  07
184  95  =
185  99  PRT
186  69  OP
187  00  00
188  04  4
189  02  2
190  02  2
191  04  4
192  01  1
193  07  7
194  04  4
195  03  3
196  01  1
197  07  7
198  69  OP
199  01  01
200  03  3
201  05  5
202  00  0
203  00  0
204  03  3
205  01  1
206  03  3
207  02  2
208  00  0
209  00  0
210  69  OP
211  02  02
212  69  OP
213  05  05
214  98  ADV
215  93  .
216  04  4
217  09  9
218  00  0
219  55  ÷
220  43  RCL
221  08  08
222  95  =
223  94  +/-
224  22  INV
225  23  LNX
226  65  ×
227  93  .
228  01  1
229  05  5
230  02  2
231  65  ×
232  43  RCL
233  09  09
234  95  =
235  42  STO
236  06  06
237  53  (
238  93  .
239  04  4
240  55  ÷
241  43  RCL
242  08  08
243  95  =
244  94  +/-
245  22  INV
246  23  LNX
247  65  ×
248  07  7
249  93  .
250  00  0
251  03  3
252  54  )
253  75  -
254  43  RCL
255  06  06
256  95  =
257  99  PRT
258  69  OP
259  00  00
260  01  1
261  07  7
262  04  4
263  04  4
264  03  3
265  03  3
266  01  1
267  07  7
268  03  3
269  05  5
270  69  OP
271  01  01
272  03  3
273  07  7
274  00  0
275  00  0
276  03  3
277  01  1
278  03  3
279  02  2
280  00  0
281  00  0
282  69  OP
283  02  02
284  69  OP
285  05  05
286  98  ADV
287  98  ADV
288  91  R/S
289  61  GTO
290  00  00
291  50  50
```

```
TV GHOST ANALYSIS

ENTER GHOST DB
          27.2
ENTER DELAY U.S
              2.
  2.389344804
VIEWER NO

  2.519663551
EXPERT NO
```

TV. GHOSTING & FM. MULTIPATH STUDY

FIGURE 32

Software program for 'Typical ' and 'Expert' viewer Picture Grades and computed FM.-Radio stereo channel noise/distortion versus Echo Delay and Echo Level.

Applicable to T.I. SR 59 Printer/Calculator

```
TELEVISION/FM-RADIO
   GHOST ANALYSIS

ENTER GHOST DB
          25.
ENTER DELAY U.S
           5.
         2.89
VIEWER GRADE

         3.04
EXPERT GRADE

         1.24
FM. NOISE/DIST %
```

```
000  03  3
001  07  7
002  01  1
003  07  7
004  02  2
005  07  7
006  01  1
007  07  7
008  04  4
009  02  2
010  69  □P
011  01  01
012  02  2
013  04  4
014  03  3
015  06  6
016  02  2
017  04  4
018  03  3
019  02  2
020  03  3
021  01  1
022  69  □P
023  02  02
024  06  6
025  03  3
026  02  2
027  01  1
028  03  3
029  00  0
030  02  2
031  00  0
032  03  3
033  05  5
034  69  □P
035  03  03
036  01  1
037  03  3
038  01  1
039  06  6
040  02  2
041  04  4
042  03  3
043  02  2
044  00  0
045  00  0
046  69  □P
047  04  04
048  69  □P
049  05  05
050  69  □P
051  00  00
052  00  0
053  00  0
054  00  0
055  00  0
056  00  0
057  00  0
058  02  2
059  02  2
060  02  2
061  03  3
062  69  □P
063  01  01
064  03  3
065  02  2
066  03  3
067  06  6
068  03  3
069  07  7
070  00  0
071  00  0
072  01  1
073  03  3
074  69  □P
075  02  02
076  03  3
077  01  1
078  01  1
079  03  3
080  02  2
081  07  7
082  04  4
083  05  5
084  03  3
085  06  6
086  69  □P
087  03  03
088  02  2
089  04  4
090  03  3
091  06  6
092  00  0
093  00  0
094  00  0
095  00  0
096  00  0
097  00  0
098  69  □P
099  04  04
100  69  □P
101  05  05
102  98  ADV
103  69  □P
104  00  00
105  01  1
106  07  7
107  03  3
108  01  1
109  03  3
110  07  7
111  01  1
112  07  7
113  03  3
114  05  5
115  69  □P
116  01  01
117  00  0
118  00  0
119  02  2
120  02  2
121  02  2
122  03  3
123  03  3
124  02  2
125  03  3
126  06  6
127  69  □P
128  02  02
129  03  3
130  07  7
```

131	00	0
132	00	0
133	01	1
134	06	6
135	01	1
136	04	4
137	00	0
138	00	0
139	69	OP
140	03	03
141	69	OP
142	05	05
143	91	R/S
144	99	PRT
145	42	STO
146	09	09
147	69	OP
148	00	00
149	01	1
150	07	7
151	03	3
152	01	1
153	03	3
154	07	7
155	01	1
156	07	7
157	03	3
158	05	5
159	69	OP
160	01	01
161	00	0
162	00	0
163	01	1
164	06	6
165	01	1
166	07	7
167	02	2
168	07	7
169	01	1
170	03	3
171	69	OP
172	02	02
173	04	4
174	05	5
175	00	0
176	00	0
177	04	4
178	01	1
179	04	4
180	00	0
181	03	3
182	06	6
183	69	OP
184	03	03
185	69	OP
186	05	05
187	91	R/S
188	99	PRT

189	42	STO
190	08	08
191	53	(
192	93	.
193	06	6
194	03	3
195	07	7
196	55	÷
197	43	RCL
198	08	08
199	95	=
200	94	+/-
201	22	INV
202	23	LNX
203	65	×
204	93	.
205	01	1
206	04	4
207	03	3
208	54	)
209	65	×
210	43	RCL
211	09	09
212	95	=
213	42	STO
214	07	07
215	53	(
216	93	.
217	04	4
218	08	8
219	05	5
220	55	÷
221	43	RCL
222	08	08
223	95	=
224	94	+/-
225	22	INV
226	23	LNX
227	65	×
228	06	6
229	93	.
230	06	6
231	05	5
232	54	)
233	75	-
234	43	RCL
235	07	07
236	95	=
237	58	FIX
238	02	02
239	99	PRT
240	22	INV
241	58	FIX
242	69	OP
243	00	00
244	04	4
245	02	2
246	02	2

247	04	4
248	01	1
249	07	7
250	04	4
251	03	3
252	01	1
253	07	7
254	69	OP
255	01	01
256	03	3
257	05	5
258	00	0
259	00	0
260	02	2
261	02	2
262	03	3
263	05	5
264	01	1
265	03	3
266	69	OP
267	02	02
268	01	1
269	06	6
270	01	1
271	07	7
272	00	0
273	00	0
274	00	0
275	00	0
276	00	0
277	00	0
278	69	OP
279	03	03
280	69	OP
281	05	05
282	98	ADV
283	93	.
284	04	4
285	09	9
286	00	0
287	55	÷
288	43	RCL
289	08	08
290	95	=
291	94	+/-
292	22	INV
293	23	LNX
294	65	×
295	53	(
296	01	1
297	05	5
298	02	2
299	65	×
300	43	RCL
301	09	09
302	95	=
303	42	STO
304	06	06

305	53	(
306	93	.
307	04	4
308	55	÷
309	43	RCL
310	08	08
311	95	=
312	94	+/-
313	22	INV
314	23	LNX
315	65	×
316	07	7
317	93	.
318	00	0
319	03	3
320	54	)
321	75	-
322	43	RCL
323	06	06
324	95	=
325	58	FIX
326	02	02
327	99	PRT
328	22	INV
329	58	FIX
330	69	OP
331	00	00
332	01	1
333	07	7
334	04	4
335	04	4
336	03	3
337	03	3
338	01	1
339	07	7
340	03	3
341	05	5
342	69	OP
343	01	01
344	03	3
345	07	7
346	00	0
347	00	0
348	02	2
349	02	2
350	03	3
351	05	5
352	01	1
353	03	3
354	69	OP
355	02	02
356	01	1
357	06	6
358	01	1
359	07	7
360	00	0
361	00	0
362	00	0
363	00	0
364	00	0
365	00	0
366	69	OP
367	03	03
368	69	OP
369	05	05
370	98	ADV
371	43	RCL
372	08	08
373	65	×
374	01	1
375	93	.
376	08	8
377	95	=
378	88	SIN
379	65	×
380	01	1
381	04	4
382	01	1
383	93	.
384	04	4
385	95	=
386	42	STO
387	10	10
388	43	RCL
389	09	09
390	55	÷
391	02	2
392	00	0
393	95	=
394	94	+/-
395	22	INV
396	28	LOG
397	65	×
398	43	RCL
399	10	10
400	95	=
401	58	FIX
402	02	02
403	99	PRT
404	22	INV
405	58	FIX
406	69	OP
407	00	00
408	02	2
409	01	1
410	03	3
411	00	0
412	04	4
413	00	0
414	00	0
415	00	0
416	03	3
417	01	1
418	69	OP
419	01	01
420	03	3
421	02	2
422	02	2
423	04	4
424	03	3
425	06	6
426	01	1
427	07	7
428	06	6
429	03	3
430	69	OP
431	02	02
432	01	1
433	06	6
434	02	2
435	04	4
436	03	3
437	06	6
438	03	3
439	07	7
440	00	0
441	00	0
442	69	OP
443	03	03
444	06	6
445	01	1
446	00	0
447	00	0
448	00	0
449	00	0
450	00	0
451	00	0
452	00	0
453	00	0
454	69	OP
455	04	04
456	69	OP
457	05	05
458	98	ADV
459	91	R/S
460	61	GTO
461	01	01
462	02	02

USE R/S TO INIATE FURTHER ENTRIES

TELEVISION GHOSTING AND FM. MULTI-PATH DISTORTION INVESTIGATION