SYSTEM CONSIDERATIONS AFFECTING ANTENNA PREAMPLIFIER DESIGN

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This paper presents the results of a study conducted as part of a preamplifier design project. It was considered important that the preamplifier being designed be the best combination of performance to suit system operator requirements. These results will also be of great interest to the system operator to aid him in choosing a suitable preamplifier.

The emphasis was placed on system considerations, that is how the performance of the preamplifier affects the overall performance of the system.

Antenna preamplifiers are used to improve the signal to noise ratio of weak signals. It is hoped that an overall improvement in signal to noise ratio will result for the entire system. The antenna preamplifiers can be characterized numerically by certain measurable parameters. These are: noise figure, overload capability, gain, and match. Not as easily measured is reliability.

The characteristics of the preamplifier are not the only factors affecting a particular system performance parameter. The signal to noise ratio of the system is affected by noise received by the antenna plus the noise figure of the head-end processor, and the noise figures and number of distribution amplifiers. Beat products and cross modulation can be generated by the antenna preamplifier and also any other active device of the cable system. For the purpose of our investigation, we have assumed values that we consider typical of the rest of the system.

Before we launch into a detailed discussion of antennas, preamplifiers and noise figures, let us talk about thermal noise. Noise is generated in any resistive device, due to the random motions of the electrons caused by the heat contained in the device. This noise power is proportional to the temperature in absolute degrees, the resistance and the bandwidth. It is a common misconception that a receiving antenna generates a noise level of -59 dBmv. This corresponds to the noise that would be generated by a 75 ohm resistor at room temperature. In the case of the antenna, the noise developed across its terminals is not being generated by the antenna, but rather, is a transformation of the electro-magnetic fields being received by that antenna. The antenna is composed of metallic elements with extremely low resistance and insulators with extremely low conductance. The impedance of the antenna is not associated with the actual elements of the antenna but rather with the space to which the antenna is coupled by the electro-magnetic fields.

The noise received by an antenna is composed of a certain amount of radiation generated by the earth, which is at approximately room temperature; atmospheric noise and radiation from outer space. The amount of noise received will depend on the pattern of the antenna and the direction in which the antenna is pointed. An antenna pointed down will receive more radiation from the earth, and an antenna pointed up will receive less. The upward pointing antenna will, of course, receive more radiation from space. The closest source in space is our sun. The amount of radiation from the sun depends on the direction and time of day. In other words, the noise is greatest when the antenna is pointed more or less directly at the sun. In certain directions the radiation from outer space can be extremely low; the temperature of intergalactic space appears to be about 3 degrees kelvin. However, the center of our galaxy is an extremely strong source of energy and the antenna pointed in that direction will receive a large amount of radiation.

Figure 1 shows graphically the relationship between noise level and frequency. Notice that the lower frequencies have a greater noise then higher frequencies. Expecially note, that the noise at the frequency of channel 2, is considerably larger then the often quoted -59 dBmv. It has often been said that the low band is noisy, this is one reason why. Figure 2 shows the noise received by an antenna pointed well above the horizon throughout a 24 hour period. The peak represents a time when the antenna is pointed at the center of our galaxy. The dip represents a time when the antenna is pointed at the very cold regions of intergalactic space. The height and width of the peaks will be affected by the beamwidth of the antenna. The antenna which has a narrower beam width will cause a higher, narrower peak.

The above does not take into consideration the affects of man-made noise. This can come from such sources as electric power distribution systems and ignition noise from vehicles. This is extremely variable and unpredictable, but, we have a certain degree of control over it, and can do

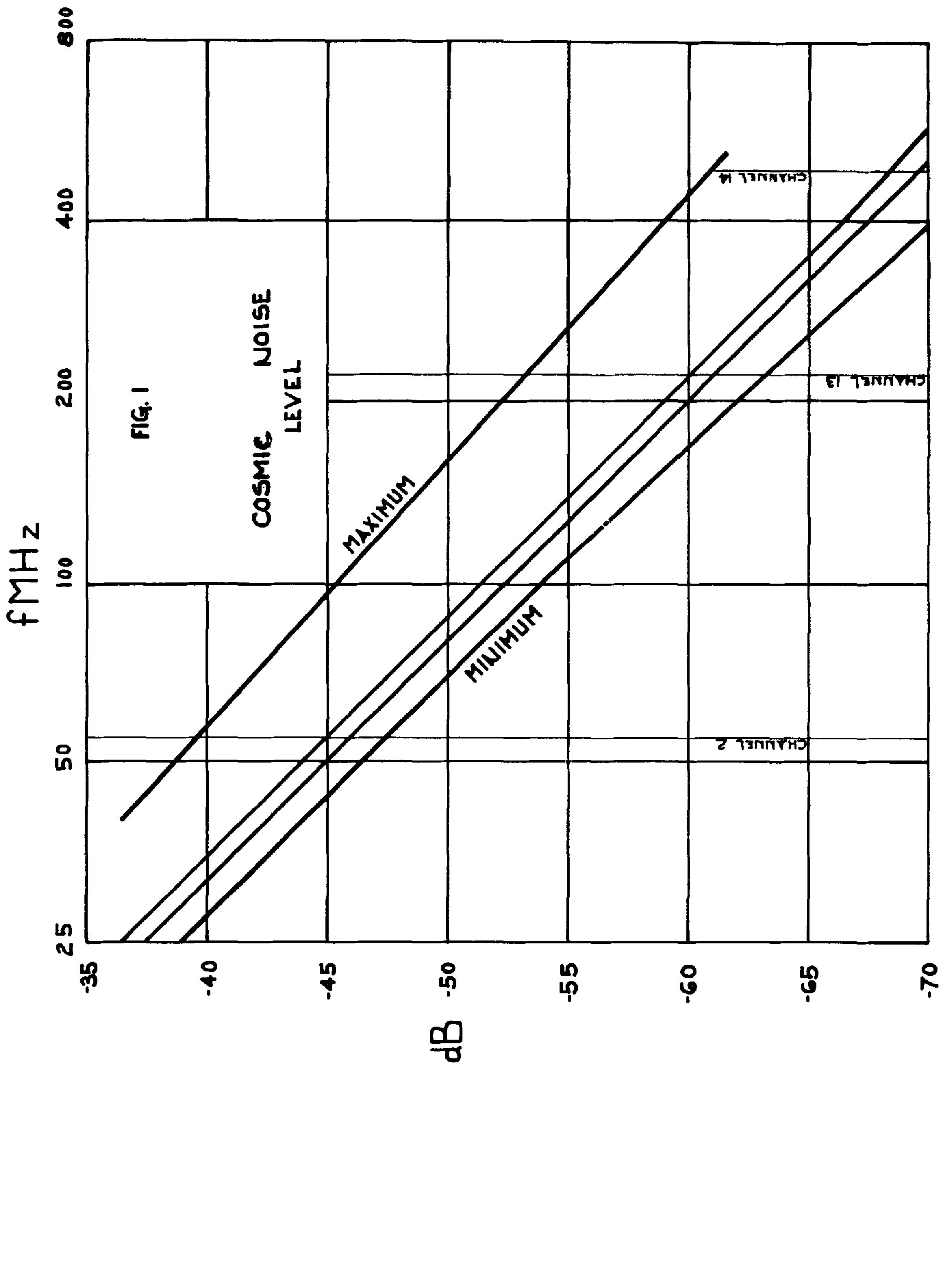


FIG. I
COSMIC NOISE LEVEL
MAXIMUM
MINIMUM
CHANNEL 14
CHANNEL 13
CHANNEL 2
fMHz
800
400
200
100
50
25
dB
-35
-40
-45
-50
-55
-60
-65
-70

something to reduce it.

As an aid to analysis and understanding, we are going to define a quantity called Delta signal to noise ratio and abbreviate it Δ SNR. This is a quantity which we will express in dB; it represents the improvement in signal to noise ratio which will be realized by using a particular kind of preamplifier. We define 0 dB Δ SNR as the signal to noise ratio which would result if the antenna were directly connected to the input of the head-end processor by a lossless cable. Thus, if the antenna is connected to the processor by an actual cable having a certain amount of loss the Δ SNR will be negative and equal to the loss of the cable. For that reason the actual improvement realized by using the preamplifier will be equal to the Δ SNR with the preamplifier minus the Δ SNR without the preamplifier. Note that Δ SNR is the improvement of signal to noise ratio which will be realized at the processor output.

By comparing Δ SNR for various situations, we can determine how much improvement in signal to noise ratio has been made by changing system parameters. We can determine how closely we have approached the maximum possible signal to noise ratio and what we will have to do to approach more closely. This can all be done with much less calculation and complexity than working with signal to noise ratio directly. After the system parameters are determined, the actual signal to noise ratio can be calculated by well known techniques.

Figure 3 shows the relationship between noise figure and Δ SNR for various levels of received antenna noise. Note that for -65 dBmv received noise, about the best that will be encountered at Channel 13, the affect of antenna preamplifier noise is quite large; much larger then one would expect, assuming that well known -59 dBmv. The change in noise figure, 1 dB to 2 dB, results in more than 2 dB change in signal to noise ratio. For -60 dBmv received noise, which is almost equal to -59 dBmv, the change is almost 1 dB for 1 dB. Let us look at the case of -45 dBmv, which is about average for Channel 2, here the change from 0 dB noise figure to 4 dB noise figure results in only 3/10 of a dB change in signal to noise ratio. This is quite an insignificant amount.

We can conclude that for low band channels, the noise figure of the preamplifier is relatively unimportant, but for high band channels it is of significant importance. This is a particularly unfortunate situation since, low noise figures are much easier to achieve at lower frequencies.

This discussion on noise figure would seem to indicate that for low band signals, the preamplifier is of no use. Let us investigate the effect of not having gain at the antenna. Figure 4 is the relationship of gain to Δ SNR, for an antenna noise level of -45 dBmv. For 5 dB loss between the antenna and the processor Δ SNR has a value of -1.2; for 4 dB noise figure and 15 dB of gain Δ SNR is +0.4. The total change is 1.6 dB. Here to simplify calculations and presentation, we have subtracted the loss between the preamplifier output and the processor from the gain of the preamplifier and called it effective gain. It appears that an effective gain of 15 dB results in a negligible degradation in Δ SNR compared to what would be realized with infinite gain. Figure 5 shows the same relationship for an antenna received noise of -55 dBmv and a processor noise figure of 7 dB. Note that a 15 dB effective gain results in only about 3/10 dB worse signal to noise ratio than would result from 30 dB of gain. We consider this 3/10 of a dB to be insignificant. Figure 6 shows the relationship for an antenna received noise of -65 dBmv.

In the case of the preamplifier with 2 dB noise figure, the difference between 15 and 30 dB of gain represents a change in signal to noise ratio of 6/10 dB. These figures show that 15 dB effective gain is sufficient for the conditions just described. These conditions are typical for reception of VHF signals. If we allow for 5 dB of cable between the antenna and the processor and the use of a hybrid splitter to run two processors off one antenna, this means that the preamplifier should have a minimum gain of 24 dB.

In the case of UHF reception, the preamplifier is the major source of noise. At these frequencies the present state of the art transistors have much higher noise figures and received antenna noise is much lower. We have assumed a received noise level of -65 dBmv and a processor noise figure of 14 dB. The results we presented in figure 7. We again see that an effective gain of 15 dB is adequate allowing for a 10 dB down lead loss we find that 25 dB is the minimum gain.

The problem of overload by high signal levels is one that has all too often been ignored by preamplifier designers. If the designer ignores the problem, the man who uses the preamp and has to suffer with it, can't. There are preamplifiers on the market with noise figures of 1 to 2 dB, which overload and produce noticeable cross modulation and beats with inputs of only 10 to 20 dBmv; in many cases these amplifiers are not satisfactory. To determine what would be satisfactory, we have made a statistical study of the maximum levels encountered in CATV head-ends. Figure 8 shows the results of this study. Here we have presented the probability of finding any particular signal level. Here are probabilities for both high band and low band. Note that there really isn't much difference. The curves indicate that a preamplifier which will not overload with 26 dBmv input will handle 95% of the head-end requirements; the preamplifier which will handle approximately 33 dBmv input without overloading will handle 99% of the requirements.

These curves were made by taking a sample of ten head-ends randomly selected throughout North America. For each head-end the maximum signal level on the high band and the maximum signal on the low band was noted. We then assumed a normal distribution curve and computed a mean and standard deviation. It is from these values that the curves were generated. Admittedly, this

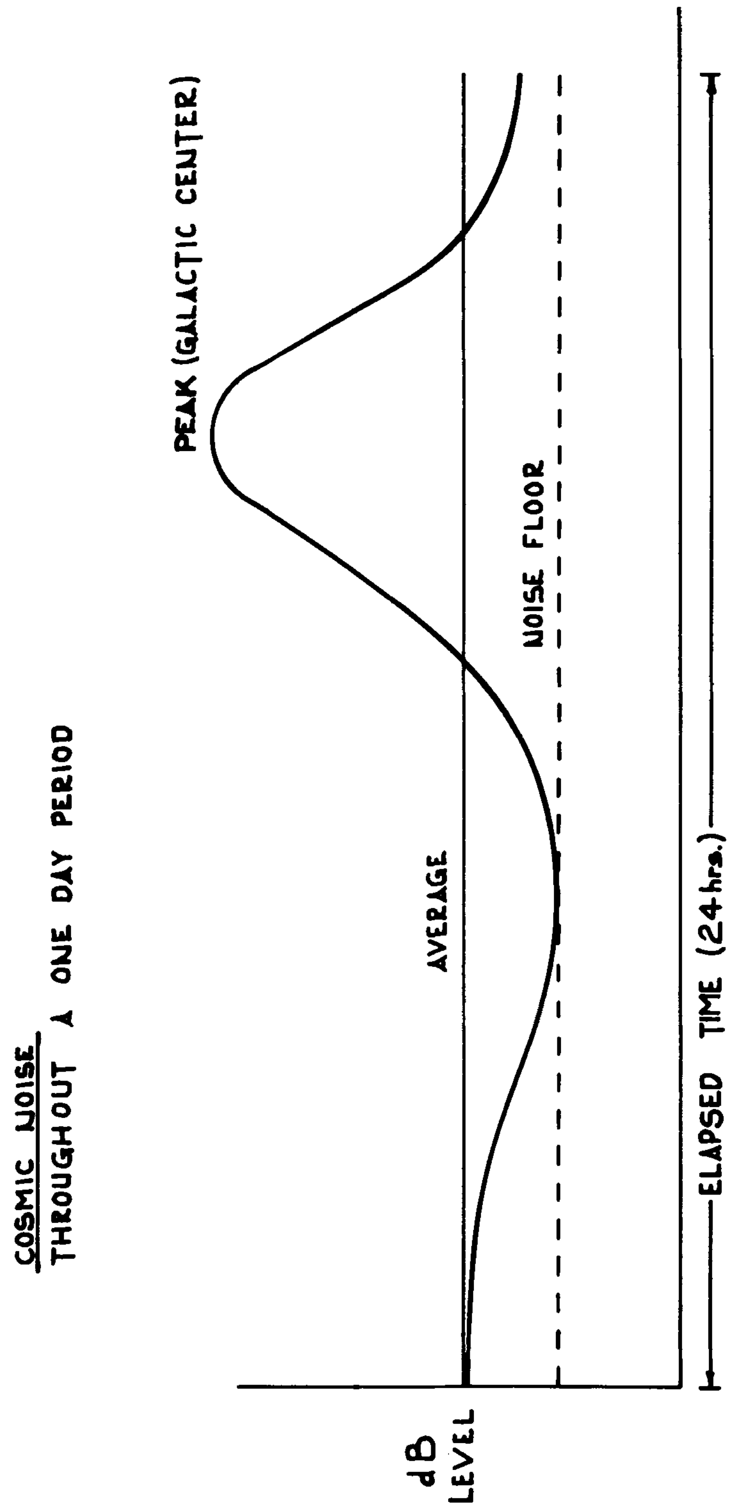

COSMIC NOISE
THROUGHOUT A ONE DAY PERIOD
PEAK (GALACTIC CENTER)
AVERAGE
NOISE FLOOR
dB
LEVEL
ELAPSED TIME (24 hrs.)

FIG. 2

is rather a small sample, but our experience in doing signal surveys of hundreds of head-ends indicates that the numbers are reasonable. In computing these curves no allowance has been made for rejection of unwanted signals by phasing antennas or other such methods. Depending on relative angles of the wanted and unwanted signals, it may not be pssible to create any rejection or the rejection might be as high as 30 dB. The curves then represent a worst case situation.

We conclude that a preamplifier that will accept +40 dBmv inputs without over-loading will handle virtually all signal conditions that would normally be encountered. In fact such a preamplifier will eliminate a considerable amount of trouble for the Antenna installers by not forcing them to carefully phase the antennas to eliminate unwanted signals. In the case of a search antenna, which is a broad band antenna used for signal surveys or as a standby, it is imperative that the preamplifier be able to accept whatever input signals are present. This, we believe, will confirm the field experience of those people who install the antennas and produce working head-ends.

There is, of course, a trade off between achievable noise figures and achievable signal handling capability. Figure 9 shows the trade off which is achievable with to-day's state of the art. As can be seen +40 dBmv input capability will involve the loss of about 2 dB of noise figure. When extremely high levels are present it is better to accept this small sacrifice in noise figure and have a bit more snow in the screen rather than have a herringbone pattern or visible cross modulation. For the low band, where the noise figure of the preamplifier is not so critical, it is our feeling that there is no merit in building an extremely low noise figure preamplifier with poor overload characteristics. If you will recall from our previous discussion, a change in 1 dB of noise figure in the preamplifier resulted in a very small fraction of a dB change in noise figure for the entire system. We have encountered numerous cases of overload which is quite a serious problem. For the high band it is questionable whether an extremely low noise preamplifier should be built. For a preamplifier with a 3½ dB noise figure the system signal to noise ratio will only be about 2 dB better than for a preamplifier with a 1½ dB noise figure. Again, we state that this 2 dB difference in signal to noise ratio will be invisible while overload distortion products will be quite visible.

For UHF channels the situation is somewhat different because of the much lower antenna noise level. In many cases there are no strong local UHF stations which would interfere with reception of more distant stations. Here, the lowest possible noise figure is called for. In other cases there are strong local stations which might interfere with distant stations. Because of the two possibilities, it appears that two different kinds of preamplifiers are required; an amplifier with high handling for cases in which there are strong local signals and a lower handling, lower noise figure amplifier for cases in which there are not strong local signals.

In the interest of thoroughness, we have also looked into the matter of the minimum acceptable return loss. Figure 10 shows time delay versus the level of reflections. As is well known, for a very short time delays the reflection can be much stronger without being visible. Superimposed on this curve showing minimum conditions, is a curve of calculated conditions for what we consider typical worst case. We have assumed a processor with a 16 dB return loss on the input and a preamplifier with 16 dB return loss on it's output; the cable is standard .412 diameter with 1.7 dB of attenuation at 216 MHz and .85 dB attenuation per hundred feet at 54 MHz. Relative velocity was assumed to be 81%. The worst case occurred with about three hundred feet of cable. Here, there was still an 11 dB margin before a visible ghost would occur. Of course, for higher frequencies the cable attenuation would be much greater and the margin much greater also. From this we can conclude that with readily attainable levels of match, there should be no ghosting problem.

Reliability is not a matter which lends itself to a similar analysis. However, one would hope that the reliability would be such that the antenna system would not have more than one failure in several years. In order that a mean time between failures of less than three years each preamplifier will need a mean time between failures of about 30 years. With proper design such a reliability level can be achieved. However, it is not easy to measure. The only practical course is to have a large number of preamplifiers in service for several years to evaluate their reliability. It should be possible to accelerate failures by such means as vibration and temperature cycling. It will not be possible to know exactly what is the exact amount of acceleration.

Preamplifiers should be designed with the maximum possible protection from lightning by incorporating both gas discharge surge protectors and diodes to protect semiconductors. Since lightning energy is mainly low frequency the preamplifiers should incorporate filters to admit only frequencies in the band of interest. Power supplies for preamplifiers should incorporate devices to prevent surges on the power line from entering the preamplifier. All components, of course, should operate at much less than their maximum ratings. It is recommended that a redundant power supply be used. Construction should be sturdy and rigid to withstand the effects of vibration, with tuning adjustments locked by some sort of adhesive to prevent detuning under vibration and temperature cycling. Although the user of the preamplifier cannot readily measure life time or mean time between failures of a preamplifier, he can examine them to determine if the above principles have been followed.

It is hoped that this paper has improved understanding on an area that has not been well understood in the past. We hope that this will result in better preamplifiers and better usage.

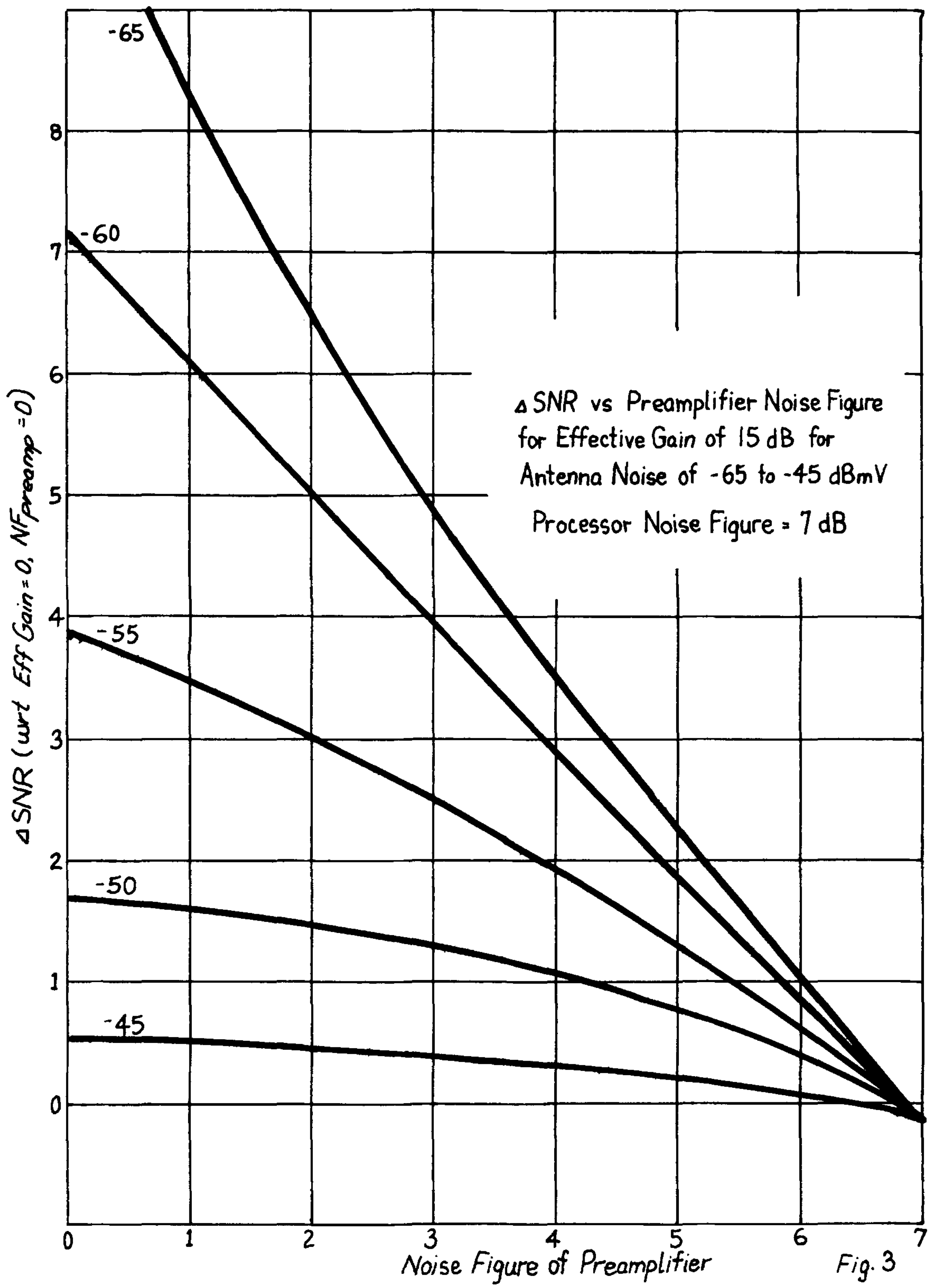
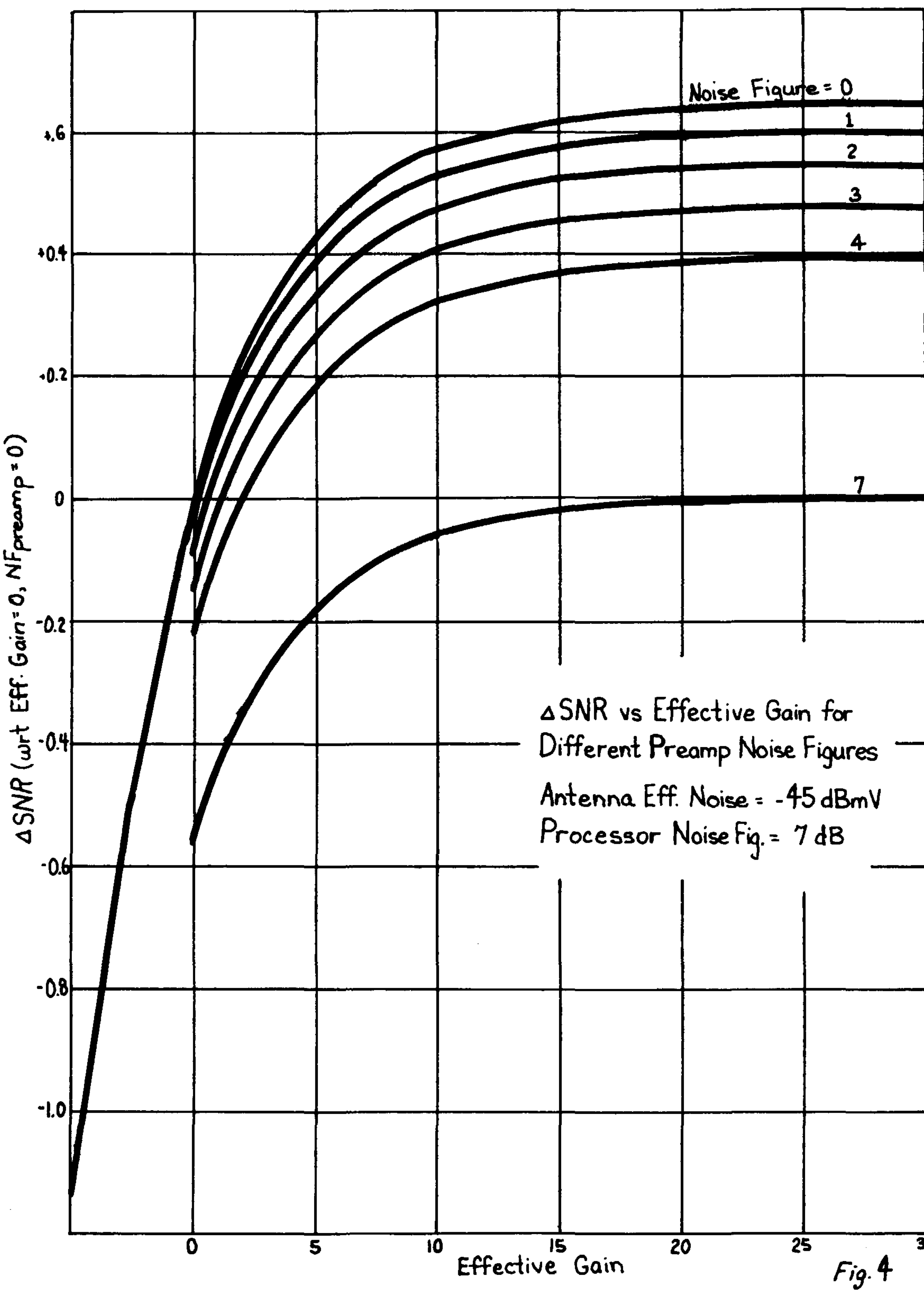
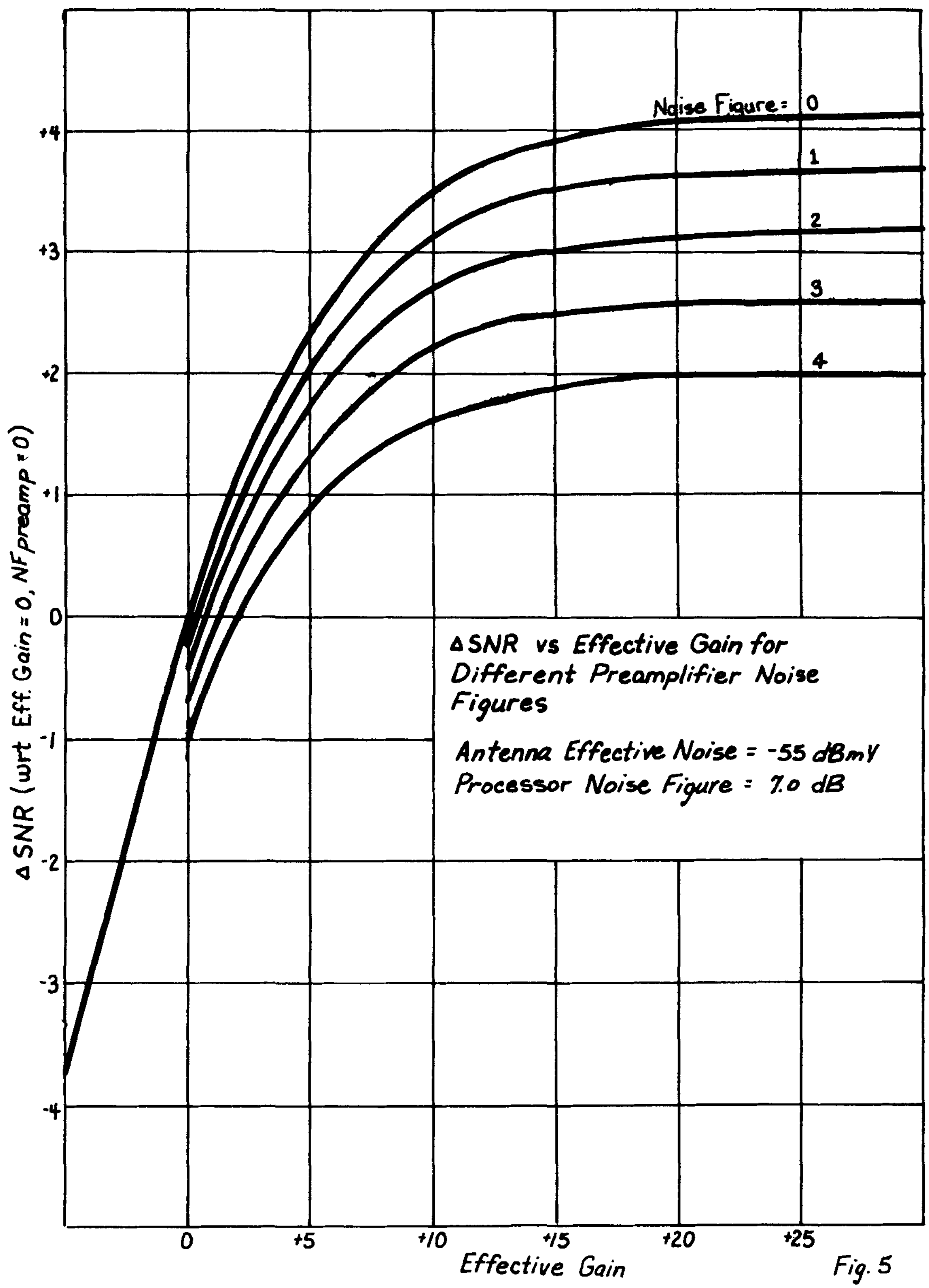

-65
-60
-55
-50
-45
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
Δ SNR (wrt Eff Gain = 0, NF_{preamp} = 0)
Δ SNR vs Preamplifier Noise Figure
for Effective Gain of 15 dB for
Antenna Noise of -65 to -45 dBmV
Processor Noise Figure = 7 dB
Noise Figure of Preamplifier

Fig. 3



Noise Figure = 0
1
2
3
4
7
+.6
+0.4
+0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
ΔSNR (wrt Eff. Gain = 0, NF preamp = 0)
0
5
10
15
20
25
30
Effective Gain
ΔSNR vs Effective Gain for
Different Preamp Noise Figures
Antenna Eff. Noise = -45 dBmV
Processor Noise Fig. = 7 dB

Fig. 4


Noise Figure = 0
1
2
3
4
+4
+3
+2
+1
0
-1
-2
-3
-4
Δ SNR (wrt Eff. Gain = 0, NF preamp = 0)
0
+5
+10
+15
+20
+25
Effective Gain
Δ SNR vs Effective Gain for Different Preamplifier Noise Figures
Antenna Effective Noise = -55 dBmV
Processor Noise Figure = 7.0 dB
Fig. 5

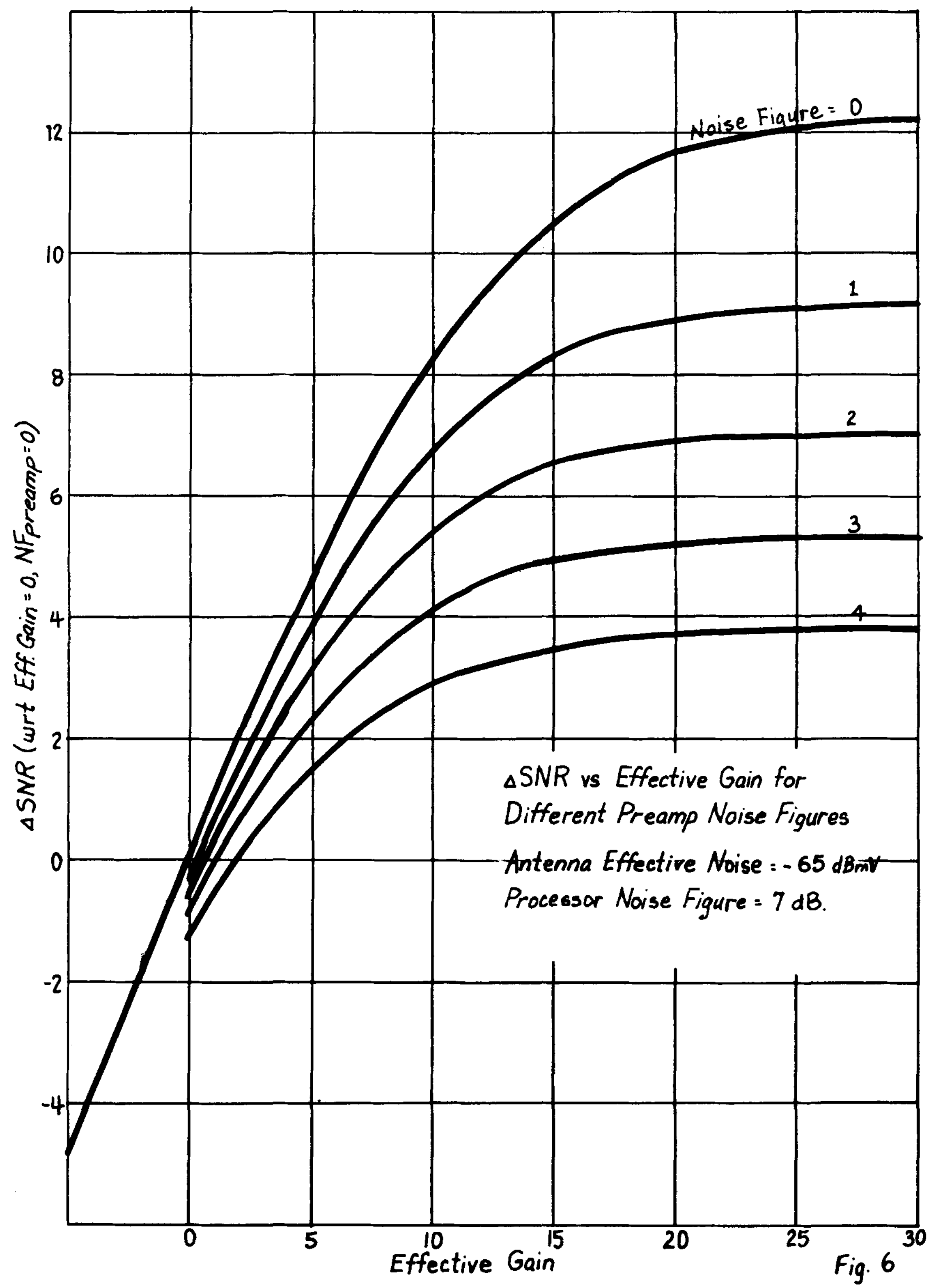
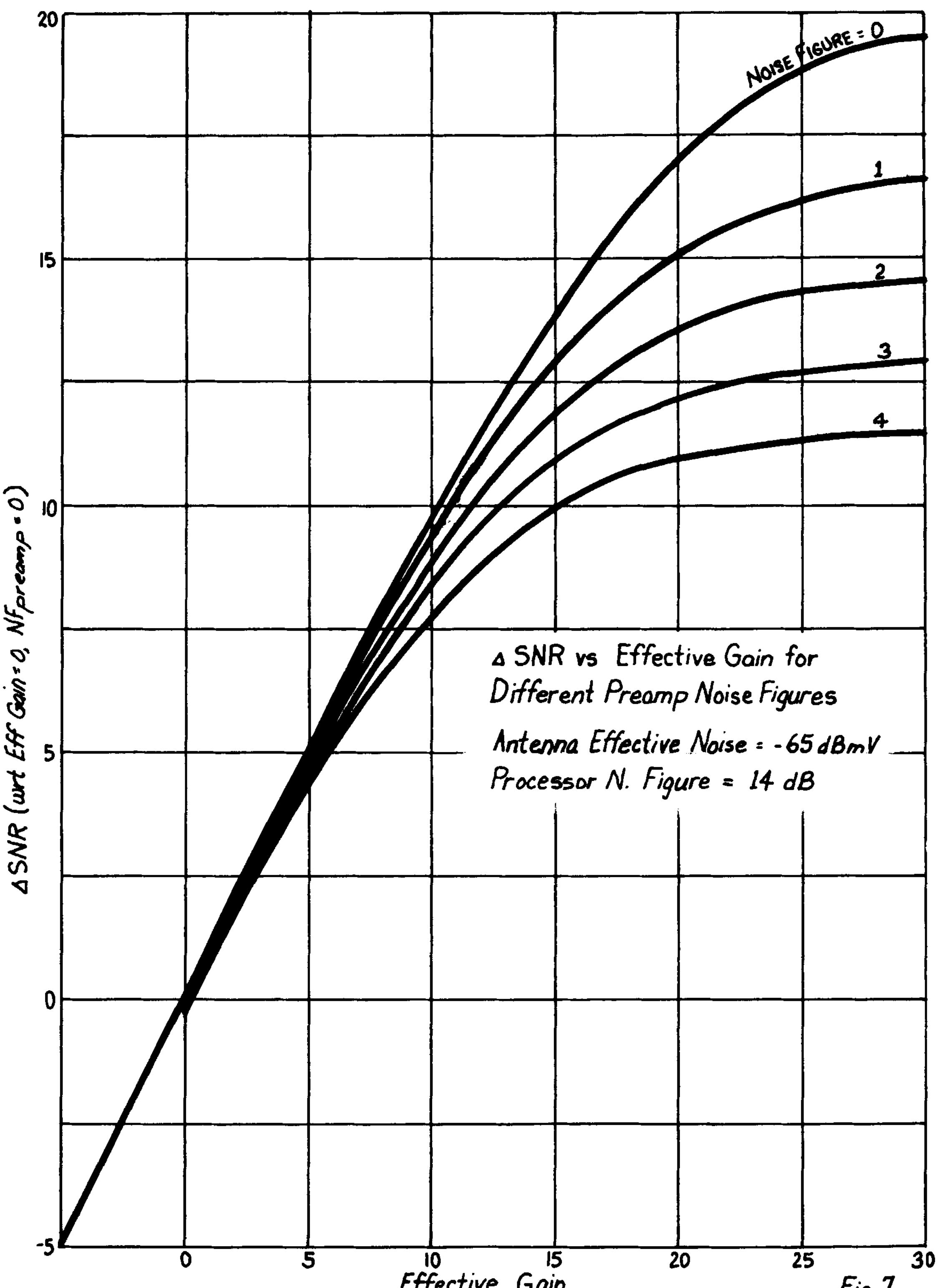
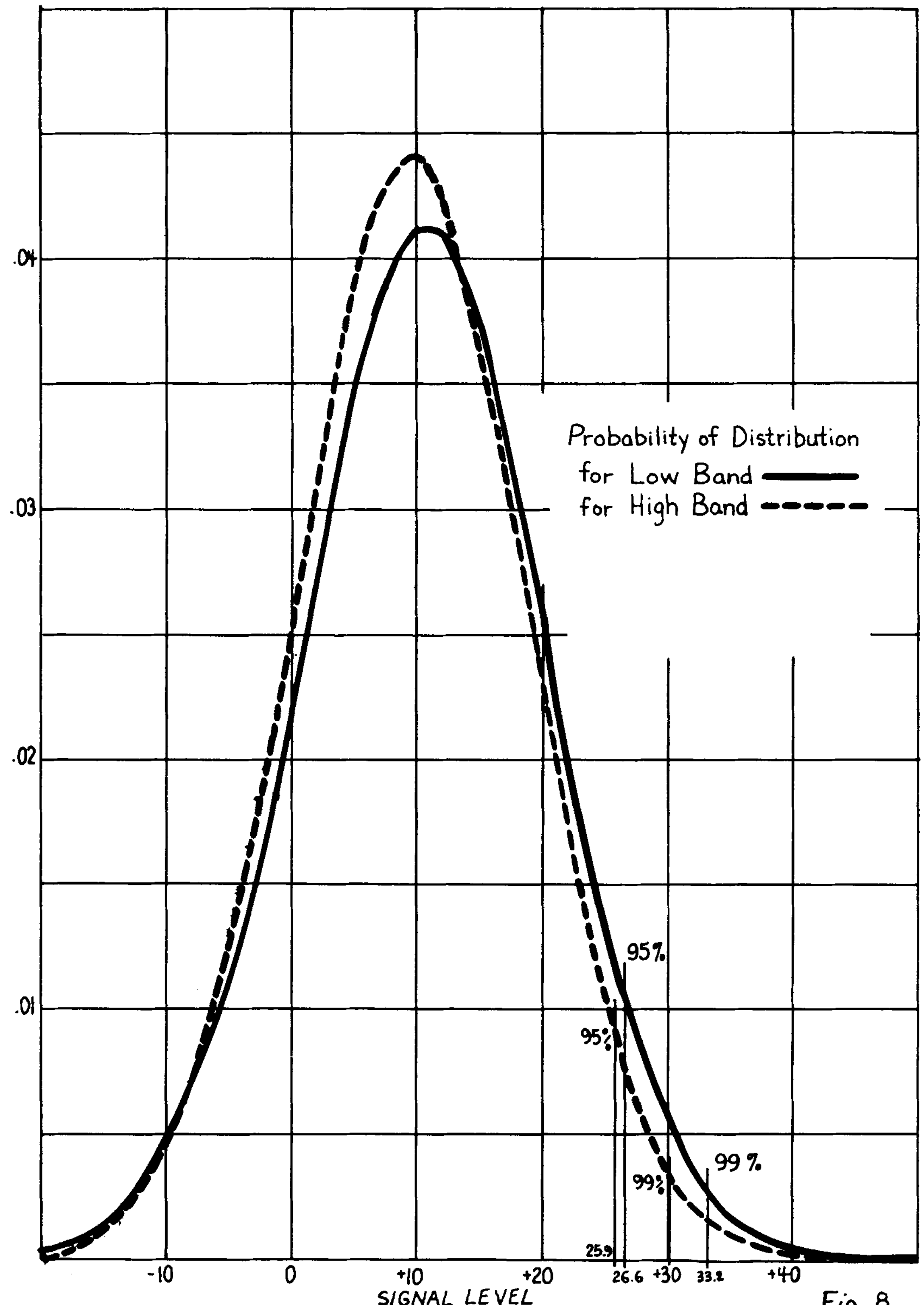

Noise Figure = 0
1
2
3
4
12
10
8
6
4
2
0
-2
-4
ΔSNR (wrt Eff. Gain = 0, NFpreamp = 0)
ΔSNR vs Effective Gain for
Different Preamp Noise Figures
Antenna Effective Noise = -65 dBmV
Processor Noise Figure = 7 dB.
0
5
10
15
20
25
30
Effective Gain

Fig. 6



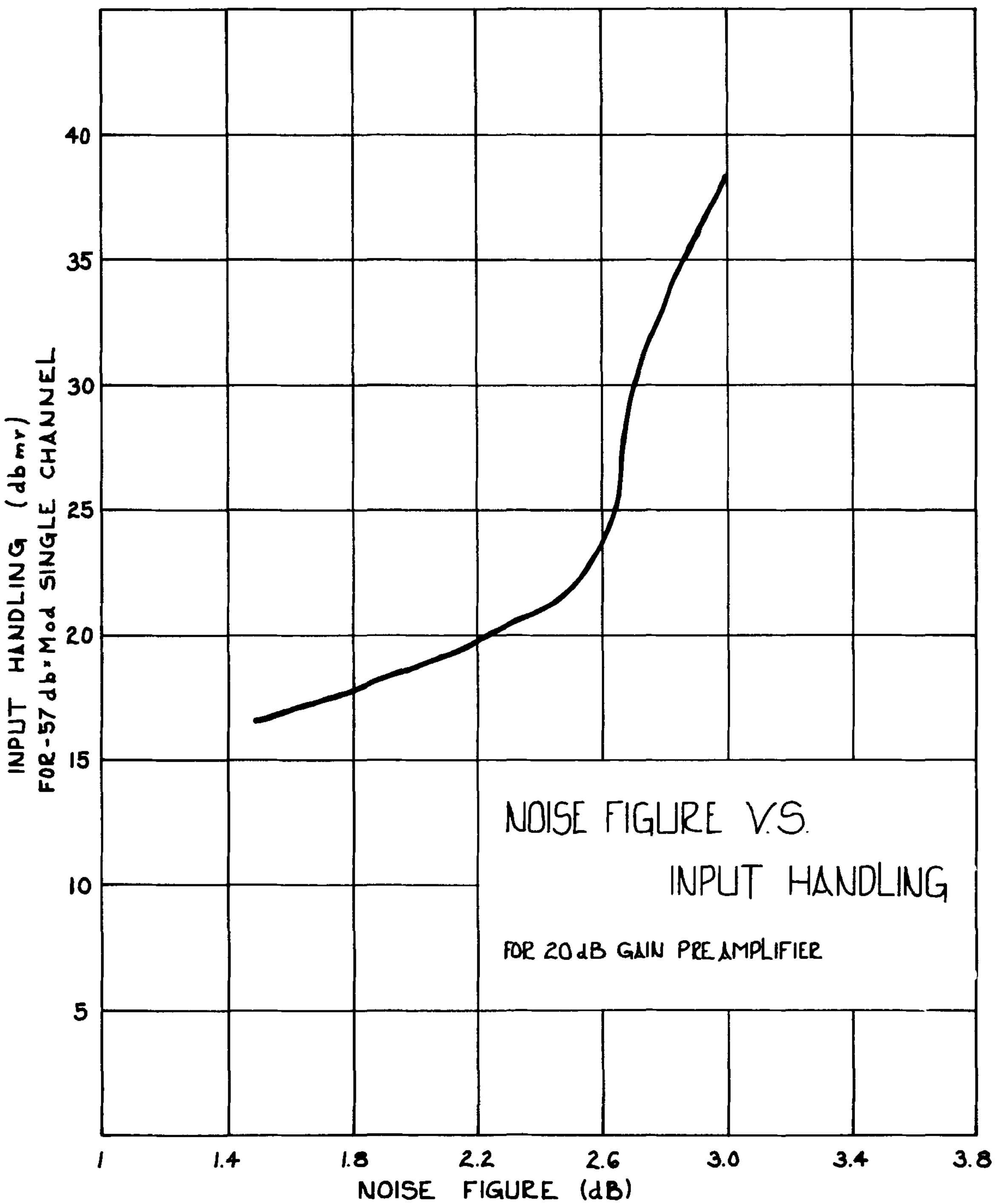
Noise Figure = 0
1
2
3
4
Δ SNR vs Effective Gain for Different Preamp Noise Figures
Antenna Effective Noise = -65 dBmV
Processor N. Figure = 14 dB
Δ SNR (wrt Eff Gain = 0, NF preamp = 0)
Effective Gain
20
15
10
5
0
-5
0
5
10
15
20
25
30

Fig. 7



.04
.03
.02
.01
-10
0
+10
+20
25.9
26.6
+30
33.2
+40
SIGNAL LEVEL
Probability of Distribution
for Low Band
for High Band
95%
95%
99%
99%

Fig. 8



INPUT HANDLING (db mv)
FOR -57 db X Mod SINGLE CHANNEL
40
35
30
25
20
15
10
5
1
1.4
1.8
2.2
2.6
3.0
3.4
3.8
NOISE FIGURE (dB)
NOISE FIGURE V.S.
INPUT HANDLING
FOR 20dB GAIN PREAMPLIFIER

FIG. 9

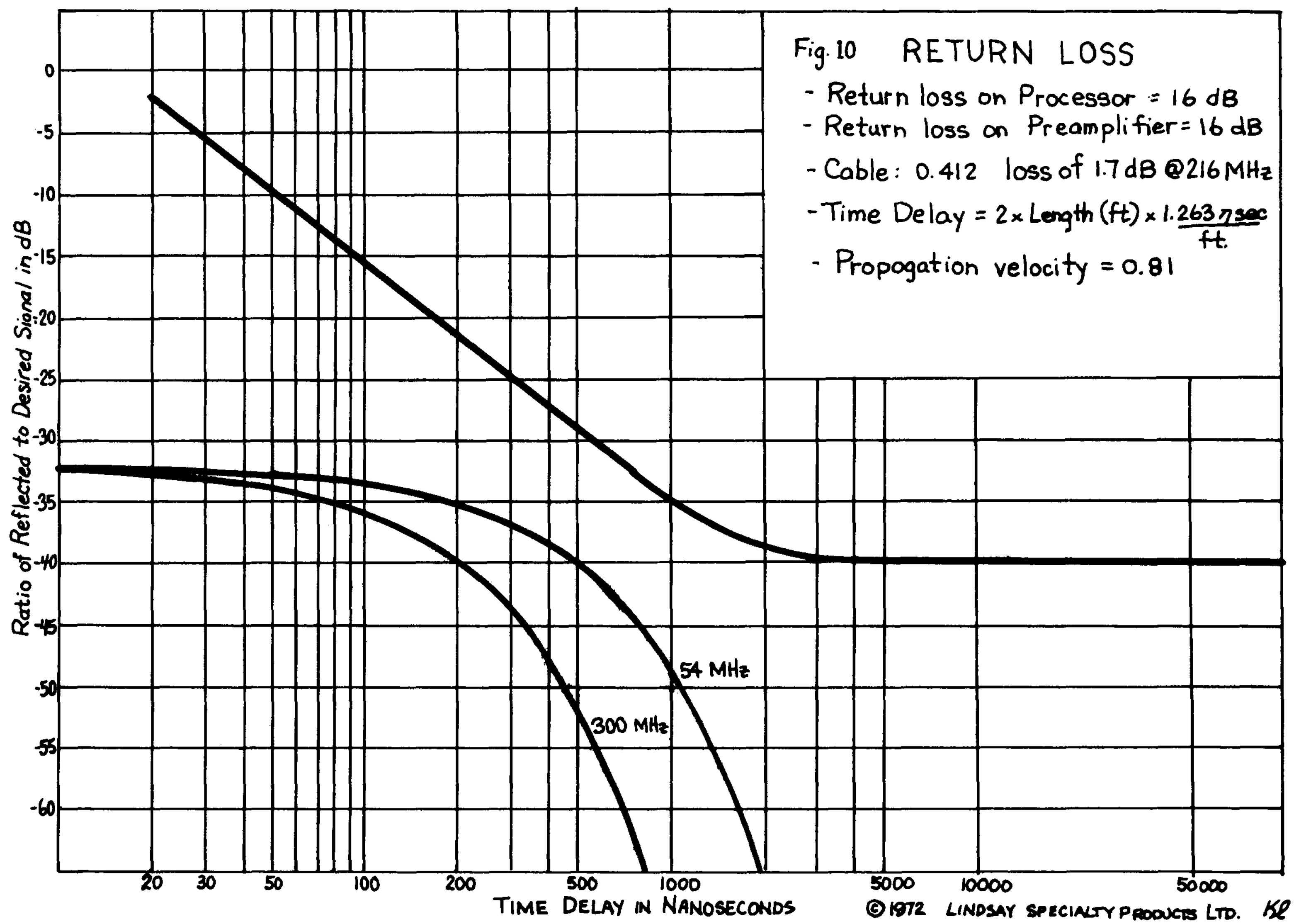


Fig. 10 RETURN LOSS
- Return loss on Processor = 16 dB
- Return loss on Preamplifier = 16 dB
- Cable: 0.412 loss of 1.7 dB @ 216 MHz
- Time Delay = 2 × Length (ft) × 1.263 ηsec/ft.
- Propogation velocity = 0.81
Ratio of Reflected to Desired Signal in dB
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
54 MHz
300 MHz
20
30
50
100
200
500
1000
5000
10000
50000
TIME DELAY IN NANOSECONDS
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