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CONSIDERATIONS FOR OPTIMIZATION OF GROUND SYSTEM FOR RECEPTION OF TELEVISION FROM THE APOLLO SPACECRAFT AT LUNAR DISTANCE

BY
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MARCH 1, 1965

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SUMMARY

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The results of a theoretical as well as an experimental investigation pertaining to the Alollo television link are presented. Emphasis is placed on improving the link by changing certain parameters in the present design of the ground system.

Although this study is concerned with the design of the ground system the results indicate that certain considerations in the design of the spacecraft equipment can contribute in obtaining good quality of video signals from the Apollo spacecraft at lunar distance.

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CONSIDERATIONS FOR OPTIMIZATION OF GROUND SYSTEM FOR RECEPTION OF TELEVISION FROM THE APOLLO SPACECRAFT AT LUNAR DISTANCE

INTRODUCTION

Computations have shown that the present spacecraft-to-ground television link at lunar distances is marginal. As a result, a theoretical study as well as an experimental investigation were conducted in order to determine whether anything could be done in the ground system to improve the link. The results of these investigations indicate that the ground carrier frequency demodulator predetection bandwidth may be reduced from 10 Mc (its present value) to 4 Mc. Thus, an improvement in the link is realized.

This report describes the theoretical computations as well as the experimental results and derives conclusions and recommendations. In addition, photographs are presented for evaluation and direct comparison of picture quality using the 10 Mc and the 4 Mc pre-detection filters.

1. THE BASIC PROBLEM

At present, transmission of television from the moon is considered as one of the communication modes from the spacecraft to the Manned Space Flight Network (MSFN). The spacecraft system to be used for transmission of television essentially consists of a television camera and an FM transmitter exciter. The transmitter exciter output is routed to a 20-Watt power amplifier and a high-gain antenna. The video information is frequency modulated on the carrier and at baseband this information is 500 kc wide.

The MSFN utilizes a modulation tracking phase lock loop for carrier demodulation and the video signal is recovered at the output of this loop using a low-pass filter. Subsequently, the video signal is routed to a monitor and video tape recorder and to commercial networks.

Detailed theoretical computations have shown that under best transmission conditions from the spacecraft (at lunar distances) the signal-to-noise ratio (SNR) at the input to the present ground carrier frequency demodulator is about 4 db.

This SNR is below "FM threshold." Such being the case, the Goddard Space Flight Center launched an investigation to determine if anything could be done to the ground equipment in order to insure that reception of television at lunar distances would be adequate. This investigation was conducted on a theoretical basis and it was largely based on previous work performed by Motorola, Inc. and a classical paper published in the Proceedings of the I.R.E. in 1948 by F. L. H. M. Stumpers. The results of this investigation indicated that it would be possible to improve the television link by narrowing the ground system demodulator pre-detection bandwidth. Thus, in order to prove the validity of the theoretical investigation, tests were conducted at the Manned Spacecraft Center S-Band Test Facility. The tests, as well as the results, are discussed later in this paper.

2. THEORETICAL CONSIDERATIONS

Much work has been performed and published on the subject of FM detection. This work generally indicates that the FM demodulator experiences a threshold. Some authors define the FM threshold (the knee of the signal-to-noise ratio in versus signal-to-noise ratio out curve) as 9 db and others as 12 db. This variation from 9 to 12 db is accounted for in the treatment of input noise. Furthermore, authors have attempted to compare the performance of different FM detectors and also arrive at some "good" definition of the threshold of a phase-lock loop demodulator, frequency feedback demodulator, etc. From all the work which has been performed, however, one can derive the conclusion that threshold is a phenomenon which is inherent in the FM process and that there is a limit which represents the threshold performance of an ideal demodulator.

Theoretically, the performance of an FM system may be determined by computing the system output signal-to-noise ratio (SNR). This requires the derivation of analytical expressions relating the output SNR to the input SNR for the cases of having a low-pass or a band-pass filter at the output of the FM detector. Such expressions will be derived below. The reader, however, should keep in mind that in deriving these mathematical equations the following assumptions are made:

1. All filters are ideal – "square"

2. Noise is "white" (flat) and Gaussian

3. Doppler effects are negligible

4. Input SNR $\geq$ 10 db in all cases.

For the derivations to follow consider the model shown in Figure 1.

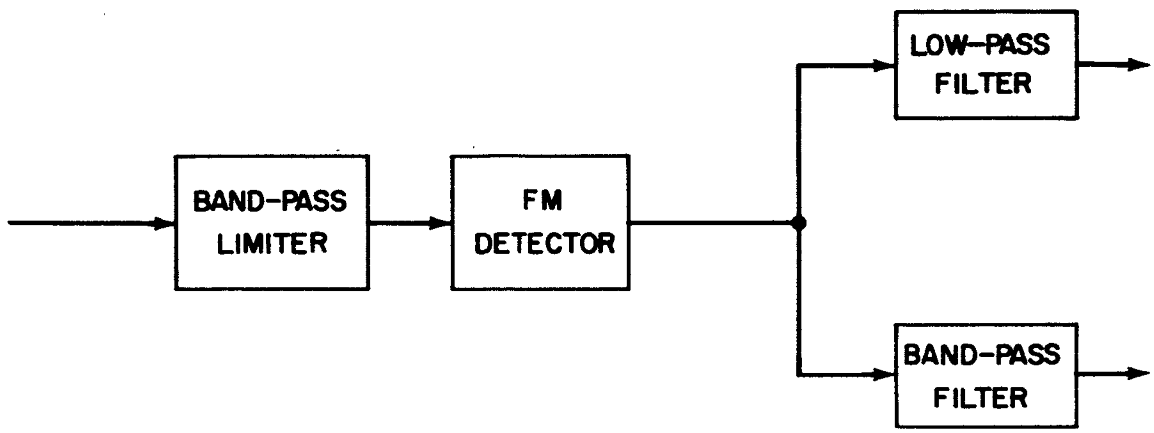

Figure 1

where

A = signal amplitude

ω_c = carrier angular frequency = $2\pi f_c$

β = modulation index

ω_m = angular frequency of modulated signal = $2\pi f_m$

The input signal-to-noise ratio computed in the band-pass limiter bandwidth, B, is given as:

$$S/N]_{in} = \frac{A^2}{2\,\eta_0\,B} \tag{1}$$

where

η_0 = input noise spectral density

Case I. Low-Pass Filter

When a low-pass filter is used at the output of the detector, the r.m.s. value of the signal at the output of this filter is given by

$$S_0 = \frac{\beta^2 \omega_m^2}{2} \tag{2}$$

The phase noise spectral density in the channel may be shown to be:

$$\Phi_N = \frac{\eta_0}{A^2/2} \tag{3}$$

Further, the noise at the output of an idealized low-pass filter (square cutoffs) has a triangular shape as shown in Figure 2.

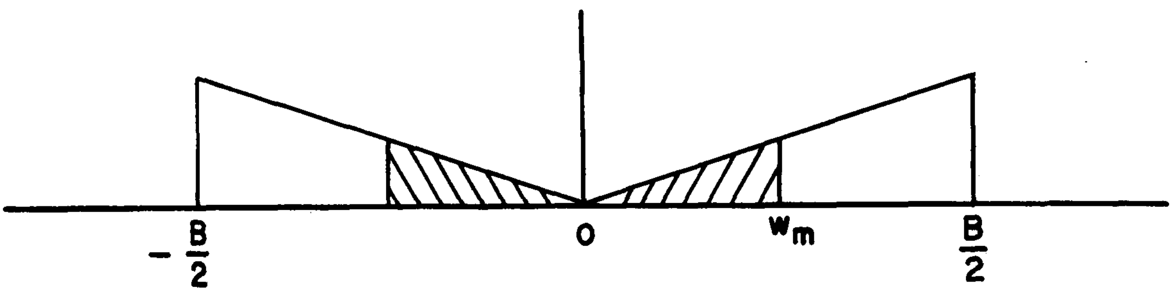

Figure 2

Thus, the noise power at the output of the low-pass filter is given by the following relationship

$$N_0 = \frac{1}{2\pi} \int_0^{\omega_m} \frac{\eta_0}{A^2/2} \omega^2 \, d\omega \tag{4}$$

and the signal-to-noise ratio at the output of the low-pass filter may be obtained from (2) and (4). Thus:

$$S_0/N_0]_{out} = \frac{\omega_m^2 \frac{\beta^2}{2}}{\frac{1}{2\pi} \int_0^{\omega_m} \frac{\eta_0}{A^2/2} \omega^2 \, d\omega}$$

$$S_0/N_0]_{out} = \frac{3}{2} \beta^2 \left(\frac{B}{f_m}\right) (S/N)_{in} \tag{5}$$

Case II. Band-Pass Filter

Again the rms value of the signal at the output of the band-pass filter is given by:

$$S_0 = \frac{\beta^2 \omega_m^2}{2} = \frac{\Delta_\omega^2}{2} \tag{6}$$

where

$$\beta = \frac{\Delta\omega}{\omega_m}$$

The noise distribution at the output of an idealized band-pass filter is shown in Figure 3.

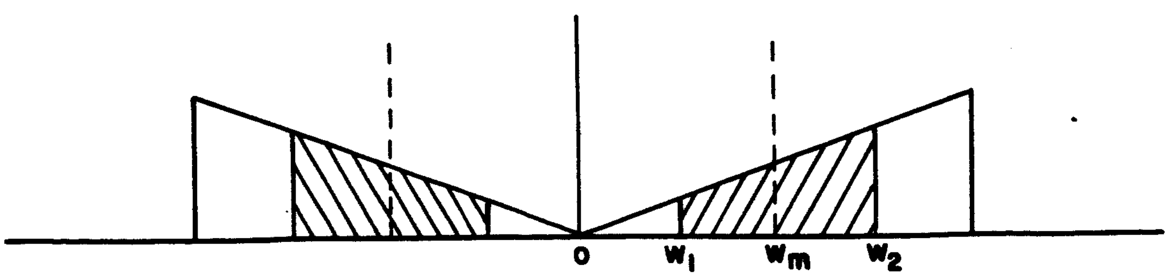

Figure 3

The noise at the output of the band-pass filter is the phase noise spectral density of the system integrated between ω_1 and ω_2 of the noise spectrum shown in Figure 3. Thus:

$$N_0 = \frac{1}{2\pi} \int_{\omega_1}^{\omega_2} \frac{\eta_0}{A^2/2} \omega^2 \, d\omega$$

$$N_0 = \left(\frac{\eta_0}{A^2/2}\right) \left(\frac{\omega_2^3 - \omega_1^3}{3}\right) \frac{1}{2\pi} \tag{7}$$

Then from (6) and (7) we obtain the signal-to-noise ratio at the output of the band-pass filter which is

$$S_0/N_0]_{out} = \frac{3}{2} (\Delta\omega)^2 \left[\frac{B}{\frac{\omega_2^3 - \omega_1^3}{2\pi}}\right] (S/N)_{in} \tag{8}$$

Equation (8) may be modified by making the approximation:

$$\omega_2^3 - \omega_1^3 \cong (\omega_2 - \omega_1)\, 3\omega_m^3$$

where

$$\omega_m = \frac{\omega_2 - \omega_1}{2}$$

If we now define the bandwidth of the band-pass filter as B_f, where

$$B_f = \frac{\omega_2 - \omega_1}{2\pi}$$

then

$$\omega_2^3 - \omega_1^3 \cong 3\,B_f\,\omega_m^2$$

Thus equation (8) may be re-written as:

$$S_0/N_0]_{out} \cong \frac{1}{2}\beta^2 \left(\frac{B}{B_f}\right)(S/N)_{in} \qquad (9)$$

Equations (5) and (9) may be used to predict the performance of an FM channel provided that the input signal-to-noise ratio is greater than 10 db; otherwise these equations are not entirely valid.

The question now arises as to how can the performance of an FM demodulator be predicted if the input signal-to-noise ratio is less than 10 db. This is not an easy task. However, in 1948 F. L. H. M. Stumpers presented a mathematical basis for independently predicting the signal output and the noise output of an FM system. This work was published in the Proceedings of the IRE in September 1948 with the title "Theory of Frequency Modulation Noise."[1] Mr. Stumpers' analysis was based on the assumption that in an FM system all of the information is in the zero crossing of the FM wave. Furthermore, no particular type of FM detector was used in this analysis.

The mathematical analysis presented by Stumpers was expended by Motorola, Inc.[2] Thus, a mathematical prediction of the behavior of the FM channel below and above "FM threshold" may be made. Therefore, based on footnotes 1, 2, and 3, the following analysis is presented.

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[1]Stumpers, F.L.H.M., "Theory of Frequency Modulation Noise," Proceedings of the IRE, September 1948.

[2]"Proposal for Advanced Threshold Reduction Techniques Study", presented to GSFC May 19, 1964 by Motorola, Inc.

[3]Lawson, J.L. and Uhlenbeck, G.E., "Threshold Signals", Vol. 24, Radiation Laboratory Series 1950.

The output signal power of a discriminator is:

$$S_0 = \frac{1}{2R} \left[K\Delta f \left(1 - e^{-C/N}\right)\right]^2 \tag{10}$$

where

S_0 = signal power at the output, watts

Δf = peak modulation deviation, cps (sinusoidal modulation is assumed)

K = discriminator constant, $\frac{\text{volts}}{\text{cps}}$

R = load resistance, ohms

C/N = total input signal power-to-noise, in the discriminator predetection bandwidth.

The output noise power of the same discriminator is:

$$N_0 = \frac{K^2 B}{R} \int_{f_1}^{f_2} \alpha(f)^2 \, df \tag{11}$$

where

N_0 = Output noise power, watts

$\alpha(f)$ = Proportional to the noise voltage density

B = Discriminator predetection bandwidth, cps

f_1, f_2 = Upper and lower limits of the output filter bandwidth

Using now equations (10) and (11) we may obtain the signal-to-noise ratio at the output of the discriminator. Thus:

$$S_0/N_0]_{out} = \frac{\Delta f^2 \left(1 - e^{-C/N}\right)^2}{\int_{f_2}^{f_2} \alpha(f)^2 \, df} \tag{12}$$

Knowing the characteristics of the received signal one can define the predetection and post detection bandwidths of the discriminator. Thus Δf , f_1, and f_2 of equation 12 are defined. The factor $\alpha(f)$, however, may be obtained from Figure 4 which was plotted by Motorola, Inc. and is reproduced here. Using now Equation 12 and Figure 4 we can compute output signal-to-noise ratios for different predetection signal-to-noise ratios and frequency deviations.

As previously stated, the ground system carrier frequency demodulator is a modulation tracking phase lock loop. In its present design, this loop is preceded by a band-pass filter, the bandwidth of which is about 10 Mc. The loop itself has a 10 Mc two-sided closed loop noise bandwidth. When television information is transmitted, the information bandwidth of the signal is estimated to be 3.2 Mc. When maximum Doppler and transmitter center frequency uncertainty are taken into consideration, the bandwidth of the signal becomes about 4 Mc. Thus, it appears that the signal is narrower, by a factor of two, than the demodulator predetection bandwidth.

Analysis of an ideal phase lock discriminator indicates that the noise into the discriminator is controlled by the loop noise bandwidth. This indicates that prefiltering of the signal before the phase-locked loop, with a filter whose noise bandwidth is less than that of the loop, would reduce the "threshold" of the demodulator by the ratio of the noise bandwidths.

Motorola has shown that the peak error of a type I, 2nd order phase-locked loop with a Rechtin filter is:

$$\epsilon_m = \frac{2540\,(\Delta f)\,(f_m)}{(2\beta_L)^2 \sqrt{1 + \left(\frac{6.66\, f_m}{2\beta_L}\right)^2}} \tag{13}$$

where

ϵ_m = Peak loop error due to modulation, degrees

$2\beta_L$ = Loop two-sided noise bandwidth, cps

f_m = Modulating frequency, cps

Δf = Peak deviation of sinusoidal signal, cps

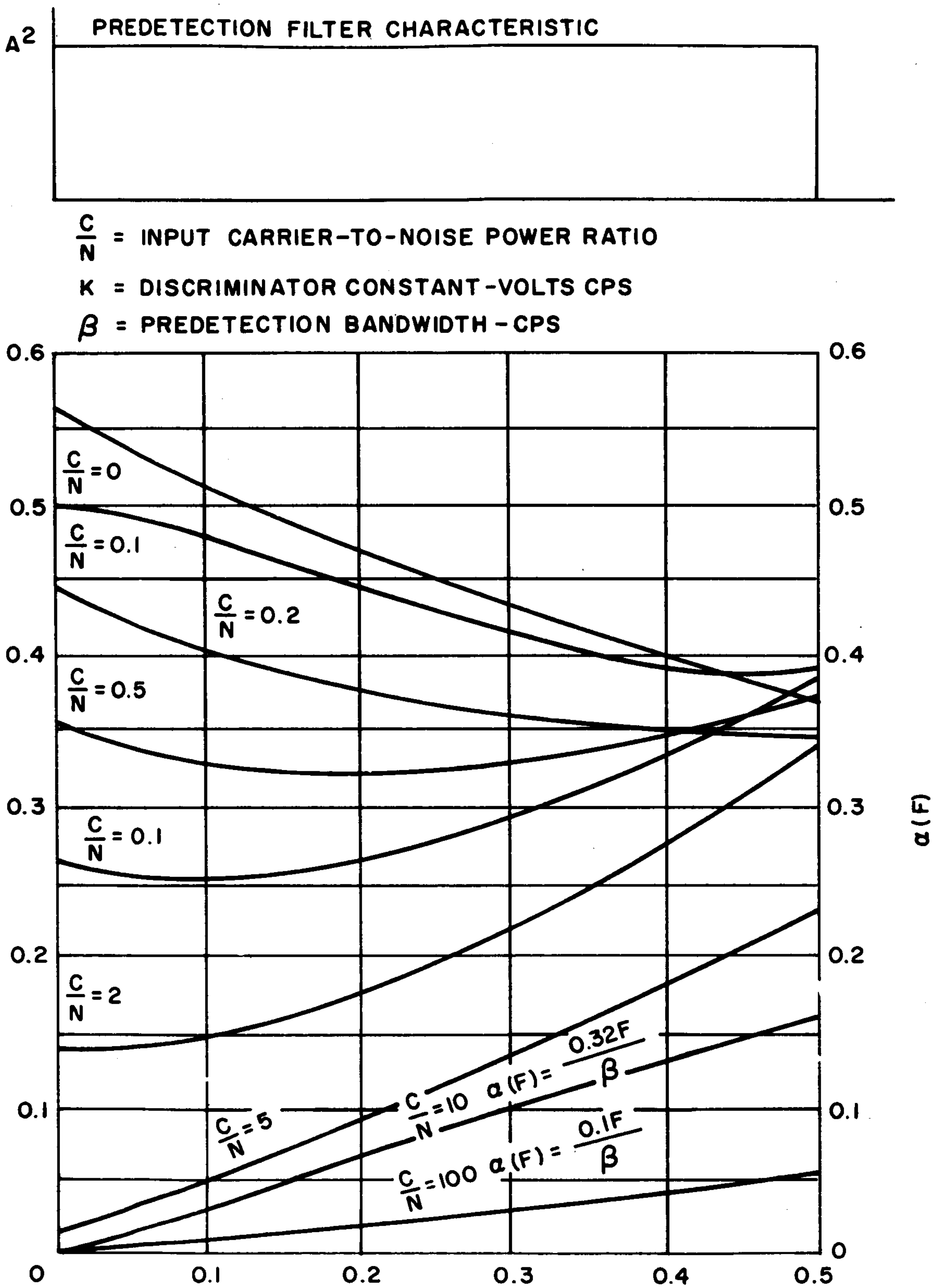


Figure 4–Noise Density Curve (Square Filter)

solving for $2\beta_L$ we have:

$$2\beta_L = 50.5\, f_m \sqrt[4]{\left(\frac{\Delta f}{f_m\, \epsilon_m}\right)^2 - \frac{1}{3310}}$$

If a 30 degree peak modulation error is assumed, then

$$2\beta_L = 9.2\, f_m \sqrt[4]{\left(\frac{\Delta f}{f_m}\right)^2 - \frac{1}{3.67}} \tag{14}$$

It may be shown that the RF bandwidth required for transmission of the signal is given by:

$$B = 2(\Delta f + f_m) \tag{15}$$

Comparison of Equations (14) and (15) indicates that the loop noise bandwidth, for small modulation indices, would be larger than required to pass the RF signal if the loop were used as a tracking filter. This indicates that a filter with a bandwidth less than the loop noise bandwidth may be placed in front of the loop. Thus the system threshold may be reduced. The ratio of bandwidth to modulating frequency may be obtained for both the filter and the phase lock loop, from Equations (14) and (15). These ratios have been plotted by Motorola, Inc. and are shown in Figure 5. The figure indicates that if the deviation ratio used is less than 20, the loop noise bandwidth is greater than the signal RF bandwidth. Thus a prefilter with a bandwidth narrower than the loop noise bandwidth may be used in the channel.

Based on the foregoing, computations were made using the Apollo Carrier Frequency Demodulator with a 4 Mc and a 10 Mc predetection bandwidths and a 500 kc post detection bandwidth. The results of these computations are shown in Figure 6. The curve labeled PRE FILTER is the one computed for the 4 Mc predetection bandwidth and the curve labeled NO PRE FILTER is the one computed using the 10 Mc predetection bandwidth. From Figure 6 it may be seen that below the "knee" of the curves an improvement in output signal-to-noise ratio is obtained by narrowing the predetection filter from 10 Mc to 4 Mc. It should be pointed out at this point, that although impulse noise, as well as system

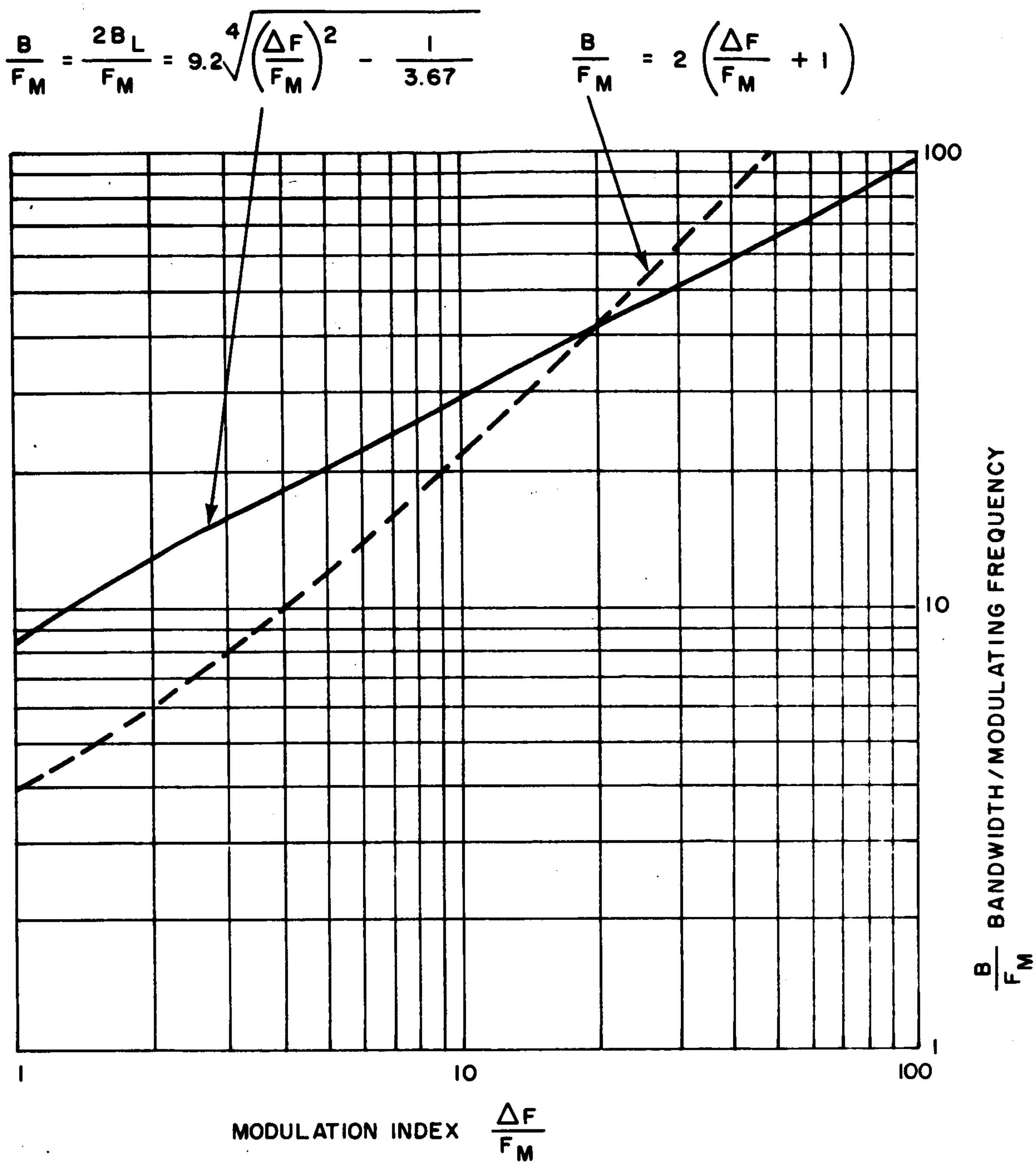


Figure 5–Bandwidth/Modulating Frequency Versus Modulation Index

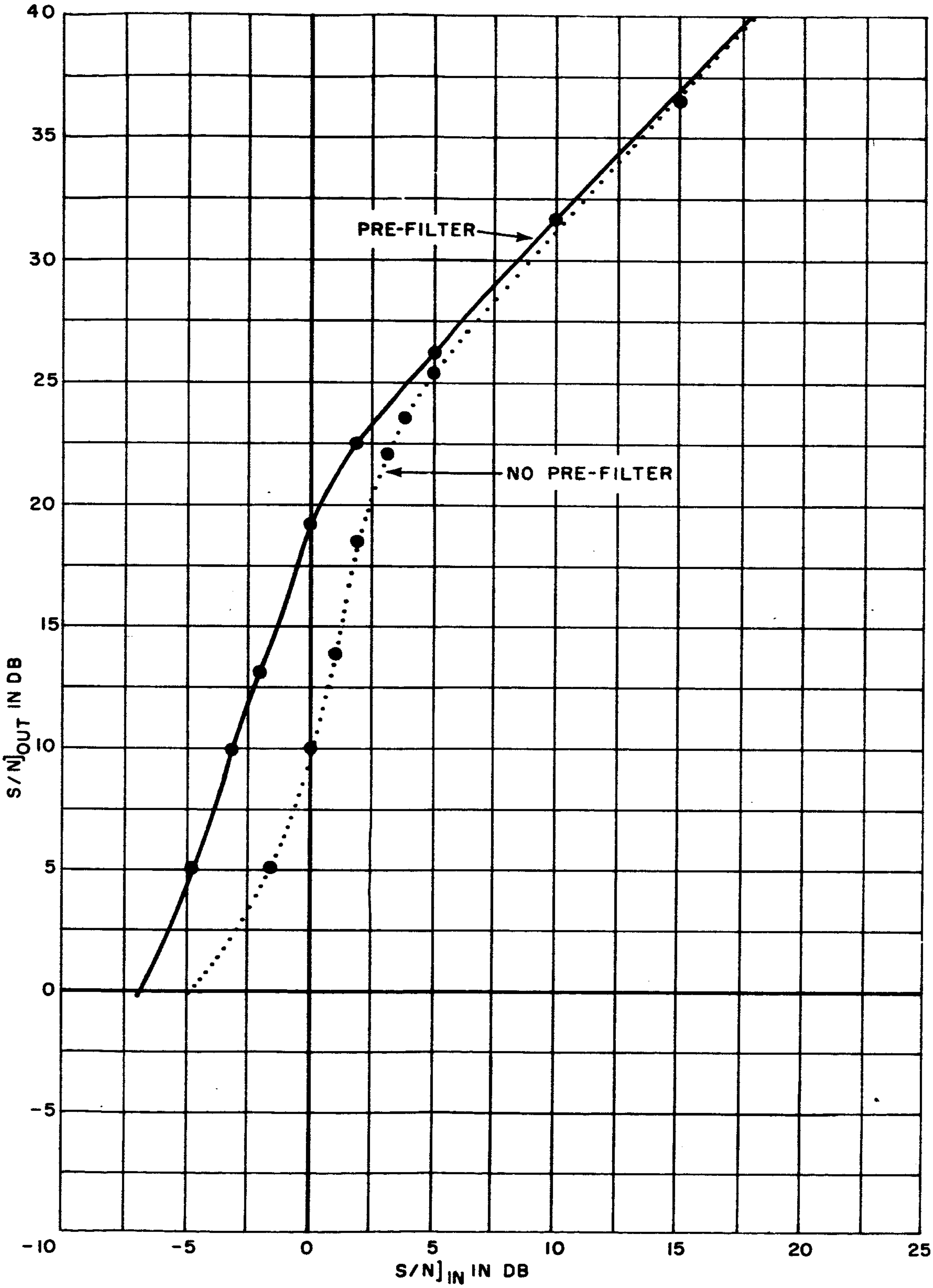


Figure 6—Theoretical Curves for Pre Filtered and Non Pre Filtered Loop

generated noise, play an important role in the system behavior below the "knee" of the curve, only white noise with Gaussian distribution was considered in the computations.

3. EXPERIMENTAL RESULTS

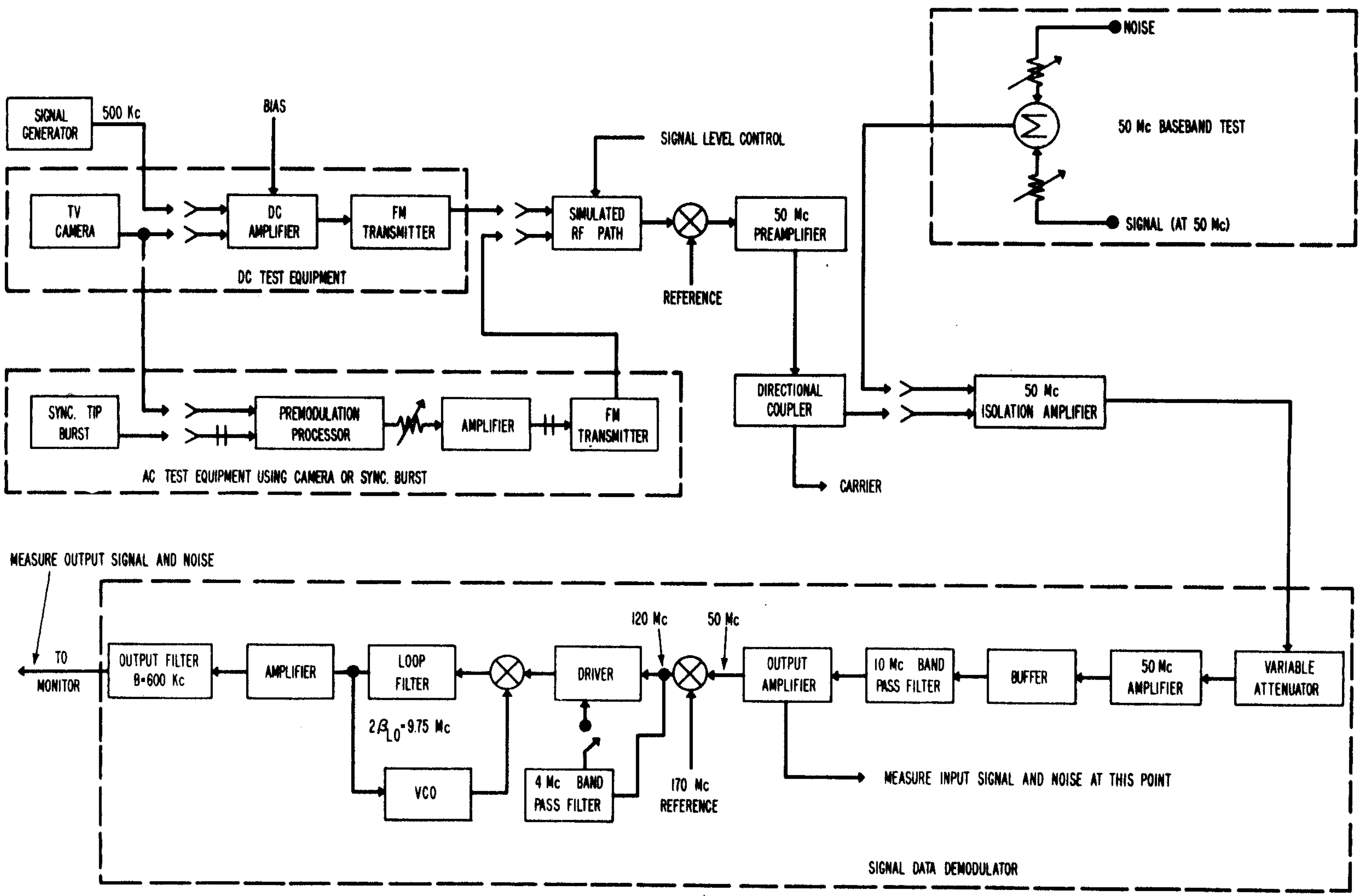
In order to prove the validity of the calculated results, a test was conducted using the 10 Mc predetection filter (already built in the demodulator) and a 4 Mc three stage double tuned filter centered at 120 Mc. This test was conducted in the Electronics Test Facility of the Manned Spacecraft Center in Houston, Texas, using the actual Unified S-Band Spacecraft and Ground equipment. Although the primary purpose of the test was to verify the theoretical computations, signal-to-noise ratio measurements were made using television "pictures" (patterns) with AC and DC response. The two different signals were used in order to evaluate the "picture" quality and obtain an indication as to whether AC or DC response should be used in the spacecraft for best system operation. In addition, a 500 kc sinusoid, along with noise, were transmitted through the ground receiver and demodulator at baseband, and signal-to-noise ratio measurements were made. Thus a baseband, an AC response, and a DC response tests were conducted.

The system set-up used to conduct the tests is shown in Figure 7. During each of the three tests mentioned above, three carrier frequency deviations were used. These were 1 Mc, 1.25 Mc, and 1.5 Mc. With each deviation, the input signal-to-noise ratio to the ground demodulator was varied from -10 db to +20 db and the output voltage due to signal V_s, signal plus noise $V_s + V_N$, and noise V_N were measured. From these measurements the output signal-to-noise was determined. Needless to say, each measurement was taken using first the 10 Mc predetection filter and then the 4 Mc predetection filter.

Since the analytical predictions were made using a 500 kc sinusoid and since the baseband test was conducted using a 500 kc sinewave, the baseband test will be discussed at first and the results will be compared with the analytical predetections.

3.1 The Baseband Test

The baseband test was conducted using a noise source and a 50 Mc signal frequency modulated by a 500 kc sinewave. The modulated signal was added with the noise in a summation network and the composite was routed to the demodulator through an isolation amplifier and a variable attenuator.



SIGNAL GENERATOR
500 Kc
BIAS
TV CAMERA
DC AMPLIFIER
FM TRANSMITTER
DC TEST EQUIPMENT
SYNC. TIP BURST
PREMODULATION PROCESSOR
AMPLIFIER
FM TRANSMITTER
AC TEST EQUIPMENT USING CAMERA OR SYNC. BURST
SIGNAL LEVEL CONTROL
SIMULATED RF PATH
REFERENCE
50 Mc PREAMPLIFIER
DIRECTIONAL COUPLER
CARRIER
NOISE
50 Mc BASEBAND TEST
SIGNAL (AT 50 Mc)
50 Mc ISOLATION AMPLIFIER
MEASURE OUTPUT SIGNAL AND NOISE
TO MONITOR
OUTPUT FILTER B=600 Kc
AMPLIFIER
LOOP FILTER
$2\beta_{L0}$=9.75 Mc
VCO
DRIVER
4 Mc BAND PASS FILTER
120 Mc
50 Mc
170 Mc REFERENCE
OUTPUT AMPLIFIER
10 Mc BAND PASS FILTER
BUFFER
50 Mc AMPLIFIER
VARIABLE ATTENUATOR
MEASURE INPUT SIGNAL AND NOISE AT THIS POINT
SIGNAL DATA DEMODULATOR

Figure 7

The input signal and noise measurements were made at the output of the output amplifier prior to conversion of the input to 120 Mc as shown in Figure 7. Then the signal and noise were routed to the loop via the 10 Mc and the 4 Mc filters, and the output measurements were made at the output of the post detection filter.

The data obtained are shown in Tables 1 through 6. The first three tables contain the data obtained using the 10 Mc filter and the rest of the tables contain the data obtained using the 4 Mc predetection filter.

In computing the signal-to-noise ratio in versus signal-to-noise ratio out curves shown in Figure 6, a modulation index of 3 was used. Thus the carrier peak deviation was 1.5 Mc. In order, then, to compare the theoretical predictions with the experimental results, the data obtained for the prefiltered and non-prefiltered cases will be plotted using the 1.5 Mc carrier deviation. Thus using Tables 3 and 6 we plot the signal-to-noise ratio in versus the signal-to-noise ratio out of the demodulator. The curves are shown in Figure 8. As predicted, below the "Knee" of the curves an improvement in output signal-to-noise ratio is obtained using the 4 Mc predetection filter. Thus it has been shown that pre-filtering the loop results in improvement of system performance.

If we now compare the theoretical predictions with the experimental results we find that there is a slight disagreement. This disagreement may be the result of several factors, the most outstanding of which is the fact that the signal power was measured at the output of the system in the absence of noise. Thus the effects of noise on the signal are not included. A secondary factor may be the fact that no impulse noise and no equipment generated noise were considered in the theoretical predictions. In any case, the experimental data clearly show that improvement is obtained by prefiltering the loop.

As previously mentioned, an AC response test and a DC response test were conducted in addition to the baseband test. In conducting these tests actual television patterns were "transmitted" to the ground system and Polaroid pictures were obtained in order to compare the loop operation with the 4 Mc and 10 Mc filters, and also the AC and DC response picture quality. These tests and their results will now be discussed.

3.2 The AC and DC Response Tests

The AC and DC response tests were conducted in the same way. The only difference between the two were the spacecraft transmitting equipment used.

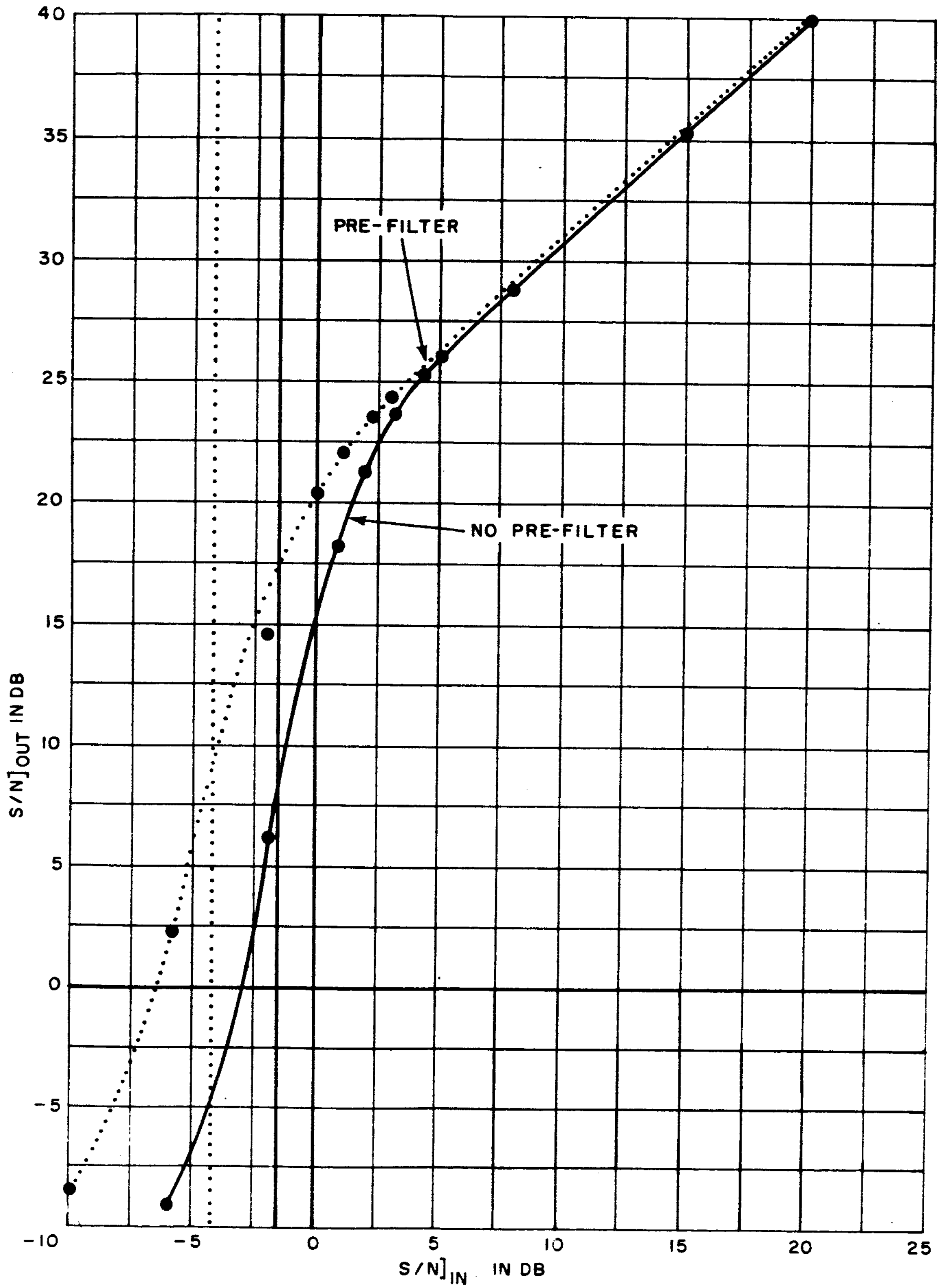


Figure 8–Experimental Curves for Pre Filtered and Non Pre Filtered Loop

As shown in Figure 7, the DC response test was conducted using the TV camera output routed to the FM transmitter via a DC amplifier which was biased. Then the transmitter output was routed to the demodulator via a simulated RF path and a 50 Mc amplifier. The AC response test was conducted using the TV camera output which was routed to the FM transmitter via the premodulation processor, an attenuator and an amplifier AC coupled to the FM transmitter. Then, as Figure 7 indicates, the output of the transmitter was routed to the ground demodulator through the same path described above for the DC test. In both tests the demodulator input signal-to-noise ratio was measured and for a range of input signal-to-noise ratios Polaroid photographs were obtained at the output of the monitor using both the 4 Mc and 10 Mc demodulator predetection bandwidths. It may be of interest to note the photographs were taken over a 5 frame interval.

A rather large number of photographs were obtained for both the AC and DC response tests and it would require a large number of pages to present all of them in this report. However, an adequate number of photographs will be presented in order to allow a comparison between the prefiltered and non-prefiltered loop and between AC and DC response.

The photographs presented in the next several pages for both the AC and DC response tests were obtained using a carrier deviation of 1.5 Mc. Several interesting things may be seen by examining the series of photographs presented in this report. First of all, in both AC and DC response tests, the prefiltered loop picture quality is better than the non-prefiltered loop picture quality in all cases except, as expected, at high signal-to-noise ratios ($S/N_{in} >$ +7 db) at the demodulator input. Secondly, it can be seen that the DC response picture quality is better than the AC response picture quality for the same input signal-to-noise ratios. In fact, at zero db input signal-to-noise ratio in the prefiltered loop with DC response, the pattern in the photograph is recognizable. With AC response however, for the same input signal-to-noise ratio, the pattern is highly disturbed.

Further examination of the photographs and use of the experimental and theoretical plots reveals that relatively good picture quality is obtained (with DC response) at output signal-to-noise ratios between 17 db and 20 db. This indicates that if DC response is used, television information at lunar distances will be obtained with 6 db to 8 db signal-to-noise ratio at the input of the pre-filtered demodulator. Examination of Tables 1 through 6 indicates that the carrier deviation of 1.5 Mc (modulation index of 3) yields higher output signal-to-noise ratios than the rest of the deviations used. Thus, it seems that a modulation index of 3 could be used and still retain the 4 Mc predetection bandwidth.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, it may be stated that if the ground demodulator is pre-filtered, an improvement is obtained in the television link. Furthermore, it has been shown that DC restoration provides better picture quality than AC response for the same input signal-to-noise ratios. It is therefore recommended that the ground carrier frequency demodulator be pre-filtered with a filter whose noise bandwidth is about 4 Mc. In addition, it is recommended that transmission of video signals with DC restoration from the spacecraft should be considered, using a modulation index of 3 or a carrier peak deviation of 1.5 Mc.

Table 1
Non Pre-Filtered Loop
(Carrier Deviation = 1. Mc)

(S/N) In (db)	VCO Atten. (db)	Noise Atten. (db)	SDD Atten. (db)	Power Meter	Signal Voltage V_s (Mv)	Sig + Noise Voltage $V_s + V_n$ (Mv)	Noise Voltage V_n (Mv)	$\frac{V_s}{V_n}$	(S/N) Out (db)
-10	25	18	26	-0.3	50	815	740	0.0675	-23.45
-6		22		-3.4	152	640	475	0.321	-9.92
-2		26		-6.0	315	470	185	1.702	4.62
0		28		-7.0	365	425	93	3.921	11.88
1		29		-7.5	375	415	65	5.773	15.23
2		30		-7.8	380	405	48	7.926	17.97
3		31		-8.2	385	405	37	10.410	20.34
4		32		-8.4	380	400	31	12.315	21.80
5		33		-8.8	380	395	27	14.198	22.98
6		34		-8.9	380	395	24	15.825	23.98
8		36		-9.3	375	395	20	18.753	25.52
10		38		-9.4	370	390	16	23.153	27.29
15		43		-9.8	370	390	9	41.116	32.27
20		48		-9.7	370	390	5	74.054	37.38

Table 2
Non Pre-Filtered Loop
(Carrier Deviation = 1.25 Mc)

(S/N) In (db)	VCO Atten. (db)	Noise Atten. (db)	SDD Atten. (db)	Power Meter	Signal Voltage V_s (Mv)	Sig + Noise Voltage $V_s + V_n$ (Mv)	Noise Voltage V_n (Mv)	$\frac{V_s}{V_n}$	(S/N) Out (db)
-10	25	18	26	-0.3	53	840	740	0.0720	-22.9
-6		22		-3.4	163	690	475	.34115	-9.4
-2		26		-6.0	360	560	185	1.9538	5.8
0		28		-7.0	420	520	93	4.5220	13.1
1		29		-7.5	460	515	65	7.0850	17.0
2		30		-7.8	475	510	48	9.9098	19.9
3		31		-8.2	480	505	37	13.0169	22.2
4		32		-8.4	475	500	31	15.3234	23.7
5		33		-8.8	480	495	27	17.8316	25.0
6		34		-8.9	475	495	24	19.8392	25.9
8		36		-9.3	470	490	20	23.5552	27.4
10		38		-9.4	465	485	16	29.1847	29.3
15		43		-9.8	470	490	9	52.2272	34.4
20		48		-9.7	465	490	5	93.8649	39.4

Table 3
Non Pre-Filtered Loop
(Carrier Deviation = 1.5 Mc)

(S/N) In (db)	VCO Atten. (db)	Noise Atten. (db)	SDD Atten. (db)	Power Meter	Signal Voltage V_s (Mv)	Sig + Noise Voltage $V_s + V_n$ (Mv)	Noise Voltage V_n (Mv)	$\frac{V_s}{V_n}$	(S/N) Out (db)
-10	25	18	26	-0.3	53	870	740	0.0716	-22.9
-6		22		-3.4	163	740	475	0.3911	-9.36
-2		26		-6.0	380	630	185	2.0542	6.23
0		28		-7.0	495	610	93	5.3228	14.5
1		29		-7.5	535	605	65	8.2367	18.3
2		30		-7.8	560	600	48	11.713	21.3
3		31		-8.2	570	600	37	15.423	23.7
4		32		-8.4	565	595	31	18.233	25.2
5		33		-8.8	565	590	27	20.943	26.4
6		34		-8.9	570	590	24	23.856	29.5
8		36		-9.3	570	590	20	28.581	29.0
10		38		-9.4	560	585	16	35.122	30.8
15		43		-9.8	560	585	9	62.238	35.8
20		48		-9.7	560	585	5	112.125	40.9

Table 4
Pre-Filtered Loop
(Carrier Deviation = 1.0 Mc)

(S/N) In (db)	VCO Atten. (db)	Noise Atten. (db)	SDD Atten. (db)	Power Meter	Signal Voltage V_s (Mv)	Sig + Noise Voltage $V_s + V_n$ (Mv)	Noise Voltage V_n (Mv)	$\frac{V_s}{V_n}$	(S/N) Out (db)
-10	25	18	26	-0.3	115	460	380	0.3009	-10.46
-6		22		-3.4	238	405	228	1.0410	0.34
-2		26		-6.2	340	380	88	3.8614	11.73
0		28		-7.4	365	385	51	7.1651	17.10
1		29		-7.8	370	385	42	8.8177	18.90
2		30		-8.3	370	390	37	10.100	20.0
3		31		-8.8	375	390	33	11.4130	21.14
4		32		-9.0	375	390	29.5	12.9161	22.07
5		33		-9.4	375	390	27	13.9193	22.8
6		34		-9.5	375	390	24	15.6243	23.86
8		36		-10.	375	385	19	19.7388	25.9
10		38		-10.1	370	385	15	24.7614	77.85
15		43		-10.5	370	385	9	41.1169	32.28
20		48		-10.5	375	385	5	75.5625	37.49

Table 5
Pre-Filtered Loop
(Carrier Deviation = 1.25 Mc)

(S/N) In (db)	VCO Atten. (db)	Noise Atten. (db)	SDD Atten. (db)	Power Meter	Signal Voltage V_s (Mv)	Sig + Noise Voltage $V_s + V_n$ (Mv)	Noise Voltage V_n (Mv)	$\frac{V_s}{V_n}$	(S/N) Out (db)
-10	25	18	26	-0.3	130	490	380	0.3411	-9.4
-6		22		-3.4	278	460	228	1.2214	1.73
-2		26		-6.2	415	465	88	4.7222	13.48
0		28		-7.4	450	475	51	8.8277	18.91
1		29		-7.8	460	482	42	10.9512	20.80
2		30		-8.3	460	480	37	12.415	21.87
3		31		-8.8	465	485	33	14.119	22.99
4		32		-9.0	465	480	29.5	15.825	23.98
5		33		-9.4	470	485	27	17.430	24.81
6		34		-9.4	465	485	24	19.437	25.75
8		36		-10.	465	480	19	24.560	27.78
10		38		-10.1	460	480	15	30.794	29.74
15		43		-10.5	465	480	9	51.726	34.27
20		48		-10.5	460	480	5	92.846	39.27

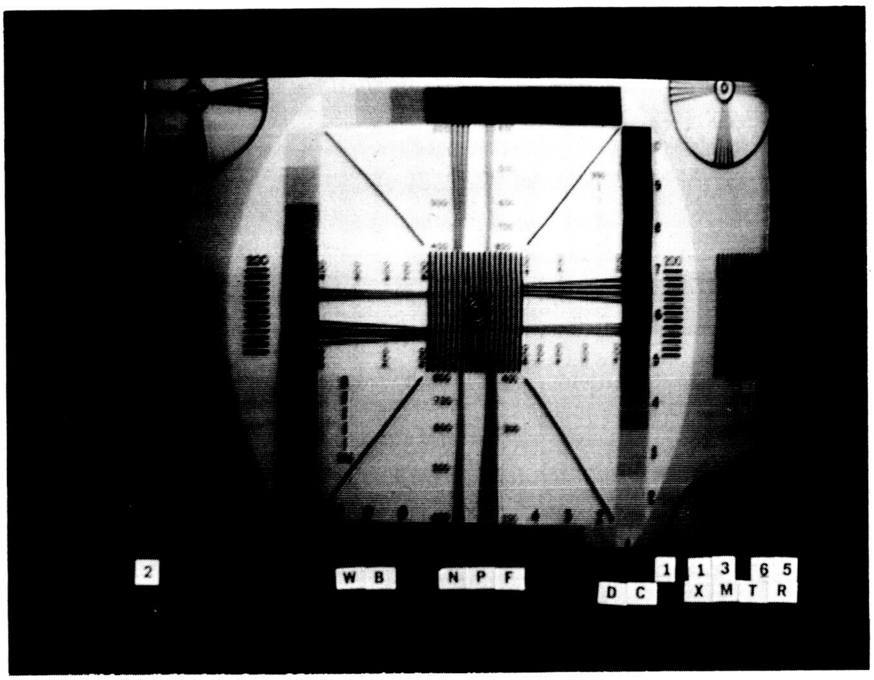
Table 6
Pre-Filtered Loop
(Carrier Deviation = 1.5 Mc)

(S/N) In (db)	VCO Atten. (db)	Noise Atten. (db)	SDD Atten. (db)	Power Meter	Signal Voltage V_s (Mv)	Sig + Noise Voltage $V_s + V_n$ (Mv)	Noise Voltage V_n (Mv)	$\frac{V_s}{V_n}$	(S/N) Out (db)
-10	25	18	26	-0.3	137	515	380	0.36	-8.86
-6		22		-3.4	297	510	228	1.301	2.28
-2		26		-6.2	480	540	88	5.4529	14.72
0		28		-7.4	530	565	51	10.4108	20.34
1		29		-7.8	545	570	42	13.169	22.28
2		30		-8.3	550	570	37	14.9222	23.46
3		31		-8.8	555	575	33	16.8282	24.50
4		32		-9.0	555	570	29.5	18.8353	25.48
5		33		-9.4	555	570	27	20.6424	26.27
6		34		-9.5	560	575	24	23.3544	27.35
8		36		-10.0	560	575	19	29.5870	29.39
10		38		-10.1	555	570	15	37.1369	31.37
15		43		-10.5	555	570	9	61.6379	35.75
20		48		-10.5	560	575	5	112.1254	40.99

DC Response

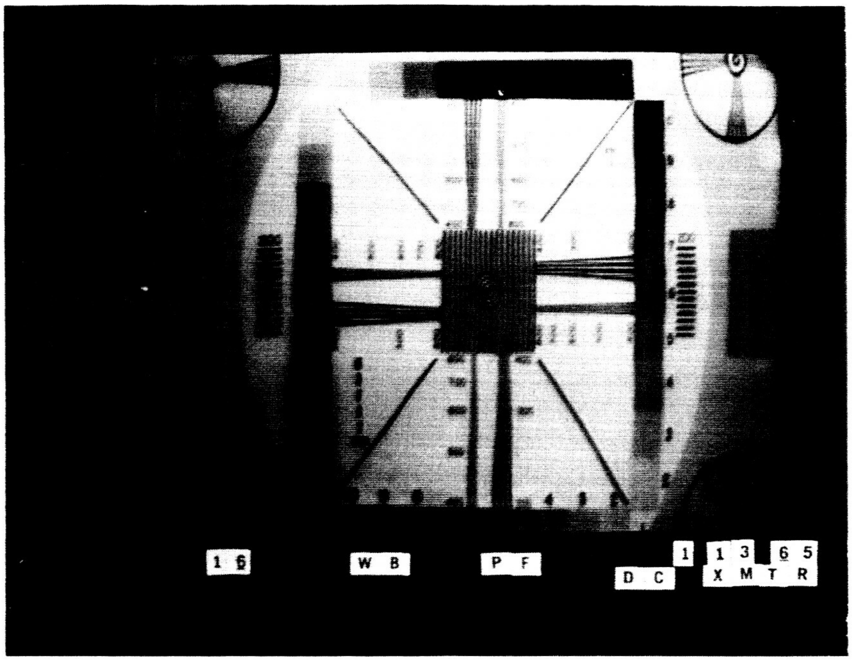
$S/N]_{in}$ in 10 Mc = +16 db

ΔF = 1.5 Mc

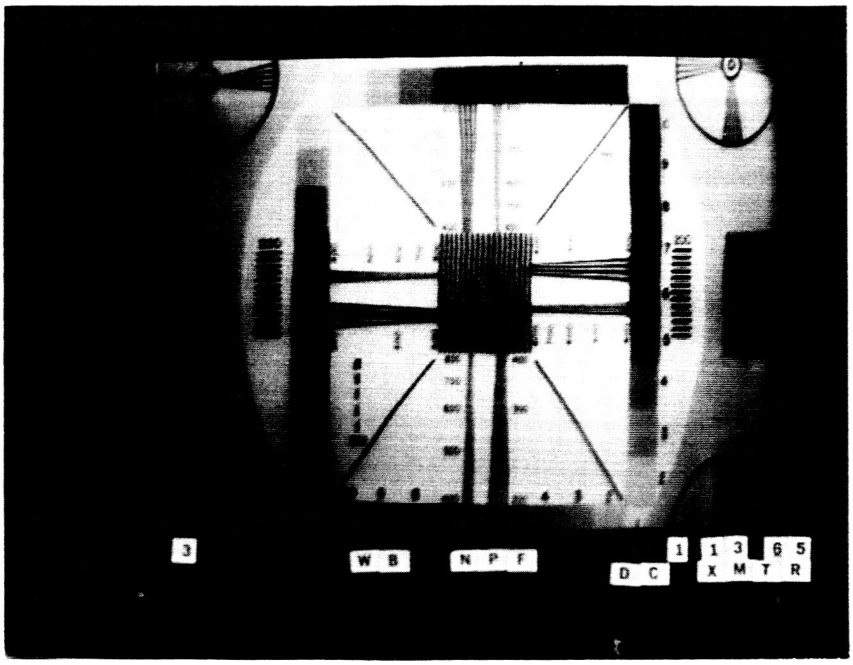


Apollo Television Channel Quality
for High Input S/N

DC Response
$S/N]_{in}$ in 10 Mc = +6 db
ΔF = 1.5 Mc



Pre Filtered Loop

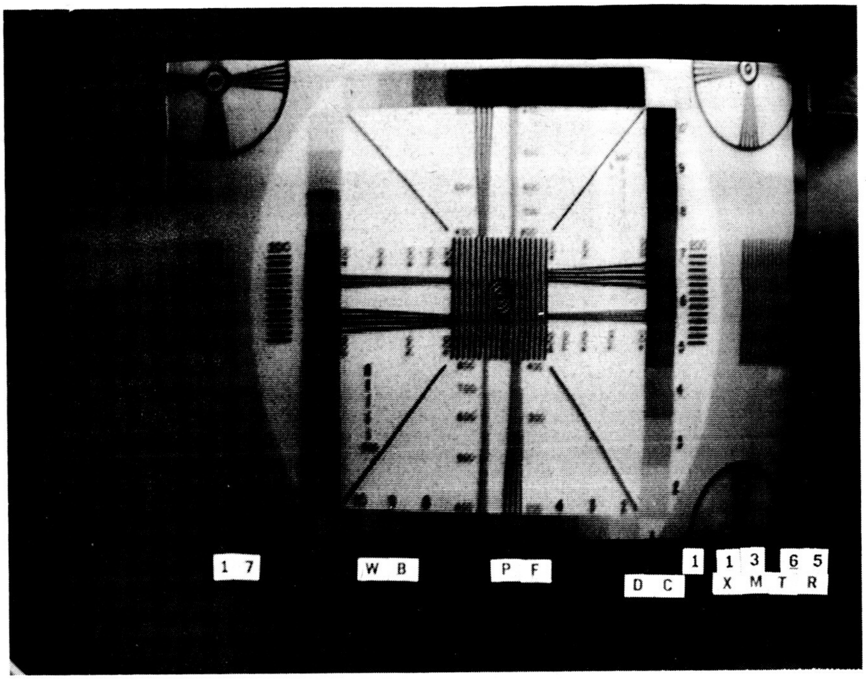


Non Pre Filtered Loop

DC Response

$S/N]_{in}$ in 10 Mc = +4 db

$\Delta F = 1.5$ Mc



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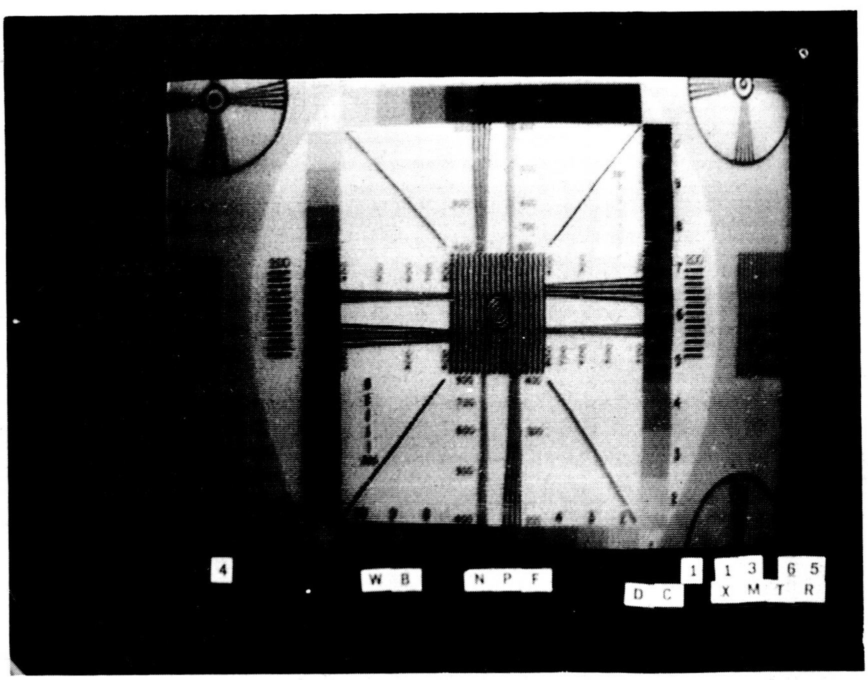
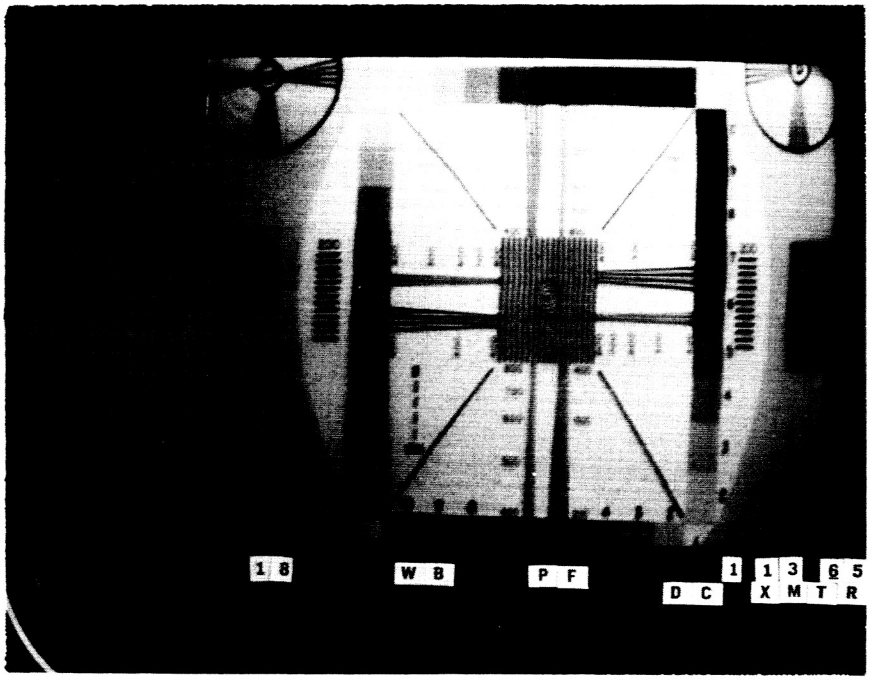


Non Pre Filtered Loop

DC Response

$S/N]_{in}$ in 10 Mc = +3 db

ΔF = 1.5 Mc



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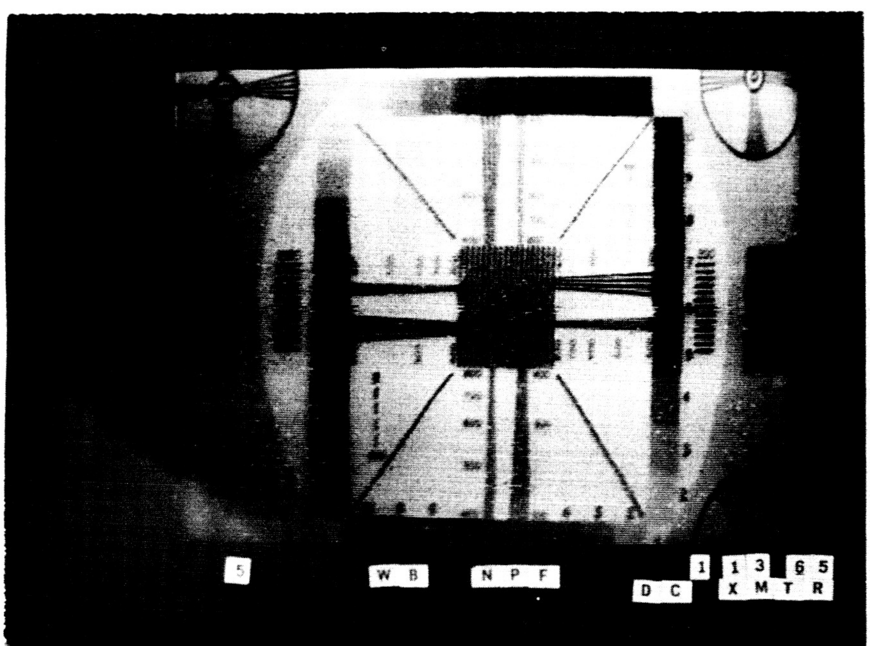
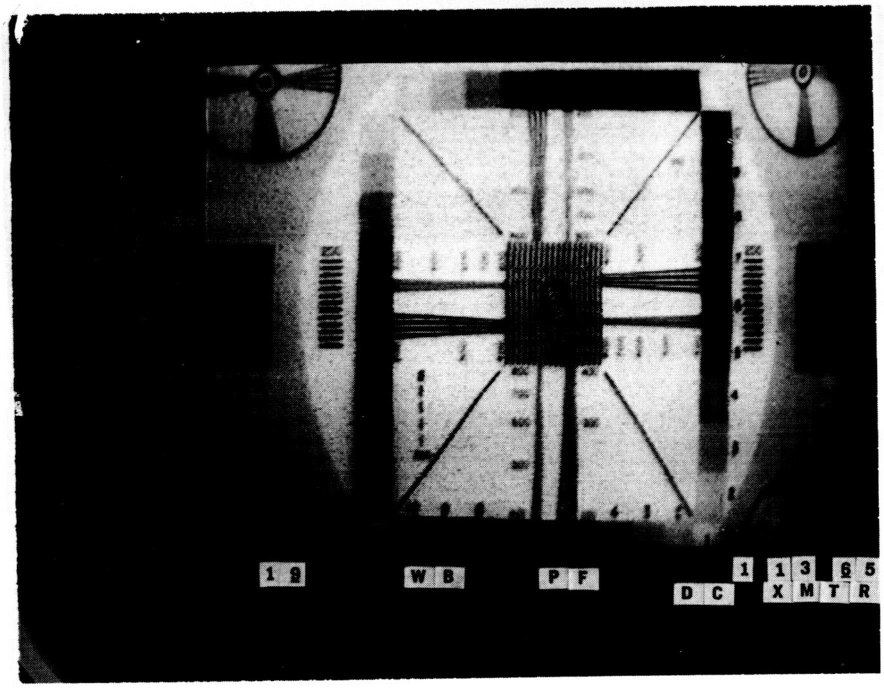


Non Pre Filtered Loop

DC Response
$S/N]_{in}$ in 10 Mc = +2 db
ΔF = 1.5 Mc



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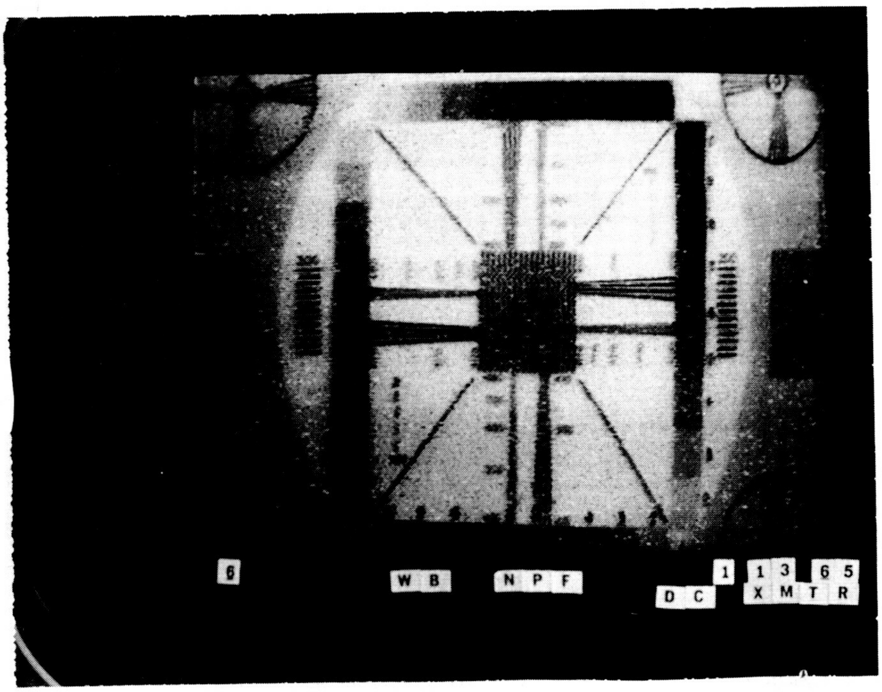
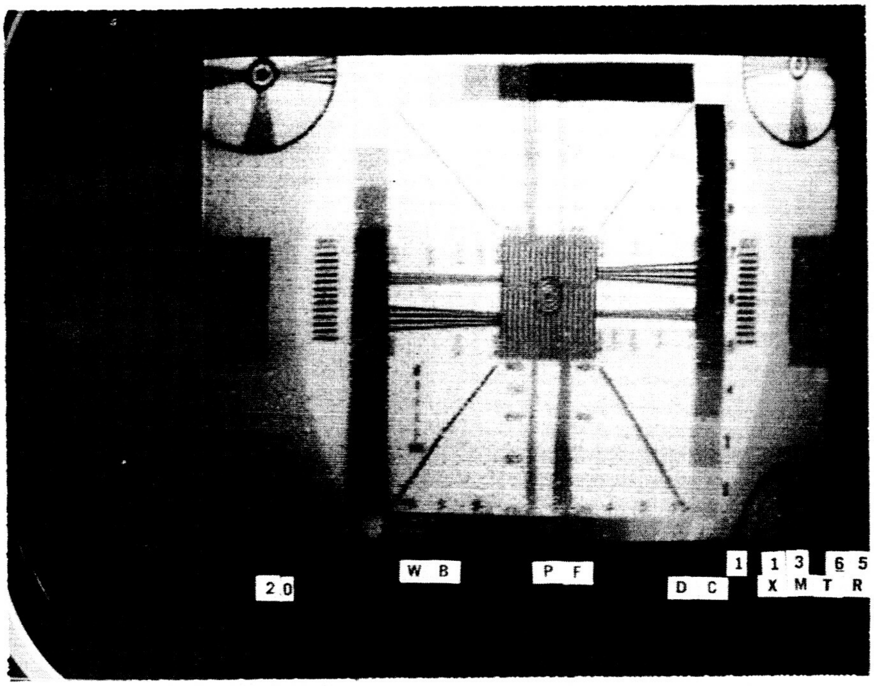


Non Pre Filtered Loop

DC Response

$S/N]_{in}$ in 10 Mc = +1

ΔF = 1.5 Mc



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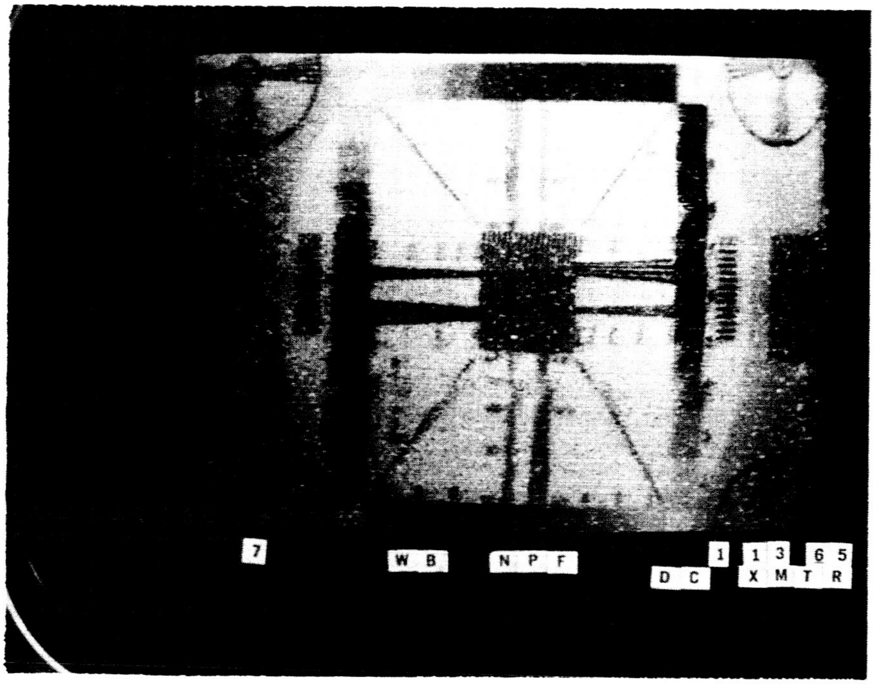
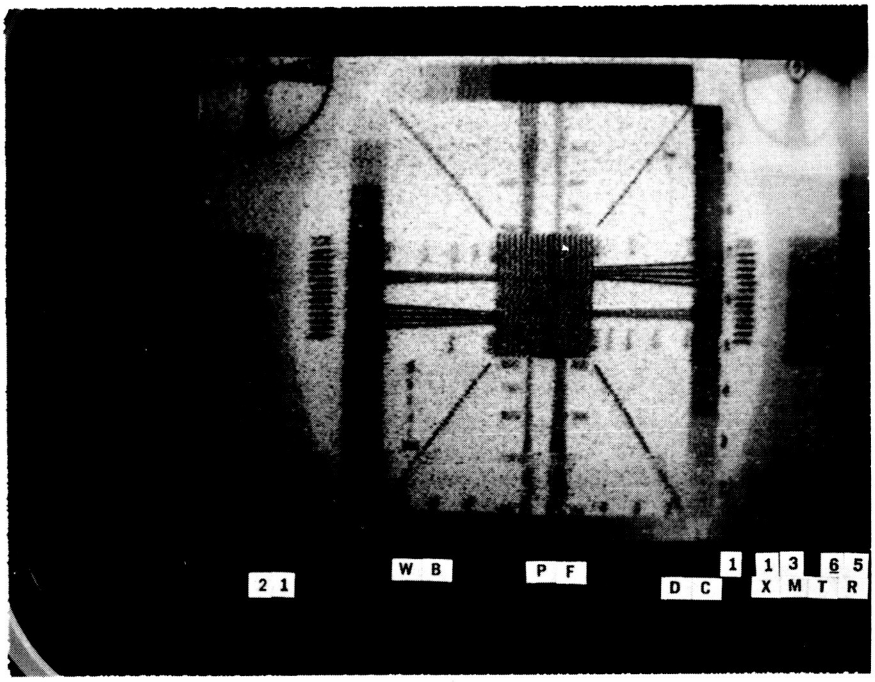


Non Pre Filtered Loop

DC Response
$S/N]_{in}$ in 10 Mc = 0 db
ΔF = 1.5 Mc



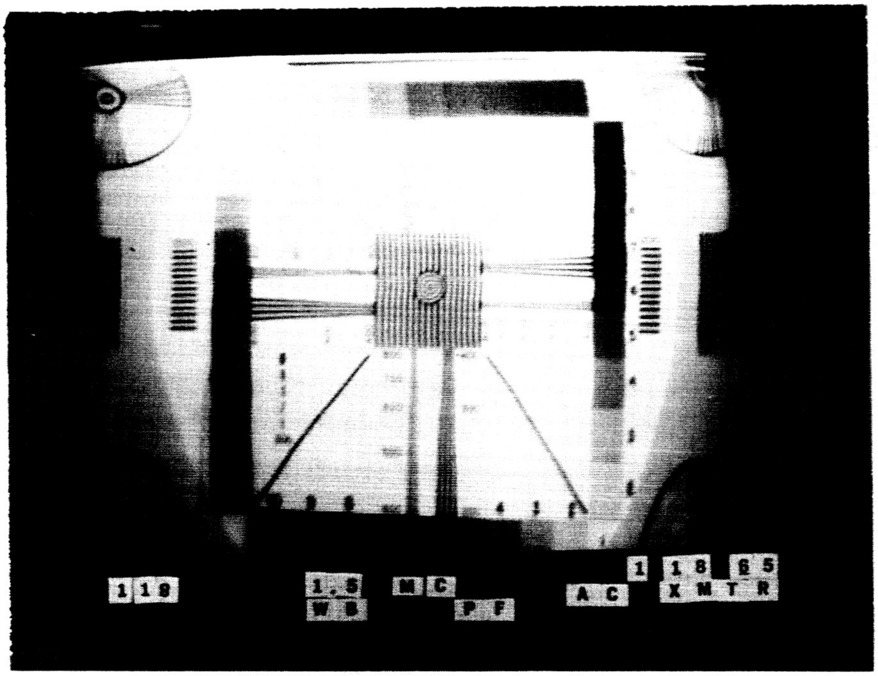
Pre Filtered Loop

No Photograph Could Be Obtained with the Non Pre Filtered Loop

AC Response

$S/N]_{in}$ in 10 Mc = +7 db

ΔF = 1.5 Mc



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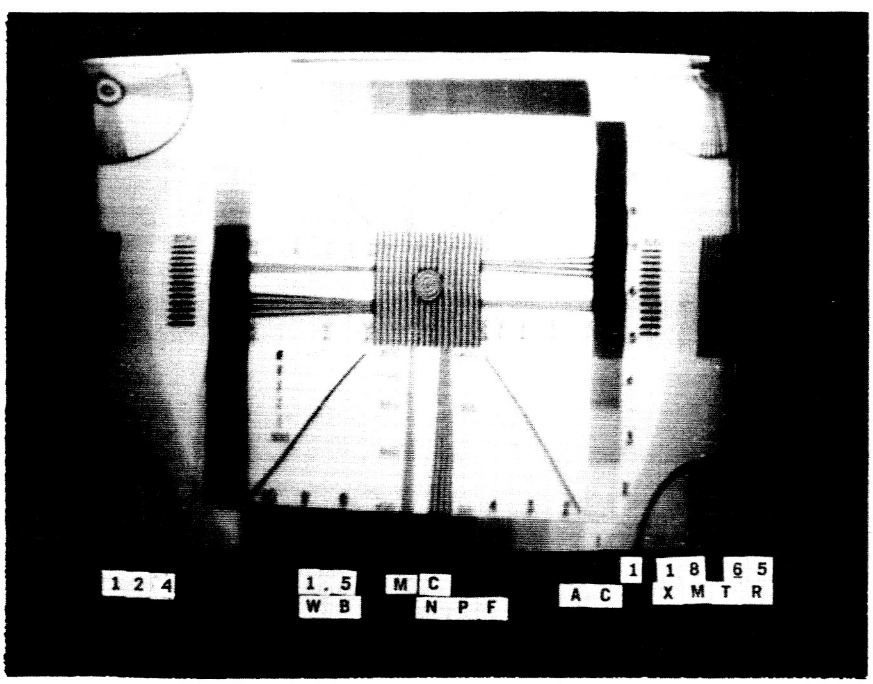
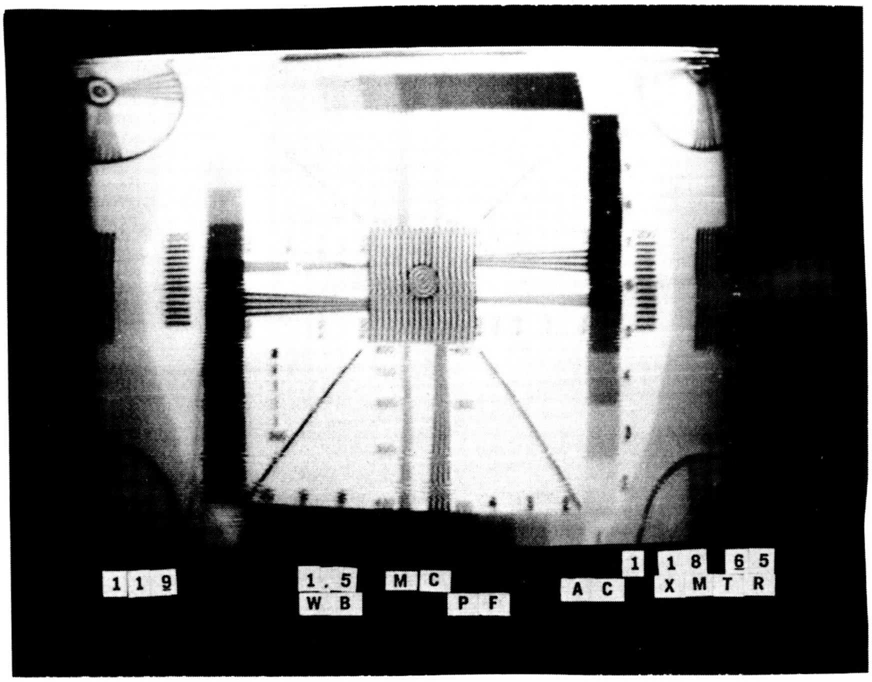


Non Pre Filtered Loop

AC Response
$S/N]_{in}$ in 10 Mc = +5 db
ΔF = 1.5 Mc



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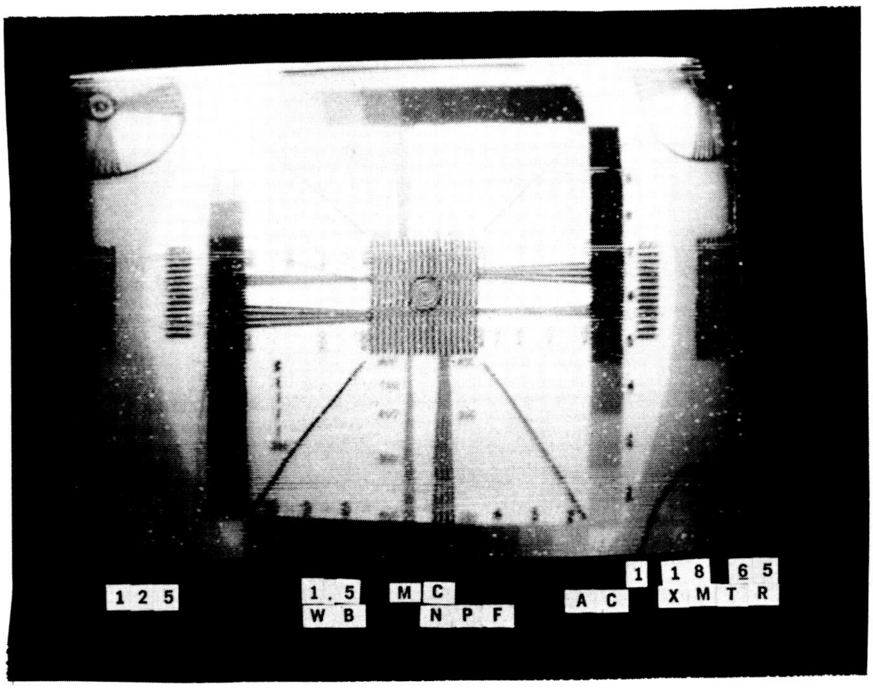
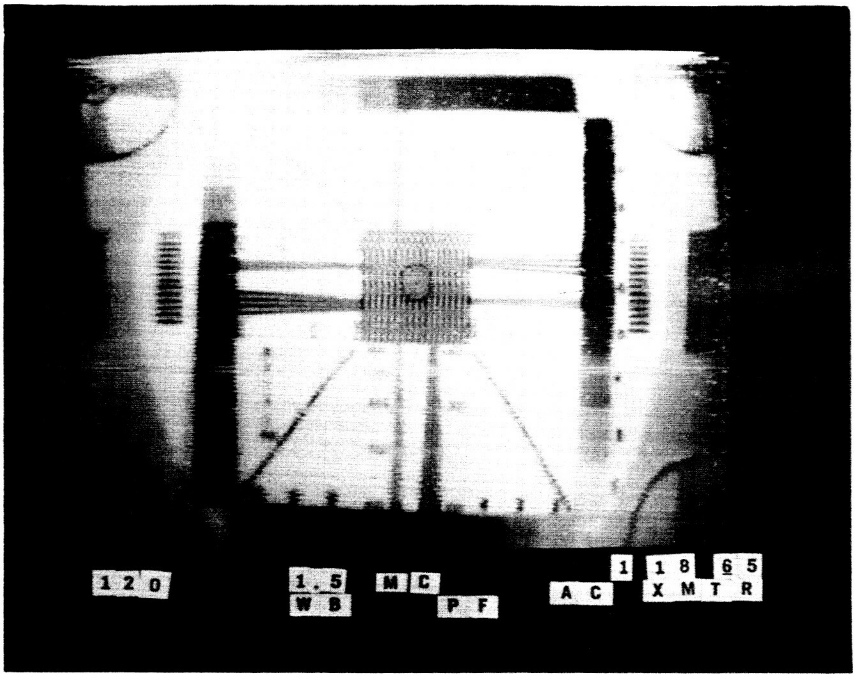


Non Pre Filtered Loop

AC Response
$S/N]_{in}$ in 10 Mc = +4 db
$\Delta F = 1.5$ Mc



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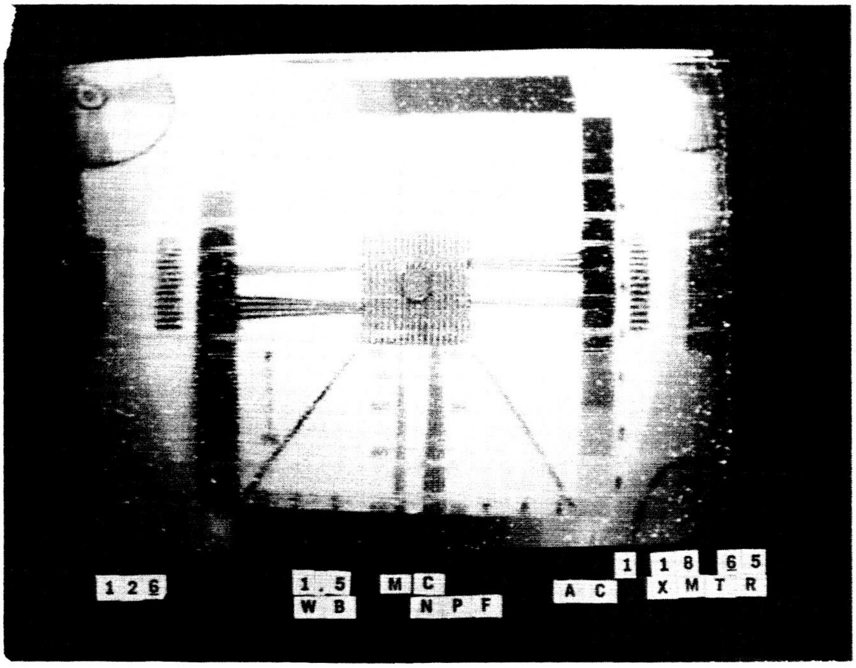
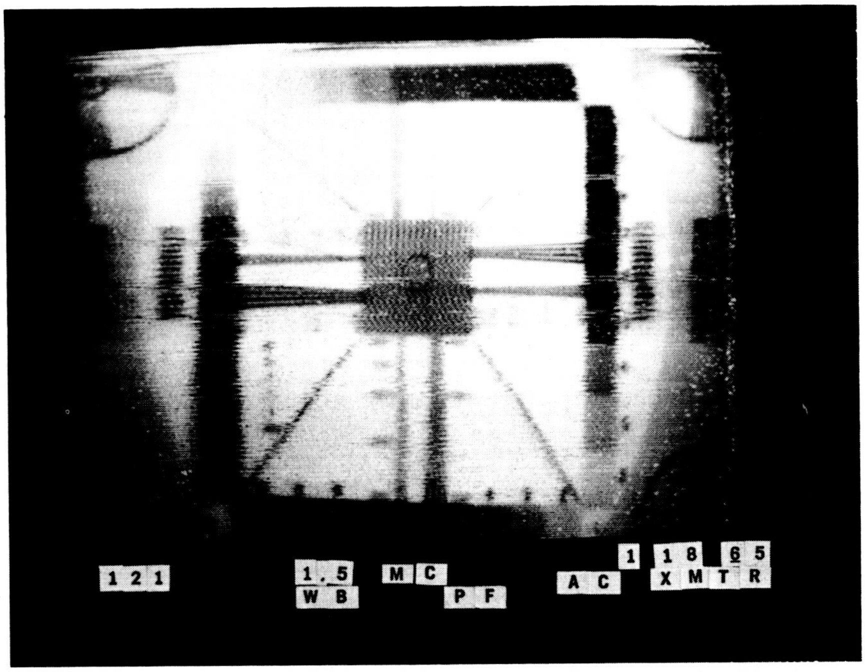
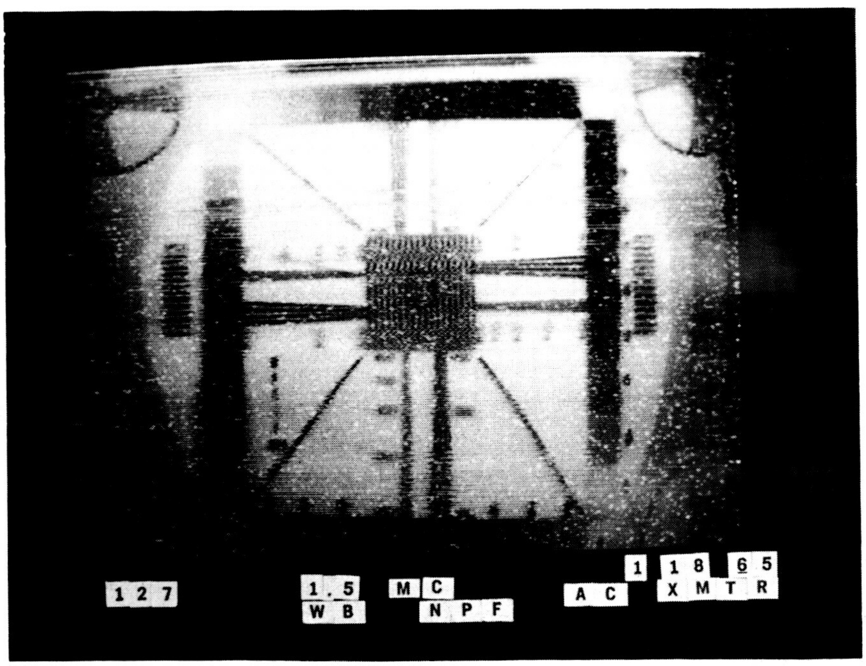


Non Pre Filtered Loop

AC Response
$S/N]_{in}$ in 10 Mc = +3 db
ΔF = 1.5 Mc



Pre Filtered Loop



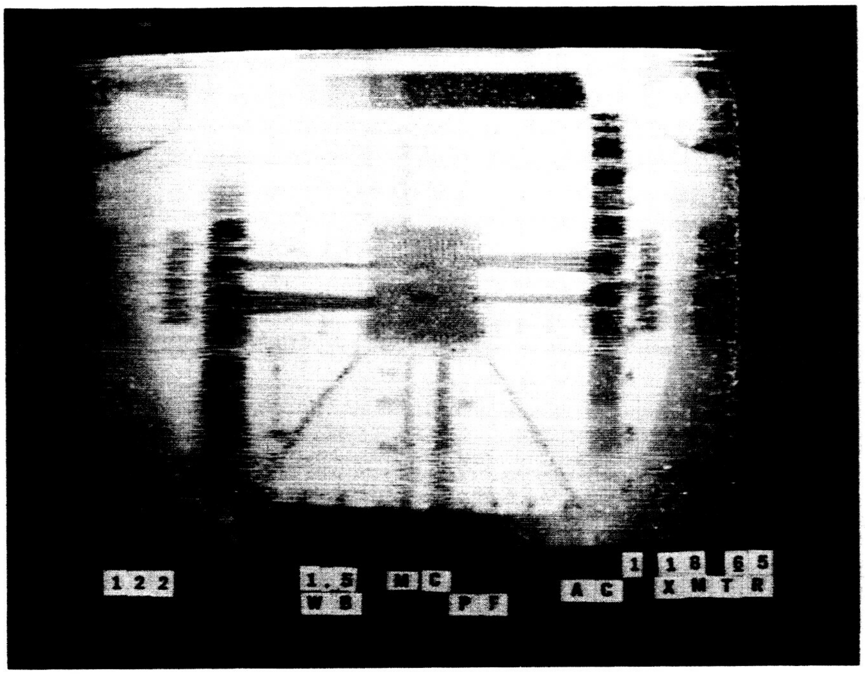
Non Pre Filtered Loop

AC Response

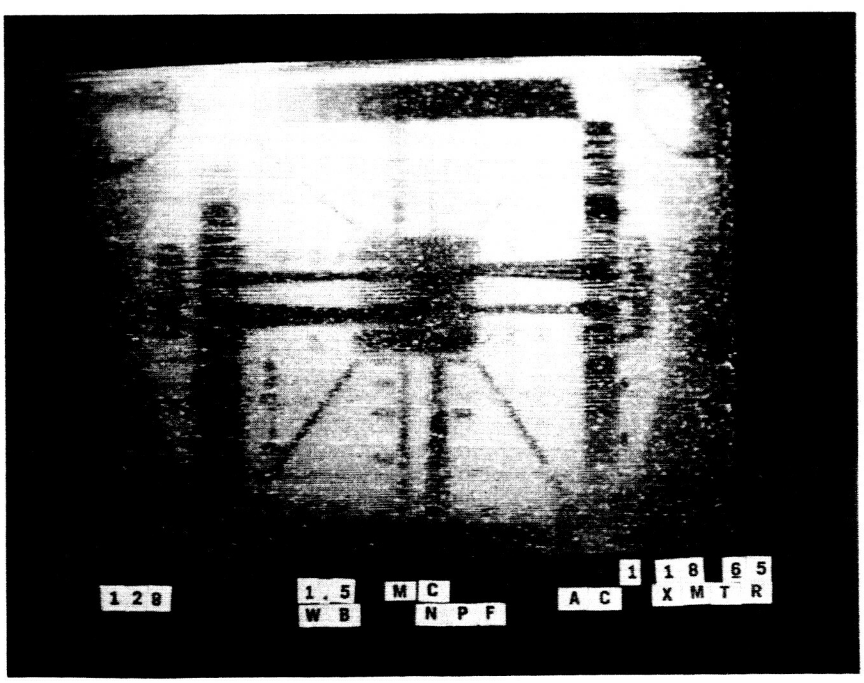
$S/N]_{in}$ in 10 Mc = +2 db (For Non Pre Filtered Loop)

$S/N]_{in}$ in 10 Mc = +1 db (For Pre Filtered Loop)

ΔF = 1.5 Mc



Pre Filtered Loop

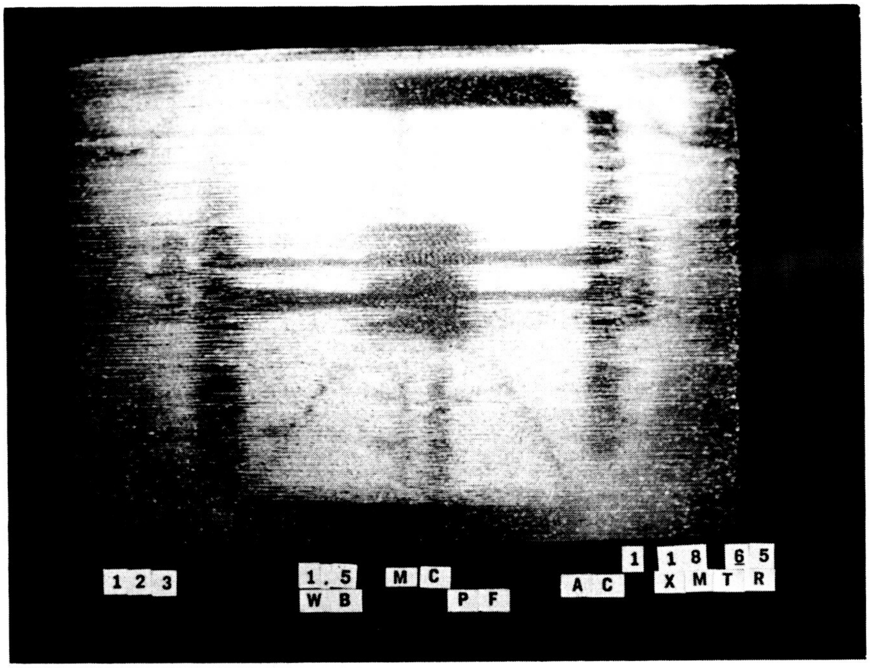


Non Pre Filtered Loop

AC Response

$S/N]_{in}$ in 10 Mc = 0 db

$\Delta F = 1.5$ Mc



Pre Filtered Loop

No Photograph Could Be Obtained with Non Pre Filtered Loop

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