FREQUENCY MODULATION TELEVISION ANALYSIS

THRESHOLD IMPULSE ANALYSIS

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A computer program is developed to calculate the FM threshold impulse rates as a function of the carrier-to-noise ratio for a specified FM system. The system parameters and a vector of 1024 integers, representing the probability density of the modulating voltage, are required as input parameters. The computer program is utilized to calculate threshold impulse rates for twenty-four sets of measured probability data supplied by NASA and for sinusoidal and Gaussian modulating waveforms. As a result of the analysis several conclusions are drawn: The use of preemphasis in an FM television system improves the threshold by reducing the impulse rate. Sinusoidal modulation produces a total impulse rate which is a practical upper bound for the impulse rates of TV signals providing the same peak deviations. As the moment of the FM spectrum about the center frequency of the predetection filter increases, the impulse rate tends to increase. A spectrum having an expected frequency above (below) the center frequency of the predetection filter produces a higher negative (positive) than positive (negative) impulse rate.
This study under NASA Contract NAS5-21872 was initiated to perform a parametric analysis using computer simulation and analysis techniques of the threshold and signal distortion effects in FM TV systems. This report is a study of the FM threshold. The FM distortion study is presented in a separate report.

A computer program was developed to estimate the FM threshold impulse rate on the basis of measured data describing the probability density function of typical TV waveforms. The data, supplied by NASA, were representative of both preemphasized and flat baseband signals with and without audio subcarriers. The threshold was also examined for sinusoidal and Gaussian modulating waveforms.

As a result of the analysis, the following conclusions can be drawn:

1. The total impulse rate for television signals (positive plus negative) generally decreases with the inclusion of preemphasis. Thus, the use of preemphasis and de-emphasis in an FM television system does improve the threshold by reducing the impulse rate for a particular carrier-to-noise ratio.

2. Sinusoidal modulation produces a total impulse rate (positive plus negative) which is a practical upper bound for the impulse rates of television signals providing the same peak deviation.

3. As the moment of the FM spectrum about the center frequency of the predetection filter increases, the impulse rate tends to increase.

4. An FM spectrum having an expected frequency above (below) the frequency at the center of a symmetrical predetection filter produces a higher negative (positive) than positive (negative) impulse rate.
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<td>Probability Data Set 17</td>
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<td>Probability Data Set 18</td>
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<td>Probability Data Set 19</td>
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<td>Probability Data Set 22</td>
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<td>Probability Data Set 23</td>
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<td>D-25</td>
<td>Mathematically-Generated Probability Data for a Sinusoidal Signal</td>
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<td>D-26</td>
<td>Mathematically-Generated Probability Data for a Gaussian Signal</td>
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SECTION 1 - INTRODUCTION

When a frequency-modulated (FM) television transmission system is operated near threshold, a very objectionable type of noise is apparent, and it gets worse as lower carrier-to-noise ratios are utilized at the FM receiver. This objectionable noise is observed as random black and white spots on the scanning lines of a television picture tube. The video impulses, causing spots in the picture, are a well-known threshold phenomenon, treated quantitatively in this report.

The primary objective of this study is to develop a computer program to calculate the FM threshold impulse, or click, rates and to use the program in quantifying the effects of preemphasis and deemphasis in an FM transmission system. The program calculates the impulse rates as a function of the carrier-to-noise ratio for specified system parameters and any specified probability density function describing the modulating waveform.

Impulse rates are calculated for twenty-four probability functions supplied by NASA. Twelve of the probability functions are for flat, or unpreemphasized, systems and the other twelve functions are for the same systems with preemphasis added. Thus, the effect of preemphasis can be studied.

Impulse rates are also calculated for probability density functions of sinusoidal and Gaussian modulating waveforms. These calculations are made on the basis of the same predetection filter specifications and the same peak deviations used for the other cases.

The computer program is based on Rice's mathematical analysis of FM threshold effects (Reference 1). In accordance with Rice's work, the results are based on predetection filter responses that are symmetric with respect to the center frequency. The predetection filter options are two-, three-, and four-pole Butterworth and Chebyshev, Gaussian, and rectangular.

The modulating signals for which the probability data were measured by NASA utilized two different formats designated as TRUST (Television Relay Using Small Terminals) and ETV (Educational Television). These formats are shown in Figures 1-1 and 1-2, respectively.
NOTE: The audio subcarriers were frequency modulated by a 1-kHz tone to provide a 70-kHz peak deviation.

Figure 1-1. Frequency Format of the Composite TRUST Signal Modulating the Carrier
NOTE: The audio subcarriers were frequency modulated by a 1-kHz one to provide a 53-kHz peak deviation.

Figure 1-2. Frequency Format of the Composite ETV Signal Modulating the Carrier
Signals with these formats, different video contents, and different combinations of audio subcarriers were used with and without preemphasis as modulating signals for an FM carrier. The probability densities of twenty-four various modulating signals were measured by NASA as input data to the computer program developed under this contract.
SECTION 2 – DISCUSSION AND APPROACH

2.1 INTRODUCTION

The effects of FM threshold impulse rates on the received signal is discussed. Then the use of Rice’s formulas for calculating the impulse rates is discussed. Finally, the analysis of the predetection filters is discussed.

2.2 DISCUSSION OF THRESHOLD CONSIDERATIONS

The threshold effect in FM receivers is the result of sudden $2\pi$-radian phase changes in the detected wave which is composed of a modulated carrier and noise. Any noise on the carrier being detected results in noise accompanying the output signal. The output noise caused by small variations in the instantaneous phase of the detected wave is called fluctuation noise. Reducing the carrier-to-noise ratio increases the probability that the noise will cause a rapid $2\pi$-radian phase change in the composite wave. Such a change causes noise impulses in the detected output. As the carrier-to-noise ratio is reduced further, the impulsive noise increases to the point that it becomes a significant portion of the output noise. When this happens, the FM threshold is said to occur.

Figure 2-1 shows the shape of the output signal-to-noise ratio as a function of the carrier-to-noise ratio ($C/N$) at the input to the frequency demodulator. As indicated by the deviation of the solid curve from the broken line, impulsive noise increases as $C/N$ decreases. The value of $C/N$ at threshold depends on system parameters such as modulation index and predetection bandwidth.

The impulses may be heard as clicks in audio signals or may be seen as light or dark impulses on a television tube. The impulse rate is therefore of interest in all FM systems.

The instantaneous composite of the modulated carrier and the associated noise at the demodulator input terminals can be represented (using Rice’s notation) by

$$Q \cos \left[ 2\pi f_c t + \phi(t) \right] + l_N(t) = R(t) \cos \left[ 2\pi f_c t + \phi(t) + \theta(t) \right]$$

(2-1)
Figure 2-1. Typical Curve of Demodulated Signal-to-Noise Ratio as a Function of Carrier-to-Noise Ratio in an FM Receiver
where \( I_N(t) \) represents the additive noise component. Notice that additive noise effectively varies the amplitude and phase of a carrier. The desired demodulated signal is \( \phi'(t) \), but the actual demodulated output is \( \phi'(t) + \theta'(t) \). Thus \( \theta'(t) \) represents the noise accompanying the demodulated signal. At times the noise vector is larger than the carrier amplitude \( Q \) and properly phased such that \( \theta(t) \), the instantaneous phase of the resultant carrier actually changes suddenly by approximately \( 2\pi \) radians. Such a sudden phase change shows up in the output as a noise impulse. Figure 2-2 (Reference 1) shows how impulses in \( \theta'(t) \) are caused by the sudden \( 2\pi \)-radian phase changes in \( \theta(t) \). A positive impulse is caused by a sudden increase in \( \theta(t) \) and a negative impulse is caused by a sudden decrease in \( \theta(t) \). These impulses are a function of various parameters of the FM system and their rates can be calculated as a function of those parameters.

The expected values of impulse rates can be calculated on the basis of Rice's work (Reference 1). His work is based on the assumption that a click occurs each time \( \theta(t) \) increases or decreases through an odd multiple of \( \pi \) radians. It has been shown that this is not strictly true (Reference 2), and that \( \theta(t) \) sometimes crosses the \( \pi \)-radian boundary and returns through it without making a complete \( 2\pi \)-phase change which is assumed. Although Rice's approximation is a slightly pessimistic approximation from this standpoint, his technique provides a relatively good approximation and is used in this effort.

2.3 ANALYTICAL APPROACH

The application of Rice's formulas to calculating the threshold impulse rates is presented. Then the predetection filter analysis is discussed.

2.3.1 Threshold Formulas

Rice represents the FM threshold impulse rates as

\[
N_\pm = \int_{-\infty}^{\infty} H_{\pm}(t_1) P_u(u) \, du \quad (2-2)
\]

where

\[
H_{\pm}(t_1) = \frac{1}{2} \left\{ \sqrt{1 + u^2} \left[ 1 - \text{erf} \sqrt{\rho + \rho u^2} \right] - u \rho e^{-\rho} \left[ 1 - \text{erf} \left( u \sqrt{\rho} \right) \right] \right\} \quad (2-3)
\]

2-3
Figure 2-2. Impulses in $\theta'(t)$ Produced by Changes of $\pm 2\pi$ in $\theta(t)$
$N_+$ and $N_-$ represent, respectively, the expected number of positive and negative impulses per second, and $r$ is the gyration radius of the RF noise spectral density. For bandlimited white noise reaching the demodulator, which will be assumed in the proposed analysis, $r$ is just the gyration radius of the predetection bandpass filter with a symmetrical response centered on the carrier frequency. $\rho$ is the carrier-to-noise power ratio and $p_u(u)$ is a probability density function (pdf) related to the voltage probability density function of the baseband signal modulating the FM carrier. $H_+(t_1)$ is obtained by changing the sign of $u$ in $H_-(t_1)$. Note that $H_+(t_1)$ depends on $t_1$ only through $u$. Hence, $t_1$ is a parameter that need not actually be considered.

Given $p_v(v)$, the pdf of the voltage modulating the carrier and several other parameters of the FM system, the required pdf, $p_u(u)$, can be calculated from $p_v(v)$. The peak deviation is given in terms of the modulation index $m$ and the highest modulating frequency $f_m$ as follows

$$D_p = m f_m$$

To provide for modulating signals that do not have a defined voltage maximum; e.g., Gaussian, let $D_p$ correspond to the deviation that is not exceeded more than a certain designated fraction $P$ of the time; e.g., 0.1 percent of the time for $P = 0.001$. This deviation corresponds to a certain modulating voltage $V$ that is not exceeded for the same percentage of time. The value of $V_c$ can then be chosen to satisfy the formula

$$\int_{V_c - V_d}^{V_c + V_d} p_v(v) \, dv = 1 - P$$

where $V_d$ is the modulating voltage defined by

$$P/2 = \int_{V_c + V_d}^{\infty} p_v(v) \, dv$$

and

$$P/2 = \int_{-\infty}^{V_c - V_d} p_v(v) \, dv$$

2-5
Thus, $V_c + V_d$ correspond directly to the modulating voltages at peak deviation.

The probability density function of the instantaneous frequency deviation then becomes

$$P_f(f) = \frac{V_d}{D} p_v \left(\frac{V_d}{D} f\right) \quad (2-8)$$

Since $u$ is defined as $\frac{f}{r}$, the desired pdf is found to be

$$p_u(u) = r p_f(ru) = \left|\frac{rV_d}{D}\right| p_v \left(\frac{rV_d}{D} u\right) \quad (2-9)$$

or, in terms of the more fundamental parameters used in the analysis,

$$p_u(u) = \left|\frac{rV_d}{mf_m}\right| p_v \left(\frac{rV_d}{mf_m} u\right) \quad (2-10)$$

One can use any pdf of a modulating waveform, and the impulse rate can be derived from it providing that the following information is given.

1. Exact specification of the predetection filter including half-power bandwidth and response.
2. Modulation index $m$.
3. Carrier-to-noise ratio, $\rho$, at the RF demodulator after the predetection filter.
4. Maximum modulating frequency, $f_m$.
5. Probability density function of the modulating voltage.
6. A fraction, $P$, defining peak deviation in terms of a deviation that is not exceeded more than 100P percent of the time.

The computer program which implements the theory in this paragraph is discussed in Section 3.
2.3.2 Predetection Filters

A value for the radius of gyration of the RF predetection filter is required for using the threshold impulse rate formulas; therefore, the filter characteristics must be considered. Since Rice's analysis assumes a filter that is symmetric with respect to a center frequency, a translation of the low-pass equivalent up in frequency to the RF frequency of interest is used. For narrow band filters, a symmetric filter is a good approximation to a real nonsymmetric filter.

A filter analysis is provided in Appendix A, and a summary of filter formulas is given in Table A-1 for symmetric filters of the following types:

1. Butterworth (one-, two-, three-, and four-pole)
2. Chebyshev (one- and two-pole)
3. Gaussian
4. Rectangular.

Explicit formulas are not presented for the radii of gyration of the three- and four-pole Chebyshev filters because of the difficulty of deriving them. The radii of gyration of these filters can be computed by use of several formulas in a computer program.
SECTION 3 - DESCRIPTION OF COMPUTER PROGRAM

3.1 INTRODUCTION

The computer program is a FORTRAN V program for calculating the positive and negative FM threshold impulse rates in accordance with the approach presented in Section 2. The input parameters define the system and the probability density function of the FM spectrum. The computer program calculates the FM threshold impulse rates and prints the results as a function of the carrier-to-noise ratio. The other parameters are also printed out for reference.

3.2 INPUT DATA FORMAT

The data are entered into three different files called File 17, File 18, and File 19. File 17 contains eight real numbers in the following order:

1. AMODX - Modulation index
2. PCPROB - Percent probability of exceeding the "peak deviation"
3. FMODMX - The maximum frequency of the modulating spectrum
4. CONDB1 - The lowest dB value of C/N for which the threshold impulse rate is to be calculated
5. CONDB2 - The highest dB value of C/N for which the threshold impulse rate is to be calculated
6. CONDBI - The dB increment to be used in increasing the C/N values from the CONDB1 to the CONDB2
7. DPNUM1 - The specified continuous probability data subscript corresponding to the "peak deviation" on the low side of the carrier. If this value is to be calculated, enter a value of zero.
8. DPNUM2 - The specified continuous probability data subscript corresponding to the "peak deviation" on the high side of the carrier. If this value is to be calculated, enter a value of zero.

File 18 contains two to four elements of filter data in the following order:

1. NFTYP - An integer from 1 to 4 describing the predetection filter as follows:
   1 for Butterworth
   2 for Chebyshev
   3 for Gaussian
   4 for Rectangular

2. BANDW - A real number describing the RF bandwidth in Hz.

3. NPOLES - An integer from 1 to 4 describing the number of poles of the filter. Omit this value for the Gaussian and rectangular cases.

4. RIPLDB - A real number describing the dB ripple in the Chebyshev passband. Omit this value for Butterworth, Gaussian, and rectangular filters.

File 19 contains a vector of order 1024 such that the components are proportional samples that would be taken from the FM spectrum under consideration. The components of the vector are integers. Other components may be zero, but the first and last components must be zero.

3.3 COMPUTER PROGRAM

The computer program is listed in Appendix B and a glossary of the program variable is listed in Appendix C. A flowchart, shown in Figure 3-1, is useful in explaining the workings of the program.

The user-defined functions and dimension statements appear at the beginning of the program. All the input variables of File 17 are read. Then the peak deviation is calculated from the input variables. All of File 19 is read for the probability vector. The data subscripts corresponding to the first and last nonzero components of the vector are determined in order to eliminate the zero components at the ends of the vector from
further consideration. The expected value, or mean value, of the data subscripts is then calculated. Normally this is not an integer. The data vector is then normalized to represent a discrete probability density. That is, each component is multiplied by a constant such that the sum of the components of the resultant vector sums to 1.0. Now the vector components are no longer integers, but nonnegative real numbers less than unity.

A check is then made to determine whether or not nonzero real numbers corresponding to data subscripts, or intermediate real numbers, have been specified as DPNUM1 and DPNUM2 in File 17. If nonzero numbers have been specified, those values are assumed to correspond to the RF peak deviation frequencies without regard for the value of PCPROB, which must be specified anyway. In this way the vector subscript domain is treated as a continuous subscript domain, and the discrete probability density function can be treated as a continuous density function by a straight line approximation between each of the points of the discrete density function. If DPNUM1 and DPNUM2 are both zero, two real numbers in the continuous subscript domain are calculated to replace DPNUM1 and DPNUM2 such that the instantaneous RF frequency falls outside the RF interval defined by DPNUM1 and DPNUM2 with equal probability at each end. The single-end probability is just half the specified probability, PCPROB.

The subscript halfway between DPNUM1 and DPNUM2 is then calculated regardless of whether these subscripts were specified or calculated. This new subscript then corresponds to the frequency located at the center of the symmetrical predetection filter. The peak subscript deviation is then calculated. It is just the subscript difference corresponding to the deviation of the RF carrier frequency at the specified peak deviation. By locating the RF spectrum on the predetection filter as described above, the probability of distortion due to exceeding the peak deviation is minimized. It does not necessarily minimize the impulse rates.

The program specifies the number of integration increments to be used. This number has a value of 5000, but it could be changed easily. The size of the integration increment is calculated as a function of the number of integration increments.
The ratio of the frequency change to the probability subscript change is calculated for use in integration, since the actual variable of integration is taken in the continuous data subscript domain.

Next, two variables are read from File 18 to define the predetection type and its RF bandwidth. If File 18 has no more data, the program ends. Otherwise, the program continues and evaluates the radius of gyration of the RF predetection filter by different paths through the program, depending on the type of filter being used.

If the filter is Butterworth, File 18 is read to determine the number of poles, after which the radius of gyration is evaluated by the method corresponding to the specified number of poles. Note that the radius of gyration is undefined for a single-pole filter and an invalid statement is printed out if a single-pole filter is specified.

If the filter is Chebyshev, File 18 is read for two variables defining the number of poles and the ripple specification in that order.

Then the radius of gyration is evaluated in accordance with the formulas for that number of poles. Again, the radius of gyration is undefined for a single-pole filter, and an invalid statement is printed out if a single-pole filter is specified.

If the filter is Gaussian or rectangular, no poles and ripple are specified and the radius of gyration is readily calculated.

After the radius of gyration is calculated for the filter of interest, the ratio of increments in the frequency domain to corresponding increments in the continuous subscript domain is evaluated for use in integration later on.

The carrier-to-noise ratio is incremented from CONDB1 to CONDB2. For each value of the carrier-to-noise ratio, integration takes place in a loop which evaluates the integrand at small increments of the variable of integration. The summation of elements is stored as SUMP for the integral relating to positive click rates and is stored as SUMN for the integral relating to negative click rates. Finally, SUMP and SUMN are multiplied by the proper constant to yield the desired positive and negative click rates, and the results are printed out.
Figure 3-1. Flowchart of Computer Program to Calculate FM Threshold Impulse Rates
Figure 3-1. Flowchart of Computer Program to Calculate FM Threshold Impulse Rates
(Continued)
Figure 3-1. Flowchart of Computer Program to Calculate FM Threshold Impulse Rates (Continued)
Figure 3-1. Flowchart of Computer Program to Calculate FM Threshold Impulse Rates (Continued)
Figure 3-1. Flowchart of Computer Program to Calculate FM Threshold Impulse Rates (Continued)
Figure 3-1. Flowchart of Computer Program to Calculate FM Threshold Impulse Rates
(Continued)
4.1 INTRODUCTION

The computer program described in Section 3 and listed in Appendix B was utilized to calculate the threshold impulse rates for various television scenes transmitted by an FM carrier with and without audio subcarriers. The impulse rates were calculated for particular FM system parameters including the modulation index, the maximum modulating frequency, the percent probability of exceeding the "peak deviation," the RF predetection filter type, its half-power bandwidth, and its number of poles. A vector of integers of order 1024 describing the probability density function of the modulating voltage was also used as an input to the program. Calculated positive and negative impulse rates are shown as a function of the carrier-to-noise ratio in tabular form and are also plotted for ease of comparison. The processed results are discussed with particular attention to the effect of preemphasis on threshold impulse rates.

4.2 INPUT DATA

The computer input data included specified parameters and laboratory-measured data supplied by NASA. Each set of measured data was a vector of nonnegative integers representing the probability density function of the voltage amplitude of the modulating waveform. The vector was formed by automatically counting samples of the modulating waveform that fell in each of the 1024 possible equal-voltage intervals during a given period of time. Thus, the vector of order 1024 was not really a probability density function but was proportional to samples taken from an actual probability density function. Twenty-four such probability density data sets were supplied in paper tape form by NASA for the cases shown in Table 4-1. These measured data are listed in Appendix D along with oscilloscope presentations of the data. All these data were processed by the computer with the four-pole Butterworth predetection filter option in the computer program. The probability of exceeding the calculated peak deviation was defined as 0.1% for the cases of no preemphasis, and the same data subscript numbers corresponding to those peak deviations were used for the corresponding cases utilizing preemphasis. This means that the modulating voltage required at the voltage-controlled oscillator to produce the peak deviation...
is unchanged by the addition of preemphasis. Thus, the effect of inserting the preemphasis filter in the system without any other changes could be seen clearly. Other parameters were specified by NASA as shown in Table 4-2.

The test patterns used for generating the video modulating waveforms are listed in Table 4-1 in the column under "Pattern." Two of the test patterns, the RETMA test pattern and the "Post Office," are shown in Figures 4-1 and 4-2, respectively. The off-the-air pattern was actually achieved by tuning to an unprogrammed television channel. Five different test patterns provided a variety of modulating signals for system analysis.

In addition to the 24 sets of probability density data supplied by NASA, two other similar sets of data were mathematically generated to represent sinusoidal and Gaussian modulating signals. These two data sets are also presented in Appendix D along with diagrams representing their probability density functions. Each of these data sets was used as a computer input with the same combinations of peak deviations and RF predetection bandwidths given in Table 4-2. Thus, the computer results for the NASA-supplied probability density data sets can be compared with the results for these two reference data sets.

4.3 COMPUTER RESULTS

The threshold impulse rates are calculated as a function of the predetection carrier-to-noise ratios. The positive and negative impulse rates, calculated separately, are presented in Tables 4-3 through 4-30 and are plotted in Figures 4-3 through 4-54. The positive impulse rates are plotted separately from the negative impulse rates to avoid confusion in those cases for which the curves would overlap so as to be indistinguishable. Since the positive and negative click rates were identical for the sinusoidal and Gaussian modulating signals, only one curve, representing either the positive or the negative rate, was plotted for each case. These curves are shown in Figures 4-51 through 4-54. A summary of the results of all the cases near the FM threshold is presented in Figure 4-55 in the form of a bar graph showing total impulse rates (positive plus negative) for a carrier-to-noise ratio of 10.0 dB.
4.3.1 General Observations

It seems reasonable that the positive and negative impulse rates would be different for an unsymmetrical FM spectrum in a white RF noise environment that is symmetrically filtered. Since the voltage probability density of the modulating waveform is an approximation to the FM spectrum, it is possible to comment on the impulse rates relative to the FM spectrum.

Because of the way the computer program locates the FM spectrum relative to the frequency response of the predetection filter, the mean spectral frequency does not necessarily fall on the filter's center frequency. These two frequencies are identical for the sinusoidal and Gaussian modulating signals and they could be the same for nonsymmetrical spectra, but in general they are different.

Examination of Tables 4-3 through 4-26 shows that there are nine cases for which the mean frequency is lower than the center frequency and 15 cases for which the mean frequency is higher than the center frequency. In each of the nine cases for which the FM spectrum is weighted on the low side, the positive impulse rate is greater than the negative impulse rate; and for each of the cases of spectral weighting on the high side of the center frequency, the negative impulse rate is greater than the positive impulse rate. Even though the positive and negative impulse rates were calculated separately for the sinusoidal and Gaussian data, they were identical, as expected. It does not follow that placing the FM spectral mean on the center frequency of the filter would result in equal numbers of positive and negative impulse rates; however, three nonsymmetrical cases can be cited for which the difference between continuous subscripts corresponding to the mean and center frequencies is less than 3.0. These cases are shown in Tables 4-4, 4-6, and 4-17 for data sets 3, 5, and 12. These data sets were processed with subscript differences of 2.9, 2.9, and 0.5, respectively, with the result that the positive and negative impulse rates were very nearly the same. Specifically, at a carrier-to-noise ratio of 10.0 dB the positive and negative impulse rates differed by 5.66%, 4.07%, and 2.14%, respectively, for these data sets. The differences are small compared with a difference of 1775% at the same 10.0-dB carrier-to-noise
ratio for data set 18 shown in Table 4-26. This large difference in impulse rates occurs for a difference of 70.7 between the mean and center continuous subscripts; however, there are cases with larger subscript differences that have a much better balance between the positive and negative impulse rates.

4.3.2 Effect of the FM Spectral Shape on Impulse Rates

The effect of the FM spectrum shape on the impulse rate is readily visible when the impulse rates for the Gaussian and sinusoidal data are examined in Tables 4-27 through 4-30. The sinusoidal probability density function, plotted in Figure D-25, indicates a higher probability for high peak deviations than does the Gaussian probability density function, plotted in Figure D-26. Thus, one would expect higher impulse rates for the sinusoidal case than for the Gaussian. This is borne out in the tables mentioned above and in Figures 4-51 through 4-54, where those data are plotted. For a peak deviation of 5.4 MHz, an RF bandwidth of 15 MHz, and a sinusoidal distribution, the positive (or negative) impulse rate is 79.00 per second for a C/N of 10.0 dB compared with 35.35 per second for the Gaussian distribution.

Of the 26 probability density functions that were considered, sinusoidal appears to have the largest moment. Therefore, one would expect a sinusoidal modulating signal to cause the largest impulse rates, and this is true. Of all cases having a 5.4-MHz peak deviation, the sinusoidal case has the highest total impulse rate (158.02/s at a $\frac{C}{N}$ of 10.0 dB), and of all cases having a 10.0-MHz peak deviation the sinusoidal case again has the highest total impulse rate (290.8/s at a $\frac{C}{N}$ of 10 dB). Thus, it appears that the use of a sinusoidal modulating signal provides an upper bound of the set of impulse rates for TV signals. While there are probably some exceptions not treated in this report, the use of a sinusoidal test signal to determine the upper bound of threshold carrier-to-noise ratio for a particular FM peak deviation seems sound.

4.3.3 Effect of Preemphasis on Impulse Rates

A preemphasis-deemphasis combination is used to increase the ratio of signal power to fluctuation noise power at the output of the receiver, particularly for the higher frequency
channels that may occupy the baseband. This improvement occurs above threshold where impulsive threshold noise is negligible. It is useful to examine the effect of preemphasis upon the impulse rate which causes the FM threshold condition. Although deemphasis filters are always employed in systems utilizing preemphasis, it is worth noting that a deemphasis filter has no effect on the impulse rate. Of the two filters, only the preemphasis filter can affect the impulse rate.

Tables 4-3 through 4-14 and Figures 4-3 through 4-26 show the impulse rates for flat systems. Tables 4-15 through 4-26 and Figures 4-27 through 4-50 show the impulse rates for the same systems having preemphasis included. The impulse rates calculated for other cases do not apply for the preemphasis-deemphasis consideration.

Of the 12 pairs of data sets considered, the negative impulse rates decreased with the addition of preemphasis for all except the 18-19 pair for which impulse rates are shown in Tables 4-14 and 4-26. The particular case can be identified easily in Table 4-1. The positive impulse rates also decreased for all cases except four corresponding to the following pairs of data sets:

- 5 and 6
- 7 and 8
- 15 and 16
- 13 and 14

These sets can also be identified in Table 4-1.

If the positive and negative rates are added, there is only one pair (15-16) for which the impulse rate does not decrease with preemphasis, and the increase is only 4%. This exception is clear in Figure 4-55, if one recalls that all even-numbered data sets are associated with preemphasis and all odd-numbered data sets are not. The effect of preemphasis depends on the modulating spectrum, since signals having low baseband frequencies are attenuated and those with high frequencies are amplified. One would expect a lower impulse rate as a result of adding preemphasis if the modulating spectrum is concentrated at the low end of the modulation band. However, a higher impulse rate would be expected if the modulating spectrum were concentrated at the high end. This is based on the effect of preemphasis on peak deviation, and a higher peak deviation implies a higher impulse rate.
### Table 4-1. Identification of Data Sets of Measured Probability Densities

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<td>2</td>
<td>Trust</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>Off-The-Air</td>
<td>4</td>
<td>ETV</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Color</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EIA Color Bars</td>
<td>4</td>
<td>ETV</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Off-The-Air</td>
<td>2</td>
<td>Trust</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>Off-The-Air</td>
<td>4</td>
<td>ETV</td>
<td>17</td>
<td>18</td>
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</table>
Table 4-2. Parameters Used in Computer Analysis of Measured Data

<table>
<thead>
<tr>
<th>FORMAT</th>
<th>TRUST</th>
<th>ETV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBCARRIERS</td>
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<td>2</td>
</tr>
<tr>
<td>Maximum Modulating Frequency</td>
<td>4.0 MHz</td>
<td>4.97 MHz</td>
</tr>
<tr>
<td>Modulation Index</td>
<td>1.35</td>
<td>1.087</td>
</tr>
<tr>
<td>Peak Deviation</td>
<td>5.4 MHz</td>
<td>5.4 MHz</td>
</tr>
<tr>
<td>RF Predetection Bandwidth</td>
<td>15.0 MHz</td>
<td>15.0 MHz</td>
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</tbody>
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Table 4-3. Impulse Rates Calculated for Data Set 1

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.555 (10)$^5$</td>
<td>7.224 (10)$^5$</td>
</tr>
<tr>
<td>2</td>
<td>1.773 (10)$^5$</td>
<td>5.144 (10)$^5$</td>
</tr>
<tr>
<td>3</td>
<td>1.136 (10)$^4$</td>
<td>3.372 (10)$^5$</td>
</tr>
<tr>
<td>4</td>
<td>6.575 (10)$^4$</td>
<td>1.991 (10)$^5$</td>
</tr>
<tr>
<td>5</td>
<td>3.345 (10)$^4$</td>
<td>1.031 (10)$^5$</td>
</tr>
<tr>
<td>6</td>
<td>1.445 (10)$^4$</td>
<td>4.514 (10)$^4$</td>
</tr>
<tr>
<td>7</td>
<td>5.070 (10)$^3$</td>
<td>1.602 (10)$^4$</td>
</tr>
<tr>
<td>8</td>
<td>1.368 (10)$^3$</td>
<td>4.359 (10)$^3$</td>
</tr>
<tr>
<td>9</td>
<td>2.645 (10)$^2$</td>
<td>8.483 (10)$^2$</td>
</tr>
<tr>
<td>10</td>
<td>3.360 (10)$^1$</td>
<td>1.083 (10)$^2$</td>
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<tr>
<td>11</td>
<td>2.513</td>
<td>8.118</td>
</tr>
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<td>12</td>
<td>9.643 (10)$^{-2}$</td>
<td>3.117 (10)$^{-1}$</td>
</tr>
<tr>
<td>13</td>
<td>1.597 (10)$^{-3}$</td>
<td>5.151 (10)$^{-3}$</td>
</tr>
<tr>
<td>14</td>
<td>9.230 (10)$^{-6}$</td>
<td>2.951 (10)$^{-5}$</td>
</tr>
<tr>
<td>15</td>
<td>1.443 (10)$^{-8}$</td>
<td>4.480 (10)$^{-8}$</td>
</tr>
</tbody>
</table>

CONDITIONS

- Modulation Index: 1.35
- Maximum Modulating Frequency: 4.0 MHz
- Peak Deviation: 5.4 MHz
- Probability of Exceeding Peak Deviation: 0.1%
- Predetection Filter: 4-pole, 15 MHz, Butterworth
- Peak Deviation Subscripts: 120.0 and 727.2
- Center Subscript: 423.6
- Mean Subscript: 516.1
Table 4-4. Impulse Rates Calculated for Data Set 3

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.036 (10)(^5)</td>
<td>3.869 (10)(^5)</td>
</tr>
<tr>
<td>2</td>
<td>2.806 (10)(^5)</td>
<td>2.686 (10)(^5)</td>
</tr>
<tr>
<td>3</td>
<td>1.796 (10)(^5)</td>
<td>1.716 (10)(^5)</td>
</tr>
<tr>
<td>4</td>
<td>1.035 (10)(^5)</td>
<td>9.872 (10)(^4)</td>
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<tr>
<td>5</td>
<td>5.230 (10)(^4)</td>
<td>4.980 (10)(^4)</td>
</tr>
<tr>
<td>6</td>
<td>2.238 (10)(^4)</td>
<td>2.128 (10)(^4)</td>
</tr>
<tr>
<td>7</td>
<td>7.772 (10)(^3)</td>
<td>7.380 (10)(^3)</td>
</tr>
<tr>
<td>8</td>
<td>2.073 (10)(^3)</td>
<td>1.966 (10)(^3)</td>
</tr>
<tr>
<td>9</td>
<td>3.964 (10)(^2)</td>
<td>3.755 (10)(^2)</td>
</tr>
<tr>
<td>10</td>
<td>4.989 (10)(^1)</td>
<td>4.721 (10)(^1)</td>
</tr>
<tr>
<td>11</td>
<td>3.707</td>
<td>3.506</td>
</tr>
<tr>
<td>12</td>
<td>1.421 (10)(^{-1})</td>
<td>1.343 (10)(^{-1})</td>
</tr>
<tr>
<td>13</td>
<td>2.375 (10)(^{-3})</td>
<td>2.248 (10)(^{-3})</td>
</tr>
<tr>
<td>14</td>
<td>1.420 (10)(^{-5})</td>
<td>1.347 (10)(^{-5})</td>
</tr>
<tr>
<td>15</td>
<td>2.510 (10)(^{-8})</td>
<td>2.401 (10)(^{-8})</td>
</tr>
</tbody>
</table>

CONDITIONS

Modulation Index: 1.35
Maximum Modulating Frequency: 4.0 MHz
Peak Deviation: 5.4 MHz
Probability of Exceeding Peak Deviation: 0.1%
Predetection Filter: 4-pole, 15 MHz, Butterworth
Peak Deviation Subscripts: 258.0 and 799.1
Center Subscript: 528.5
Mean Subscript: 525.6
Table 4-5. Impulse Rates Calculated for Data Set 11

<table>
<thead>
<tr>
<th>C</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>(dB)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.240 (10)^5</td>
<td>5.918 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>3.605 (10)^5</td>
<td>4.094 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td>2.281 (10)^5</td>
<td>2.606 (10)^5</td>
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<tr>
<td>4</td>
<td>1.300 (10)^5</td>
<td>1.493 (10)^5</td>
</tr>
<tr>
<td>5</td>
<td>6.493 (10)^4</td>
<td>7.503 (10)^4</td>
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<tr>
<td>6</td>
<td>2.747 (10)^4</td>
<td>3.193 (10)^4</td>
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<tr>
<td>7</td>
<td>9.431 (10)^3</td>
<td>1.102 (10)^4</td>
</tr>
<tr>
<td>8</td>
<td>2.487 (10)^3</td>
<td>2.921 (10)^3</td>
</tr>
<tr>
<td>9</td>
<td>4.707 (10)^2</td>
<td>5.555 (10)^2</td>
</tr>
<tr>
<td>10</td>
<td>5.867 (10)^1</td>
<td>6.951 (10)^1</td>
</tr>
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<td>11</td>
<td>4.329</td>
<td>5.142</td>
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<tr>
<td>12</td>
<td>1.656 (10)^{-1}</td>
<td>1.968 (10)^{-1}</td>
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<td>13</td>
<td>2.798 (10)^{-3}</td>
<td>3.314 (10)^{-3}</td>
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<td>14</td>
<td>1.744 (10)^{-5}</td>
<td>2.038 (10)^{-5}</td>
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<tr>
<td>15</td>
<td>3.532 (10)^{-8}</td>
<td>3.973 (10)^{-8}</td>
</tr>
</tbody>
</table>

CONDITIONS

- Modulation Index: 2.381
- Maximum Modulating Frequency: 4.2 MHz
- Peak Deviation: 10.0 MHz
- Probability of Exceeding Peak Deviation: 0.1%
- Predetection Filter: 4-pole, 23 MHz, Butterworth
- Peak Deviation Subscripts: 223.3 and 808.8
- Center Subscript: 516.1
- Mean Subscript: 523.1
Table 4-6. Impulse Rates Calculated for Data Set 5

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.237 (10)^5</td>
<td>7.494 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>5.099 (10)^5</td>
<td>5.285 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td>3.309 (10)^5</td>
<td>3.432 (10)^5</td>
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<tr>
<td>4</td>
<td>1.935 (10)^5</td>
<td>2.008 (10)^5</td>
</tr>
<tr>
<td>5</td>
<td>9.923 (10)^4</td>
<td>1.031 (10)^5</td>
</tr>
<tr>
<td>6</td>
<td>4.310 (10)^4</td>
<td>4.479 (10)^4</td>
</tr>
<tr>
<td>7</td>
<td>1.518 (10)^4</td>
<td>1.578 (10)^4</td>
</tr>
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<td>8</td>
<td>4.103 (10)^3</td>
<td>4.267 (10)^3</td>
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<td>7.942 (10)^2</td>
<td>8.263 (10)^2</td>
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<td>10</td>
<td>1.009 (10)^2</td>
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<td>3.014 (10)^-1</td>
</tr>
<tr>
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<td>4.803 (10)^-3</td>
<td>4.998 (10)^-3</td>
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<td>14</td>
<td>2.787 (10)^-5</td>
<td>2.898 (10)^-5</td>
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<tr>
<td>15</td>
<td>4.450 (10)^-8</td>
<td>4.617 (10)^-8</td>
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</table>

CONDITIONS

Modulation Index: 2.381
Maximum Modulating Frequency: 4.2 MHz
Peak Deviation: 10.0 MHz
Probability of Exceeding Peak Deviation: 0.1%
Predetection Filter: 4-pole, 23 MHz, Butterworth
Peak Deviation Subscripts: 310.6 and 946.5
Center Subscript: 628.5
Mean Subscript: 631.4

4-11
### Table 4-7. Impulse Rates Calculated for Data Set 7

<table>
<thead>
<tr>
<th>C</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (dB)</td>
<td>(Impulses/s)</td>
<td>(Impulses/s)</td>
</tr>
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<td>2</td>
<td>3.070 (10)$^5$</td>
<td>3.289 (10)$^5$</td>
</tr>
<tr>
<td>3</td>
<td>1.986 (10)$^5$</td>
<td>2.131 (10)$^5$</td>
</tr>
<tr>
<td>4</td>
<td>1.158 (10)$^5$</td>
<td>1.245 (10)$^5$</td>
</tr>
<tr>
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<td>6.379 (10)$^4$</td>
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<td>2.569 (10)$^4$</td>
<td>2.769 (10)$^4$</td>
</tr>
<tr>
<td>7</td>
<td>9.034 (10)$^3$</td>
<td>9.745 (10)$^3$</td>
</tr>
<tr>
<td>8</td>
<td>2.439 (10)$^3$</td>
<td>2.633 (10)$^3$</td>
</tr>
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<td>4.717 (10)$^2$</td>
<td>5.096 (10)$^2$</td>
</tr>
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<td>5.991 (10)$^1$</td>
<td>6.476 (10)$^1$</td>
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</tr>
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<td>2.850 (10)$^{-3}$</td>
<td>3.081 (10)$^{-3}$</td>
</tr>
<tr>
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<td>1.654 (10)$^{-5}$</td>
<td>1.786 (10)$^{-5}$</td>
</tr>
<tr>
<td>15</td>
<td>2.644 (10)$^{-8}$</td>
<td>2.841 (10)$^{-8}$</td>
</tr>
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</table>

### CONDITIONS

Modulation Index: 1.35  
Maximum Modulating Frequency: 4.0 MHz  
Peak Deviation: 5.4 MHz  
Probability of Exceeding Peak Deviation: 0.1%  
Predetection Filter: 4-pole, 15 MHz, Butterworth  
Peak Deviation Subscripts: 319.2 and 989.6  
Center Subscript: 654.4  
Mean Subscript: 661.0
Table 4-8. Impulse Rates Calculated for Data Set 9

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.650 \times 10^5</td>
<td>6.990 \times 10^5</td>
</tr>
<tr>
<td>2</td>
<td>3.189 \times 10^5</td>
<td>4.879 \times 10^5</td>
</tr>
<tr>
<td>3</td>
<td>2.013 \times 10^5</td>
<td>3.134 \times 10^5</td>
</tr>
<tr>
<td>4</td>
<td>1.145 \times 10^5</td>
<td>1.814 \times 10^5</td>
</tr>
<tr>
<td>5</td>
<td>5.712 \times 10^4</td>
<td>9.201 \times 10^4</td>
</tr>
<tr>
<td>6</td>
<td>2.416 \times 10^4</td>
<td>3.954 \times 10^4</td>
</tr>
<tr>
<td>7</td>
<td>8.295 \times 10^3</td>
<td>1.378 \times 10^4</td>
</tr>
<tr>
<td>8</td>
<td>2.190 \times 10^3</td>
<td>3.689 \times 10^3</td>
</tr>
<tr>
<td>9</td>
<td>4.151 \times 10^2</td>
<td>7.078 \times 10^2</td>
</tr>
<tr>
<td>10</td>
<td>5.185 \times 10^1</td>
<td>8.927 \times 10^1</td>
</tr>
<tr>
<td>11</td>
<td>3.832</td>
<td>6.642</td>
</tr>
<tr>
<td>12</td>
<td>1.467 \times 10^{-1}</td>
<td>2.546 \times 10^{-1}</td>
</tr>
<tr>
<td>13</td>
<td>2.470 \times 10^{-3}</td>
<td>4.251 \times 10^{-3}</td>
</tr>
<tr>
<td>14</td>
<td>1.518 \times 10^{-5}</td>
<td>2.534 \times 10^{-5}</td>
</tr>
<tr>
<td>15</td>
<td>2.938 \times 10^{-8}</td>
<td>4.460 \times 10^{-8}</td>
</tr>
</tbody>
</table>

CONDITIONS

Modulation Index: 2.381
Maximum Modulating Frequency: 4.2 MHz
Peak Deviation: 10.0 MHz
Probability of Exceeding Peak Deviation: 0.1%
Predetection Filter: 4-pole, 23 MHz, Butterworth
Peak Deviation Subscripts: 349.0 and 650.2
Center Subscript: 499.6
Mean Subscript: 512.0
Table 4-9. Impulse Rates Calculated for Data Set 19

<table>
<thead>
<tr>
<th>C N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.500 (10^5)</td>
<td>6.142 (10^5)</td>
</tr>
<tr>
<td>2</td>
<td>1.717 (10^5)</td>
<td>4.346 (10^5)</td>
</tr>
<tr>
<td>3</td>
<td>1.088 (10^5)</td>
<td>2.832 (10^5)</td>
</tr>
<tr>
<td>4</td>
<td>6.220 (10^4)</td>
<td>1.662 (10^5)</td>
</tr>
<tr>
<td>5</td>
<td>3.127 (10^4)</td>
<td>8.556 (10^4)</td>
</tr>
<tr>
<td>6</td>
<td>1.335 (10^4)</td>
<td>3.729 (10^4)</td>
</tr>
<tr>
<td>7</td>
<td>4.635 (10^3)</td>
<td>1.318 (10^4)</td>
</tr>
<tr>
<td>8</td>
<td>1.238 (10^3)</td>
<td>3.571 (10^3)</td>
</tr>
<tr>
<td>9</td>
<td>2.375 (10^2)</td>
<td>6.929 (10^2)</td>
</tr>
<tr>
<td>10</td>
<td>2.998 (10^1)</td>
<td>8.821 (10^1)</td>
</tr>
<tr>
<td>11</td>
<td>2.233</td>
<td>6.605</td>
</tr>
<tr>
<td>12</td>
<td>8.561 (10^{-2})</td>
<td>2.535 (10^{-1})</td>
</tr>
<tr>
<td>13</td>
<td>1.425 (10^{-3})</td>
<td>4.197 (10^{-3})</td>
</tr>
<tr>
<td>14</td>
<td>8.395 (10^{-6})</td>
<td>2.421 (10^{-5})</td>
</tr>
<tr>
<td>15</td>
<td>1.410 (10^{-8})</td>
<td>3.779 (10^{-8})</td>
</tr>
</tbody>
</table>

CONDITIONS

- Modulation Index: 1.087
- Maximum Modulating Frequency: 4.97 MHz
- Peak Deviation: 5.4 MHz
- Probability of Exceeding Peak Deviation: 0.1%
- Predetection Filter: 4-pole, 15 MHz, Butterworth
- Peak Deviation Subscripts: 118.0 and 762.7
- Center Subscript: 440.3
- Mean Subscript: 516.9
### Table 4-10. Impulse Rates Calculated for Data Set 21

<table>
<thead>
<tr>
<th>$\frac{C}{N}$ (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.134 (10)$^5$</td>
<td>3.617 (10)$^5$</td>
</tr>
<tr>
<td>2</td>
<td>2.140 (10)$^5$</td>
<td>2.488 (10)$^5$</td>
</tr>
<tr>
<td>3</td>
<td>1.343 (10)$^5$</td>
<td>1.574 (10)$^5$</td>
</tr>
<tr>
<td>4</td>
<td>7.589 (10)$^4$</td>
<td>8.967 (10)$^4$</td>
</tr>
<tr>
<td>5</td>
<td>3.758 (10)$^4$</td>
<td>4.478 (10)$^4$</td>
</tr>
<tr>
<td>6</td>
<td>1.577 (10)$^4$</td>
<td>1.894 (10)$^4$</td>
</tr>
<tr>
<td>7</td>
<td>5.389 (10)$^3$</td>
<td>6.501 (10)$^3$</td>
</tr>
<tr>
<td>8</td>
<td>1.405 (10)$^3$</td>
<td>1.715 (10)$^3$</td>
</tr>
<tr>
<td>9</td>
<td>2.642 (10)$^2$</td>
<td>3.245 (10)$^2$</td>
</tr>
<tr>
<td>10</td>
<td>3.275 (10)$^1$</td>
<td>4.046 (10)$^1$</td>
</tr>
<tr>
<td>11</td>
<td>2.407</td>
<td>2.986</td>
</tr>
<tr>
<td>12</td>
<td>9.203 (10)$^{-2}$</td>
<td>1.143 (10)$^{-1}$</td>
</tr>
<tr>
<td>13</td>
<td>1.562 (10)$^{-3}$</td>
<td>1.929 (10)$^{-3}$</td>
</tr>
<tr>
<td>14</td>
<td>9.882 (10)$^{-6}$</td>
<td>1.198 (10)$^{-5}$</td>
</tr>
<tr>
<td>15</td>
<td>2.080 (10)$^{-8}$</td>
<td>2.394 (10)$^{-8}$</td>
</tr>
</tbody>
</table>

**CONDITIONS**

- **Modulation Index:** 1.087
- **Maximum Modulating Frequency:** 4.97 MHz
- **Peak Deviation:** 5.4 MHz
- **Probability of Exceeding Peak Deviation:** 0.1% 
- **Predetection Filter:** 4-pole, 15 MHz, Butterworth
- **Peak Deviation Subscripts:** 181.5 and 805.7
- **Center Subscript:** 493.6
- **Mean Subscript:** 503.4
Table 4-11. Impulse Rates Calculated for Data Set 15

<table>
<thead>
<tr>
<th>( \frac{C}{N} ) (dB)</th>
<th>POSITIVE ( \text{(Impulses/s)} )</th>
<th>NEGATIVE ( \text{(Impulses/s)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.116 ( \times 10^5 )</td>
<td>3.997 ( \times 10^5 )</td>
</tr>
<tr>
<td>2</td>
<td>4.959 ( \times 10^5 )</td>
<td>2.708 ( \times 10^5 )</td>
</tr>
<tr>
<td>3</td>
<td>3.180 ( \times 10^5 )</td>
<td>1.686 ( \times 10^5 )</td>
</tr>
<tr>
<td>4</td>
<td>1.837 ( \times 10^5 )</td>
<td>9.455 ( \times 10^4 )</td>
</tr>
<tr>
<td>5</td>
<td>9.298 ( \times 10^4 )</td>
<td>4.647 ( \times 10^4 )</td>
</tr>
<tr>
<td>6</td>
<td>3.986 ( \times 10^4 )</td>
<td>1.936 ( \times 10^4 )</td>
</tr>
<tr>
<td>7</td>
<td>1.386 ( \times 10^4 )</td>
<td>6.547 ( \times 10^3 )</td>
</tr>
<tr>
<td>8</td>
<td>3.701 ( \times 10^3 )</td>
<td>1.703 ( \times 10^3 )</td>
</tr>
<tr>
<td>9</td>
<td>7.086 ( \times 10^2 )</td>
<td>3.185 ( \times 10^2 )</td>
</tr>
<tr>
<td>10</td>
<td>8.920 ( \times 10^1 )</td>
<td>3.932 ( \times 10^1 )</td>
</tr>
<tr>
<td>11</td>
<td>6.628</td>
<td>2.883</td>
</tr>
<tr>
<td>12</td>
<td>2.540 ( \times 10^{-1} )</td>
<td>1.102 ( \times 10^{-1} )</td>
</tr>
<tr>
<td>13</td>
<td>4.249 ( \times 10^{-3} )</td>
<td>1.875 ( \times 10^{-3} )</td>
</tr>
<tr>
<td>14</td>
<td>2.550 ( \times 10^{-5} )</td>
<td>1.195 ( \times 10^{-5} )</td>
</tr>
<tr>
<td>15</td>
<td>4.587 ( \times 10^{-8} )</td>
<td>2.559 ( \times 10^{-8} )</td>
</tr>
</tbody>
</table>

CONDITIONS

Modulation Index: 1.847
Maximum Modulating Frequency: 5.413 MHz
Peak Deviation: 10.0 MHz
Probability of Exceeding Peak Deviation: 0.1%
Predetection Filter: 4-pole, 23 MHz, Butterworth
Peak Deviation Subscripts: 374.5 and 712.5
Center Subscript: 543.5
Mean Subscript: 524.9
Table 4-12. Impulse Rates Calculated for Data Set 13

<table>
<thead>
<tr>
<th>C</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>(dB)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>7.351 (10)</td>
<td>7.416 (10)</td>
</tr>
<tr>
<td>2</td>
<td>5.183 (10)</td>
<td>5.230 (10)</td>
</tr>
<tr>
<td>3</td>
<td>3.365 (10)</td>
<td>3.397 (10)</td>
</tr>
<tr>
<td>4</td>
<td>1.969 (10)</td>
<td>1.988 (10)</td>
</tr>
<tr>
<td>5</td>
<td>1.011 (10)</td>
<td>1.020 (10)</td>
</tr>
<tr>
<td>6</td>
<td>4.392 (10)</td>
<td>4.435 (10)</td>
</tr>
<tr>
<td>7</td>
<td>1.548 (10)</td>
<td>1.563 (10)</td>
</tr>
<tr>
<td>8</td>
<td>4.185 (10)</td>
<td>4.227 (10)</td>
</tr>
<tr>
<td>9</td>
<td>8.104 (10)</td>
<td>8.158 (10)</td>
</tr>
<tr>
<td>10</td>
<td>1.030 (10)</td>
<td>1.041 (10)</td>
</tr>
<tr>
<td>11</td>
<td>7.705</td>
<td>7.784</td>
</tr>
<tr>
<td>12</td>
<td>2.957 (10)</td>
<td>2.987 (10)</td>
</tr>
<tr>
<td>13</td>
<td>4.902 (10)</td>
<td>4.951 (10)</td>
</tr>
<tr>
<td>14</td>
<td>2.841 (10)</td>
<td>2.869 (10)</td>
</tr>
<tr>
<td>15</td>
<td>4.513 (10)</td>
<td>4.555 (10)</td>
</tr>
</tbody>
</table>

CONDITIONS

Modulation Index: 1.847
Maximum Modulating Frequency: 5.413 MHz
Peak Deviation: 10.0 MHz
Probability of Exceeding Peak Deviation: 0.1%
Predetection Filter: 4-pole, 23 MHz, Butterworth
Peak Deviation Subscripts: 332.6 and 915.3
Center Subscript: 623.9
Mean Subscript: 624.6
Table 4-13. Impulse Rates Calculated for Data Set 23

<table>
<thead>
<tr>
<th>C</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>(dB)</td>
<td>(Impulses/s)</td>
</tr>
<tr>
<td>1</td>
<td>2.650 (10)^5</td>
<td>4.366 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>1.796 (10)^5</td>
<td>3.034 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td>1.119 (10)^5</td>
<td>1.941 (10)^5</td>
</tr>
<tr>
<td>4</td>
<td>6.283 (10)^4</td>
<td>1.118 (10)^5</td>
</tr>
<tr>
<td>5</td>
<td>3.093 (10)^4</td>
<td>5.650 (10)^4</td>
</tr>
<tr>
<td>6</td>
<td>1.291 (10)^4</td>
<td>2.418 (10)^4</td>
</tr>
<tr>
<td>7</td>
<td>4.375 (10)^3</td>
<td>8.398 (10)^3</td>
</tr>
<tr>
<td>8</td>
<td>1.141 (10)^3</td>
<td>2.240 (10)^3</td>
</tr>
<tr>
<td>9</td>
<td>2.140 (10)^2</td>
<td>4.285 (10)^2</td>
</tr>
<tr>
<td>10</td>
<td>2.649 (10)^1</td>
<td>5.392 (10)^1</td>
</tr>
<tr>
<td>11</td>
<td>1.946</td>
<td>4.005</td>
</tr>
<tr>
<td>12</td>
<td>7.438 (10)^-2</td>
<td>1.535 (10)^-1</td>
</tr>
<tr>
<td>13</td>
<td>1.262 (10)^-3</td>
<td>2.568 (10)^-3</td>
</tr>
<tr>
<td>14</td>
<td>7.972 (10)^-6</td>
<td>1.542 (10)^-5</td>
</tr>
<tr>
<td>15</td>
<td>1.665 (10)^-8</td>
<td>2.781 (10)^-8</td>
</tr>
</tbody>
</table>

**CONDITIONS**

Modulation Index: 1.087
Maximum Modulating Frequency: 4.97 MHz
Peak Deviation: 5.4 MHz
Probability of Exceeding Peak Deviation: 0.1%
Predetection Filter: 4-pole, 15 MHz, Butterworth
Peak Deviation Subscripts: 206.9 and 760.0
Center Subscript: 483.4
Mean Subscript: 514.4
Table 4-14. Impulse Rates Calculated for Data Set 17

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.365 (10)^5</td>
<td>8.367 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>3.003 (10)^5</td>
<td>5.892 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td>1.903 (10)^5</td>
<td>3.820 (10)^5</td>
</tr>
<tr>
<td>4</td>
<td>1.088 (10)^5</td>
<td>2.231 (10)^5</td>
</tr>
<tr>
<td>5</td>
<td>5.461 (10)^4</td>
<td>1.143 (10)^5</td>
</tr>
<tr>
<td>6</td>
<td>2.325 (10)^4</td>
<td>4.957 (10)^4</td>
</tr>
<tr>
<td>7</td>
<td>8.045 (10)^3</td>
<td>1.743 (10)^4</td>
</tr>
<tr>
<td>8</td>
<td>2.140 (10)^3</td>
<td>4.704 (10)^3</td>
</tr>
<tr>
<td>9</td>
<td>4.088 (10)^2</td>
<td>9.093 (10)^2</td>
</tr>
<tr>
<td>10</td>
<td>5.142 (10)^1</td>
<td>1.154 (10)^2</td>
</tr>
<tr>
<td>11</td>
<td>3.819</td>
<td>8.624</td>
</tr>
<tr>
<td>12</td>
<td>1.463 (10)^-1</td>
<td>3.308 (10)^-1</td>
</tr>
<tr>
<td>13</td>
<td>2.446 (10)^-3</td>
<td>5.493 (10)^-3</td>
</tr>
<tr>
<td>14</td>
<td>1.463 (10)^-5</td>
<td>3.201 (10)^-5</td>
</tr>
<tr>
<td>15</td>
<td>2.589 (10)^-8</td>
<td>5.192 (10)^-8</td>
</tr>
</tbody>
</table>

CONDITIONS

- Modulation Index: 1.847
- Maximum Modulating Frequency: 5.413 MHz
- Peak Deviation: 10.0 MHz
- Probability of Exceeding Peak Deviation: 0.1%
- Predetection Filter: 4-pole, 23 MHz, Butterworth
- Peak Deviation Subscripts: 184.5 and 711.4
- Center Subscript: 448.0
- Mean Subscript: 485.1
## Table 4-15. Impulse Rates Calculated for Data Set 2

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.227 (10)$^5$</td>
<td>6.013 (10)$^5$</td>
</tr>
<tr>
<td>2</td>
<td>7.745 (10)$^4$</td>
<td>4.229 (10)$^5$</td>
</tr>
<tr>
<td>3</td>
<td>4.461 (10)$^4$</td>
<td>2.738 (10)$^5$</td>
</tr>
<tr>
<td>4</td>
<td>2.297 (10)$^4$</td>
<td>1.597 (10)$^5$</td>
</tr>
<tr>
<td>5</td>
<td>1.030 (10)$^4$</td>
<td>8.164 (10)$^4$</td>
</tr>
<tr>
<td>6</td>
<td>3.891 (10)$^3$</td>
<td>3.535 (10)$^4$</td>
</tr>
<tr>
<td>7</td>
<td>1.190 (10)$^3$</td>
<td>1.241 (10)$^4$</td>
</tr>
<tr>
<td>8</td>
<td>2.799 (10)$^2$</td>
<td>3.345 (10)$^3$</td>
</tr>
<tr>
<td>9</td>
<td>4.753 (10)$^1$</td>
<td>6.459 (10)$^2$</td>
</tr>
<tr>
<td>10</td>
<td>5.389</td>
<td>8.191 (10)$^1$</td>
</tr>
<tr>
<td>11</td>
<td>3.719 (10)$^{-1}$</td>
<td>6.117</td>
</tr>
<tr>
<td>12</td>
<td>1.402 (10)$^{-2}$</td>
<td>2.346 (10)$^{-1}$</td>
</tr>
<tr>
<td>13</td>
<td>2.558 (10)$^{-4}$</td>
<td>3.898 (10)$^{-3}$</td>
</tr>
<tr>
<td>14</td>
<td>2.017 (10)$^{-6}$</td>
<td>2.280 (10)$^{-5}$</td>
</tr>
<tr>
<td>15</td>
<td>6.384 (10)$^{-9}$</td>
<td>3.751 (10)$^{-8}$</td>
</tr>
</tbody>
</table>

**CONDITIONS**

- Modulation Index: 1.35
- Maximum Modulating Frequency: 4.0 MHz
- Peak Deviation: 5.4 MHz
- Probability of Exceeding Peak Deviation: Not Specified
- Predetection Filter: 4-pole, 15 MHz, Butterworth
- Peak Deviation Subscripts: 120.0 and 727.2
- Center Subscript: 423.6
- Mean Subscript: 518.4
Table 4-16. Impulse Rates Calculated for Data Set 4

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.333 (10)^5</td>
<td>2.503 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>2.265 (10)^5</td>
<td>1.666 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td>1.414 (10)^5</td>
<td>1.016 (10)^5</td>
</tr>
<tr>
<td>4</td>
<td>7.930 (10)^4</td>
<td>5.558 (10)^4</td>
</tr>
<tr>
<td>5</td>
<td>3.893 (10)^4</td>
<td>2.655 (10)^4</td>
</tr>
<tr>
<td>6</td>
<td>1.616 (10)^4</td>
<td>1.071 (10)^4</td>
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<td>7</td>
<td>5.440 (10)^3</td>
<td>3.493 (10)^3</td>
</tr>
<tr>
<td>8</td>
<td>1.406 (10)^3</td>
<td>8.742 (10)^2</td>
</tr>
<tr>
<td>9</td>
<td>2.609 (10)^2</td>
<td>1.570 (10)^2</td>
</tr>
<tr>
<td>10</td>
<td>3.183 (10)^1</td>
<td>1.866 (10)^1</td>
</tr>
<tr>
<td>11</td>
<td>2.325</td>
<td>1.329</td>
</tr>
<tr>
<td>12</td>
<td>8.871 (10)^-2</td>
<td>5.043 (10)^-2</td>
</tr>
<tr>
<td>13</td>
<td>1.527 (10)^-3</td>
<td>8.948 (10)^-4</td>
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<tr>
<td>14</td>
<td>1.015 (10)^-5</td>
<td>6.546 (10)^-6</td>
</tr>
<tr>
<td>15</td>
<td>2.420 (10)^-8</td>
<td>1.880 (10)^-8</td>
</tr>
</tbody>
</table>

CONDITIONS

Modulation Index: 1.35
Maximum Modulating Frequency: 4.0 MHz
Peak Deviation: 5.4 MHz
Probability of Exceeding Peak Deviation: Not Specified
Predetection Filter: 4-pole, 15 MHz, Butterworth
Peak Deviation Subscripts: 258.0 and 799.1
Center Subscript: 528.5
Mean Subscript: 513.9
Table 4-17. Impulse Rates Calculated for Data Set 12

<table>
<thead>
<tr>
<th>C N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.472 (10)^5</td>
<td>4.422 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>3.011 (10)^5</td>
<td>2.975 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td>1.860 (10)^5</td>
<td>1.836 (10)^5</td>
</tr>
<tr>
<td>4</td>
<td>1.032 (10)^5</td>
<td>1.017 (10)^5</td>
</tr>
<tr>
<td>5</td>
<td>5.003 (10)^4</td>
<td>4.928 (10)^4</td>
</tr>
<tr>
<td>6</td>
<td>2.051 (10)^4</td>
<td>2.018 (10)^4</td>
</tr>
<tr>
<td>7</td>
<td>6.807 (10)^3</td>
<td>6.689 (10)^3</td>
</tr>
<tr>
<td>8</td>
<td>1.734 (10)^3</td>
<td>1.702 (10)^3</td>
</tr>
<tr>
<td>9</td>
<td>3.172 (10)^2</td>
<td>3.109 (10)^2</td>
</tr>
<tr>
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<td>3.831 (10)^1</td>
<td>3.750 (10)^1</td>
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<tr>
<td>11</td>
<td>2.761</td>
<td>2.700</td>
</tr>
<tr>
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<td>1.051 (10)^-1</td>
<td>1.027 (10)^-1</td>
</tr>
<tr>
<td>13</td>
<td>1.835 (10)^-3</td>
<td>1.797 (10)^-3</td>
</tr>
<tr>
<td>14</td>
<td>1.283 (10)^-5</td>
<td>1.262 (10)^-5</td>
</tr>
<tr>
<td>15</td>
<td>3.416 (10)^-8</td>
<td>3.383 (10)^-8</td>
</tr>
</tbody>
</table>

CONDITIONS

Modulation Index: 2.381
Maximum Modulating Frequency: 4.2 MHz
Peak Deviation: 10.0 MHz
Probability of Exceeding Peak Deviation: Not Specified
Predetection Filter: 4-pole, 23 MHz, Butterworth
Peak Deviation Subscripts: 223.3 and 808.8
Center Subscript: 516.1
Mean Subscript: 515.6
Table 4-18. Impulse Rates Calculated for Data Set 6

<table>
<thead>
<tr>
<th>C</th>
<th>N</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>9.410 (10)^5</td>
<td>3.258 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>6.645 (10)^5</td>
<td>2.204 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>4.320 (10)^5</td>
<td>1.374 (10)^5</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>2.530 (10)^5</td>
<td>7.728 (10)^4</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>1.299 (10)^5</td>
<td>3.819 (10)^4</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>5.647 (10)^4</td>
<td>1.603 (10)^4</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>1.990 (10)^4</td>
<td>5.470 (10)^3</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>5.379 (10)^3</td>
<td>1.438 (10)^3</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>1.041 (10)^3</td>
<td>2.719 (10)^2</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>1.323 (10)^2</td>
<td>3.391 (10)^1</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>9.888</td>
<td>2.504</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>3.794 (10)^-1</td>
<td>9.579 (10)^-2</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>6.296 (10)^-3</td>
<td>1.614 (10)^-3</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>3.668 (10)^-5</td>
<td>9.960 (10)^-6</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>5.956 (10)^-8</td>
<td>1.955 (10)^-8</td>
</tr>
</tbody>
</table>

CONDITIONS

Modulation Index: 2.381
Maximum Modulating Frequency: 4.2 MHz
Peak Deviation: 10.0 MHz
Probability of Exceeding Peak Deviation: Not Specified
Predetection Filter: 4-pole, 23 MHz, Butterworth
Peak Deviation Subscripts: 310.6 and 946.5
Center Subscript: 628.5
Mean Subscript: 559.7
Table 4-19. Impulse Rates Calculated for Data Set 8

<table>
<thead>
<tr>
<th>C</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (dB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.285 (10)⁵</td>
<td>1.501 (10)⁵</td>
</tr>
<tr>
<td>2</td>
<td>3.695 (10)⁵</td>
<td>9.632 (10)⁴</td>
</tr>
<tr>
<td>3</td>
<td>2.377 (10)⁵</td>
<td>5.649 (10)⁴</td>
</tr>
<tr>
<td>4</td>
<td>1.377 (10)⁵</td>
<td>2.964 (10)⁴</td>
</tr>
<tr>
<td>5</td>
<td>6.997 (10)⁴</td>
<td>1.356 (10)⁴</td>
</tr>
<tr>
<td>6</td>
<td>3.011 (10)⁴</td>
<td>5.230 (10)³</td>
</tr>
<tr>
<td>7</td>
<td>1.051 (10)⁴</td>
<td>1.632 (10)³</td>
</tr>
<tr>
<td>8</td>
<td>2.815 (10)³</td>
<td>3.911 (10)²</td>
</tr>
<tr>
<td>9</td>
<td>5.406 (10)²</td>
<td>6.748 (10)¹</td>
</tr>
<tr>
<td>10</td>
<td>6.825 (10)¹</td>
<td>7.747</td>
</tr>
<tr>
<td>11</td>
<td>5.081</td>
<td>5.386 (10)⁻¹</td>
</tr>
<tr>
<td>12</td>
<td>1.948 (10)⁻¹</td>
<td>2.033 (10)⁻²</td>
</tr>
<tr>
<td>13</td>
<td>3.250 (10)⁻³</td>
<td>3.697 (10)⁻⁴</td>
</tr>
<tr>
<td>14</td>
<td>1.933 (10)⁻⁵</td>
<td>2.897 (10)⁻⁶</td>
</tr>
<tr>
<td>15</td>
<td>3.380 (10)⁻⁸</td>
<td>9.183 (10)⁻⁹</td>
</tr>
</tbody>
</table>

**CONDITIONS**

- Modulation Index: 1.35
- Maximum Modulating Frequency: 4.0 MHz
- Peak Deviation: 5.4 MHz
- Probability of Exceeding Peak Deviation: Not Specified
- Predetection Filter: 4-pole, 15 MHz, Butterworth
- Peak Deviation Subscripts: 319.2 and 989.6
- Center Subscript: 654.4
- Mean Subscript: 571.7
## Table 4-20. Impulse Rates Calculated for Data Set 10

<table>
<thead>
<tr>
<th>$C_N$ (dB)</th>
<th><strong>POSITIVE</strong> (Impulses/s)</th>
<th><strong>NEGATIVE</strong> (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.096 ($10^5$)</td>
<td>6.559 ($10^5$)</td>
</tr>
<tr>
<td>2</td>
<td>2.772 ($10^5$)</td>
<td>4.550 ($10^5$)</td>
</tr>
<tr>
<td>3</td>
<td>1.725 ($10^5$)</td>
<td>2.904 ($10^5$)</td>
</tr>
<tr>
<td>4</td>
<td>9.659 ($10^4$)</td>
<td>1.670 ($10^5$)</td>
</tr>
<tr>
<td>5</td>
<td>4.741 ($10^4$)</td>
<td>8.413 ($10^4$)</td>
</tr>
<tr>
<td>6</td>
<td>1.971 ($10^4$)</td>
<td>3.591 ($10^4$)</td>
</tr>
<tr>
<td>7</td>
<td>6.656 ($10^3$)</td>
<td>1.243 ($10^4$)</td>
</tr>
<tr>
<td>8</td>
<td>1.728 ($10^3$)</td>
<td>3.306 ($10^3$)</td>
</tr>
<tr>
<td>9</td>
<td>3.225 ($10^2$)</td>
<td>6.304 ($10^2$)</td>
</tr>
<tr>
<td>10</td>
<td>3.973 ($10^1$)</td>
<td>7.911 ($10^1$)</td>
</tr>
<tr>
<td>11</td>
<td>2.908</td>
<td>5.864</td>
</tr>
<tr>
<td>12</td>
<td>1.111 ($10^{-1}$)</td>
<td>2.246 ($10^{-1}$)</td>
</tr>
<tr>
<td>13</td>
<td>1.895 ($10^{-3}$)</td>
<td>3.770 ($10^{-3}$)</td>
</tr>
<tr>
<td>14</td>
<td>1.222 ($10^{-5}$)</td>
<td>2.291 ($10^{-5}$)</td>
</tr>
<tr>
<td>15</td>
<td>2.699 ($10^{-8}$)</td>
<td>4.301 ($10^{-8}$)</td>
</tr>
</tbody>
</table>

**CONDITIONS**

- **Modulation Index:** 2.381
- **Maximum Modulating Frequency:** 4.2 MHz
- **Peak Deviation:** 10.0 MHz
- **Probability of Exceeding Peak Deviation:** Not Specified
- **Predetection Filter:** 4-pole, 23 MHz, Butterworth
- **Peak Deviation Subscripts:** 349.0 and 650.2
- **Center Subscript:** 499.6
- **Mean Subscript:** 512.7
Table 4-21. Impulse Rates Calculated for Data Set 20

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.575 (10)</td>
<td>4.966 (10)</td>
</tr>
<tr>
<td>2</td>
<td>1.012 (10)</td>
<td>3.460 (10)</td>
</tr>
<tr>
<td>3</td>
<td>5.939 (10)</td>
<td>2.218 (10)</td>
</tr>
<tr>
<td>4</td>
<td>3.116 (10)</td>
<td>1.280 (10)</td>
</tr>
<tr>
<td>5</td>
<td>1.424 (10)</td>
<td>6.478 (10)</td>
</tr>
<tr>
<td>6</td>
<td>5.478 (10)</td>
<td>2.777 (10)</td>
</tr>
<tr>
<td>7</td>
<td>1.703 (10)</td>
<td>9.653 (10)</td>
</tr>
<tr>
<td>8</td>
<td>4.061 (10)</td>
<td>2.578 (10)</td>
</tr>
<tr>
<td>9</td>
<td>6.967 (10)</td>
<td>4.936 (10)</td>
</tr>
<tr>
<td>10</td>
<td>7.957</td>
<td>6.217 (10)</td>
</tr>
<tr>
<td>11</td>
<td>5.514 (10)</td>
<td>1.621</td>
</tr>
<tr>
<td>12</td>
<td>2.082 (10)</td>
<td>1.771 (10)</td>
</tr>
<tr>
<td>13</td>
<td>3.795 (10)</td>
<td>2.960 (10)</td>
</tr>
<tr>
<td>14</td>
<td>2.969 (10)</td>
<td>1.769 (10)</td>
</tr>
<tr>
<td>15</td>
<td>9.312 (10)</td>
<td>3.136 (10)</td>
</tr>
</tbody>
</table>

CONDITIONS

- Modulation Index: 1.087
- Maximum Modulating Frequency: 4.97 MHz
- Peak Deviation: 5.4 MHz
- Probability of Exceeding Peak Deviation: Not Specified
- Predetection Filter: 4-pole, 15 MHz, Butterworth
- Peak Deviation Subscripts: 118.0 and 762.7
- Center Subscript: 440.3
- Mean Subscript: 511.6
Table 4-22. Impulse Rates Calculated for Data Set 22

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.246 (10)^5</td>
<td>3.540 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>1.479 (10)^5</td>
<td>2.414 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td>8.914 (10)^4</td>
<td>1.511 (10)^5</td>
</tr>
<tr>
<td>4</td>
<td>1.810 (10)^4</td>
<td>8.508 (10)^4</td>
</tr>
<tr>
<td>5</td>
<td>2.262 (10)^4</td>
<td>4.192 (10)^4</td>
</tr>
<tr>
<td>6</td>
<td>8.961 (10)^3</td>
<td>1.747 (10)^4</td>
</tr>
<tr>
<td>7</td>
<td>2.866 (10)^3</td>
<td>5.902 (10)^3</td>
</tr>
<tr>
<td>8</td>
<td>7.019 (10)^2</td>
<td>1.531 (10)^3</td>
</tr>
<tr>
<td>9</td>
<td>1.232 (10)^2</td>
<td>2.851 (10)^2</td>
</tr>
<tr>
<td>10</td>
<td>1.431 (10)^1</td>
<td>3.501 (10)^1</td>
</tr>
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<td>11</td>
<td>1.001</td>
<td>2.555</td>
</tr>
<tr>
<td>12</td>
<td>3.784 (10)^-2</td>
<td>9.751 (10)^-2</td>
</tr>
<tr>
<td>13</td>
<td>6.879 (10)^-4</td>
<td>1.673 (10)^-3</td>
</tr>
<tr>
<td>14</td>
<td>5.391 (10)^-6</td>
<td>1.101 (10)^-5</td>
</tr>
<tr>
<td>15</td>
<td>1.726 (10)^-8</td>
<td>2.567 (10)^-8</td>
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</tbody>
</table>

CONDITIONS

Modulation Index: 1.087
Maximum Modulating Frequency: 4.97 MHz
Peak Deviation: 5.4 MHz
Probability of Exceeding Peak Deviation: Not Specified
Predetection Filter: 4-pole, 15 MHz, Butterworth
Peak Deviation Subscripts: 181.5 and 805.7
Center Subscript: 493.6
Mean Subscript: 519.9

4-27
Table 4-23. Impulse Rates Calculated for Data Set 16

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.709 (10)^5</td>
<td>2.501 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>6.115 (10)^5</td>
<td>1.634 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td>3.951 (10)^5</td>
<td>9.784 (10)^4</td>
</tr>
<tr>
<td>4</td>
<td>2.300 (10)^5</td>
<td>5.264 (10)^4</td>
</tr>
<tr>
<td>5</td>
<td>1.173 (10)^5</td>
<td>2.479 (10)^4</td>
</tr>
<tr>
<td>6</td>
<td>5.070 (10)^4</td>
<td>9.888 (10)^3</td>
</tr>
<tr>
<td>7</td>
<td>1.776 (10)^4</td>
<td>3.204 (10)^3</td>
</tr>
<tr>
<td>8</td>
<td>4.776 (10)^3</td>
<td>7.999 (10)^2</td>
</tr>
<tr>
<td>9</td>
<td>9.202 (10)^2</td>
<td>1.440 (10)^2</td>
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<tr>
<td>10</td>
<td>1.165 (10)^2</td>
<td>1.723 (10)^1</td>
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<tr>
<td>11</td>
<td>8.688</td>
<td>1.236</td>
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<tr>
<td>12</td>
<td>3.322 (10)^{-1}</td>
<td>4.702 (10)^{-2}</td>
</tr>
<tr>
<td>13</td>
<td>5.545 (10)^{-3}</td>
<td>8.203 (10)^{-4}</td>
</tr>
<tr>
<td>14</td>
<td>3.263 (10)^{-5}</td>
<td>5.667 (10)^{-6}</td>
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<tr>
<td>15</td>
<td>5.483 (10)^{-8}</td>
<td>1.445 (10)^{-8}</td>
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</table>

CONDITIONS

- Modulation Index: 1.847
- Maximum Modulating Frequency: 5.413 MHz
- Peak Deviation: 10.0 MHz
- Probability of Exceeding Peak Deviation: Not Specified
- Predetection Filter: 4-pole, 23 MHz, Butterworth
- Peak Deviation Subscripts: 374.5 and 712.5
- Center Subscript: 543.5
- Mean Subscript: 506.5
Table 4-24. Impulse Rates Calculated for Data Set 14

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.035 (10)^6</td>
<td>3.316 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>7.333 (10)^5</td>
<td>2.257 (10)^5</td>
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<tr>
<td>3</td>
<td>4.784 (10)^5</td>
<td>1.416 (10)^5</td>
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<td>4</td>
<td>2.810 (10)^5</td>
<td>8.015 (10)^4</td>
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<tr>
<td>5</td>
<td>1.447 (10)^5</td>
<td>3.986 (10)^4</td>
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<td>6.306 (10)^4</td>
<td>1.683 (10)^4</td>
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<td>7</td>
<td>2.227 (10)^4</td>
<td>5.781 (10)^3</td>
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<td>6.032 (10)^3</td>
<td>1.528 (10)^3</td>
</tr>
<tr>
<td>9</td>
<td>1.169 (10)^3</td>
<td>2.901 (10)^2</td>
</tr>
<tr>
<td>10</td>
<td>1.487 (10)^2</td>
<td>3.630 (10)^1</td>
</tr>
<tr>
<td>11</td>
<td>1.113 (10)^1</td>
<td>2.686</td>
</tr>
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<td>12</td>
<td>4.270 (10)^-1</td>
<td>1.028 (10)^-1</td>
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<tr>
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<td>7.080 (10)^-3</td>
<td>1.728 (10)^-3</td>
</tr>
<tr>
<td>14</td>
<td>4.113 (10)^-5</td>
<td>1.059 (10)^-5</td>
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<tr>
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<td>6.611 (10)^-8</td>
<td>2.037 (10)^-8</td>
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CONDITIONS

Modulation Index: 1.847
Maximum Modulating Frequency: 5.413 MHz
Peak Deviation: 10.0 MHz
Probability of Exceeding Peak Deviation: Not Specified
Predetection Filter: 4-pole, 23 MHz, Butterworth
Peak Deviation Subscripts: 332.6 and 915.3
Center Subscript: 623.9
Mean Subscript: 551.8
Table 4-25. Impulse Rates Calculated for Data Set 24

<table>
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<tr>
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<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
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</thead>
<tbody>
<tr>
<td>N (dB)</td>
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<tr>
<td>1</td>
<td>1.976 (10)^5</td>
<td>4.278 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>1.295 (10)^5</td>
<td>2.956 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td>7.767 (10)^4</td>
<td>1.879 (10)^5</td>
</tr>
<tr>
<td>4</td>
<td>4.174 (10)^4</td>
<td>1.075 (10)^5</td>
</tr>
<tr>
<td>5</td>
<td>1.957 (10)^4</td>
<td>5.388 (10)^4</td>
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<td>7.745 (10)^3</td>
<td>2.287 (10)^4</td>
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<td>7</td>
<td>2.480 (10)^3</td>
<td>7.876 (10)^3</td>
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<td>8</td>
<td>6.092 (10)^2</td>
<td>2.083 (10)^3</td>
</tr>
<tr>
<td>9</td>
<td>1.076 (10)^2</td>
<td>3.954 (10)^2</td>
</tr>
<tr>
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<td>1.261 (10)^1</td>
<td>4.940 (10)^1</td>
</tr>
<tr>
<td>11</td>
<td>8.892 (10)^-1</td>
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</tr>
<tr>
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<td>3.370 (10)^-2</td>
<td>1.398 (10)^-1</td>
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<td>6.032 (10)^-4</td>
<td>2.355 (10)^-3</td>
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<tr>
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<td>4.511 (10)^-6</td>
<td>1.451 (10)^-5</td>
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<tr>
<td>15</td>
<td>1.334 (10)^-8</td>
<td>2.831 (10)^-8</td>
</tr>
</tbody>
</table>

**CONDITIONS**

- Modulation Index: 1.087
- Maximum Modulating Frequency: 4.97 MHz
- Peak Deviation: 5.4 MHz
- Probability of Exceeding Peak Deviation: Not Specified
- Predetection Filter: 4-pole, 15 MHz, Butterworth
- Peak Deviation Subscripts: 206.9 and 760.0
- Center Subscript: 483.4
- Mean Subscript: 524.9
### Table 4-26. Impulse Rates Calculated for Data Set 18

<table>
<thead>
<tr>
<th>C</th>
<th>N (dB)</th>
<th>POSITIVE (Impulses/s)</th>
<th>NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>5</td>
</tr>
<tr>
<td>2</td>
<td>1.119</td>
<td>6.575 (10)^5</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>6.389</td>
<td>4.258 (10)^5</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>3.252</td>
<td>2.484 (10)^5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>1.438</td>
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</tr>
<tr>
<td>6</td>
<td>5.344</td>
<td>5.502 (10)^4</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>1.603</td>
<td>1.932 (10)^4</td>
<td>4</td>
</tr>
<tr>
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<td>3</td>
</tr>
<tr>
<td>9</td>
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<td>2</td>
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<td>11</td>
<td>4.637</td>
<td>9.535</td>
<td></td>
</tr>
<tr>
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<td>1.745</td>
<td>3.658 (10)^1</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>3.214</td>
<td>6.073 (10)^3</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>2.564</td>
<td>3.538 (10)^5</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>8.116</td>
<td>5.727 (10)^8</td>
<td></td>
</tr>
</tbody>
</table>

**CONDITIONS**

- Modulation Index: 1.847
- Maximum Modulating Frequency: 5.413 MHz
- Peak Deviation: 10.0 MHz
- Probability of Exceeding Peak Deviation: Not Specified
- Predetection Filter: 4-pole, 23 MHz, Butterworth
- Peak Deviation Subscripts: 184.5 and 711.4
- Center Subscript: 448.0
- Mean Subscript: 518.1
Table 4-27. Impulse Rates Calculated For a Sinusoidal Distribution With a Peak Deviation of 5.4 MHz

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE or NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.387 (10)^5</td>
</tr>
<tr>
<td>2</td>
<td>3.825 (10)^5</td>
</tr>
<tr>
<td>3</td>
<td>2.501 (10)^5</td>
</tr>
<tr>
<td>4</td>
<td>1.473 (10)^5</td>
</tr>
<tr>
<td>5</td>
<td>7.606 (10)^4</td>
</tr>
<tr>
<td>6</td>
<td>3.324 (10)^4</td>
</tr>
<tr>
<td>7</td>
<td>1.177 (10)^4</td>
</tr>
<tr>
<td>8</td>
<td>3.194 (10)^3</td>
</tr>
<tr>
<td>9</td>
<td>6.203 (10)^2</td>
</tr>
<tr>
<td>10</td>
<td>7.901 (10)^1</td>
</tr>
<tr>
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<td>5.917</td>
</tr>
<tr>
<td>12</td>
<td>2.271 (10)^{-1}</td>
</tr>
<tr>
<td>13</td>
<td>3.761 (10)^{-3}</td>
</tr>
<tr>
<td>14</td>
<td>2.171 (10)^{-5}</td>
</tr>
<tr>
<td>15</td>
<td>3.401 (10)^{-8}</td>
</tr>
</tbody>
</table>

CONDITIONS

Modulation Index: 1.087
Maximum Modulating Frequency: 4.97 MHz
Peak Deviation: 5.4 MHz
Probability of Exceeding Peak Deviation: 0.1%
Predetection Filter: 4-pole, 15.0 MHz, Butterworth
Peak Deviation Subscripts: 9.3 and 1010.7
Center Subscript: 510.0
Mean Subscript: 510.0

4-32
Table 4-28. Impulse Rates Calculated For a Sinusoidal Distribution With a Peak Deviation of 10.0 MHz

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE or NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.642 (10)^{5}</td>
</tr>
<tr>
<td>2</td>
<td>6.882 (10)^{5}</td>
</tr>
<tr>
<td>3</td>
<td>4.520 (10)^{5}</td>
</tr>
<tr>
<td>4</td>
<td>2.674 (10)^{5}</td>
</tr>
<tr>
<td>5</td>
<td>1.385 (10)^{5}</td>
</tr>
<tr>
<td>6</td>
<td>6.070 (10)^{4}</td>
</tr>
<tr>
<td>7</td>
<td>2.154 (10)^{4}</td>
</tr>
<tr>
<td>8</td>
<td>5.859 (10)^{3}</td>
</tr>
<tr>
<td>9</td>
<td>1.140 (10)^{3}</td>
</tr>
<tr>
<td>10</td>
<td>1.454 (10)^{2}</td>
</tr>
<tr>
<td>11</td>
<td>1.089 (10)^{1}</td>
</tr>
<tr>
<td>12</td>
<td>4.182 (10)^{-1}</td>
</tr>
<tr>
<td>13</td>
<td>6.919 (10)^{-3}</td>
</tr>
<tr>
<td>14</td>
<td>3.979 (10)^{-5}</td>
</tr>
<tr>
<td>15</td>
<td>6.150 (10)^{-8}</td>
</tr>
</tbody>
</table>

**CONDITIONS**

Modulation Index: 2.381  
Maximum Modulating Frequency: 4.2 MHz  
Peak Deviation: 10.0 MHz  
Probability of Exceeding Peak Deviation: 0.1%  
Predetection Filter: 4-pole, 23.0 MHz, Butterworth  
Peak Deviation Subscripts: 9.3 and 1010.7  
Center Subscript: 510.0  
Mean Subscript: 510.0
Table 4-29. Impulse Rates Calculated For a Gaussian Distribution
With a Peak Deviation of 5.4 MHz

<table>
<thead>
<tr>
<th>( \frac{C}{N} ) (dB)</th>
<th>POSITIVE or NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.305 ( 10^5 )</td>
</tr>
<tr>
<td>2</td>
<td>2.261 ( 10^5 )</td>
</tr>
<tr>
<td>3</td>
<td>1.423 ( 10^5 )</td>
</tr>
<tr>
<td>4</td>
<td>8.058 ( 10^4 )</td>
</tr>
<tr>
<td>5</td>
<td>4.001 ( 10^4 )</td>
</tr>
<tr>
<td>6</td>
<td>1.683 ( 10^4 )</td>
</tr>
<tr>
<td>7</td>
<td>5.747 ( 10^3 )</td>
</tr>
<tr>
<td>8</td>
<td>1.509 ( 10^3 )</td>
</tr>
<tr>
<td>9</td>
<td>2.844 ( 10^2 )</td>
</tr>
<tr>
<td>10</td>
<td>3.535 ( 10^1 )</td>
</tr>
<tr>
<td>11</td>
<td>2.604</td>
</tr>
<tr>
<td>12</td>
<td>9.958 ( 10^{-2} )</td>
</tr>
<tr>
<td>13</td>
<td>1.685 ( 10^{-3} )</td>
</tr>
<tr>
<td>14</td>
<td>1.054 ( 10^{-5} )</td>
</tr>
<tr>
<td>15</td>
<td>2.146 ( 10^{-8} )</td>
</tr>
</tbody>
</table>

CONDITIONS

- Modulation Index: 1.087
- Maximum Modulating Frequency: 4.97 MHz
- Peak Deviation: 5.4 MHz
- Probability of Exceeding Peak Deviation: 0.1%
- Predetection Filter: 4-pole, 15.0 MHz, Butterworth
- Peak Deviation Subscripts: 181.4 and 838.6
- Center Subscript: 510.0
- Mean Subscript: 510.0
Table 4-30. Impulse Rates Calculated For a Gaussian Distribution With a Peak Deviation of 10.0 MHz

<table>
<thead>
<tr>
<th>C/N (dB)</th>
<th>POSITIVE or NEGATIVE (Impulses/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.428 \times 10^5</td>
</tr>
<tr>
<td>2</td>
<td>3.739 \times 10^5</td>
</tr>
<tr>
<td>3</td>
<td>2.370 \times 10^5</td>
</tr>
<tr>
<td>4</td>
<td>1.354 \times 10^5</td>
</tr>
<tr>
<td>5</td>
<td>6.778 \times 10^4</td>
</tr>
<tr>
<td>6</td>
<td>2.876 \times 10^4</td>
</tr>
<tr>
<td>7</td>
<td>9.908 \times 10^3</td>
</tr>
<tr>
<td>8</td>
<td>2.623 \times 10^3</td>
</tr>
<tr>
<td>9</td>
<td>4.985 \times 10^2</td>
</tr>
<tr>
<td>10</td>
<td>6.238 \times 10^1</td>
</tr>
<tr>
<td>11</td>
<td>4.617</td>
</tr>
<tr>
<td>12</td>
<td>1.768 \times 10^{-1}</td>
</tr>
<tr>
<td>13</td>
<td>2.972 \times 10^{-3}</td>
</tr>
<tr>
<td>14</td>
<td>1.816 \times 10^{-5}</td>
</tr>
<tr>
<td>15</td>
<td>3.455 \times 10^{-8}</td>
</tr>
</tbody>
</table>

CONDITIONS

Modulation Index: 2.381
Maximum Modulating Frequency: 4.2 MHz
Peak Deviation: 10.0 MHz
Probability of Exceeding Peak Deviation: 0.1%
Predetection Filter: 4-pole, 23.0 MHz, Butterworth
Peak Deviation Subscripts: 181.4 and 838.6
Center Subscript: 510.0
Mean Subscript: 510.0
Figure 4-1. RETMA Test Pattern
Figure 4-2. "Post Office" Test Pattern
Figure 4-3. Positive Impulse Rates Plotted As a Function of C/N for Data Set 1
Figure 4-4. Negative Impulse Rate Plotted As A Function of C/N for Data Set 1
Figure 4-5. Positive Impulse Rates Plotted
As a Function of C/N for Data Set 3
Figure 4-6. Negative Impulse Rates Plotted As a Function of C/N for Data Set 3
Figure 4-7. Positive Impulse Rates Plotted As a Function of C/N for Data Set 11
Figure 4-8. Negative Impulse Rates Plotted As a Function of C/N for Data Set 11.
Figure 4-9. Positive Impulse Rates Plotted
As a Function of C/N for Data Set 5

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Figure 4-10. Negative Impulse Rates Plotted As a Function of C/N for Data Set 5
Figure 4-11. Positive Impulse Rates Plotted As a Function of C/N for Data Set 7
Figure 4-12. Negative Impulse Rates Plotted As a Function of C/N for Data Set 7
Figure 4-13. Positive Impulse Rates Plotted As a Function of C/N for Data Set 9
Figure 4-14. Negative Impulse Rates Plotted As a Function of C/N for Data Set 9
Figure 4-15. Positive Impulse Rates Plotted As a Function of C/N for Data Set 19
Figure 4-16. Negative Impulse Rates Plotted As a Function of C/N for Data Set 19
Figure 4-17. Positive Impulse Rates Plotted As a Function of C/N for Data Set 21
Figure 4-18. Negative Impulse Rates Plotted As a Function of C/N for Data Set 21
Figure 4-19. Positive Impulse Rates Plotted As a Function of C/N for Data Set 15
Figure 4-20. Negative Impulse Rates Plotted As a Function of C/N for Data Set 15
Figure 4-21. Positive Impulse Rates Plotted As a Function of $C/N$ for Data Set 13
Figure 4-22. Negative Impulse Rates Plotted As a Function of C/N for Data Set 13
Figure 4-23. Positive Impulse Rates Plotted
As a Function of C/N for Data Set 23
Figure 4-24. Negative Impulse Rates Plotted As a Function of C/N for Data Set 23
Figure 4-25. Positive Impulse Rates Plotted As a Function of C/N for Data Set 17
Figure 4-26. Negative Impulse Rates Plotted As a Function of C/N for Data Set 17
Figure 4-27. Positive Impulse Rates Plotted As a Function of C/N for Data Set 2
Figure 4-28. Negative Impulse Rates Plotted As a Function of C/N for Data Set 2
Figure 4-29. Positive Impulse Rates Plotted As a Function of C/N for Data Set 4
Figure 4-30. Negative Impulse Rates Plotted As a Function of C/N for Data Set 4
Figure 4-31. Positive Impulse Rates Plotted
As a Function of C/N for Data Set 12
Figure 4-32. Negative Impulse Rates Plotted
As a Function of C/N for Data Set 12
Figure 4-33. Positive Impulse Rates Plotted As a Function of C/N for Data Set 6
Figure 4-34. Negative Impulse Rates Plotted As a Function of C/N for Data Set 6
Figure 4-35. Positive Impulse Rates Plotted As a Function of C/N for Data Set 8

4-70
Figure 4-36. Negative Impulse Rates Plotted As a Function of C/N for Data Set 8
Figure 4-37. Positive Impulse Rates Plotted As a Function of C/N for Data Set 10
Figure 4-38. Negative Impulse Rates Plotted As a Function of C/N for Data Set 10
Figure 4-39. Positive Impulse Rates Plotted As a Function of C/N for Data Set 20
Figure 4-40. Negative Impulse Rates Plotted As a Function of C/N for Data Set 20
Figure 4-41. Positive Impulse Rates Plotted As a Function of C/N for Data Set 22
Figure 4-42. Negative Impulse Rates Plotted As a Function of C/N for Data Set 22
Figure 4-43. Positive Impulse Rates Plotted As a Function of C/N for Data Set 16
Figure 4-44. Negative Impulse Rates Plotted As a Function of C/N for Data Set 16
Figure 4-45. Positive Impulse Rates Plotted As a Function of C/N for Data Set 14
Figure 4-46. Negative Impulse Rates Plotted As a Function of C/N for Data Set 14
Figure 4-47. Positive Impulse Rates Plotted As a Function of C/N for Data Set 24
Figure 4-48. Negative Impulse Rates Plotted As a Function of C/N for Data Set 24
Figure 4-49. Positive Impulse Rates Plotted As a Function of C/N for Data Set 18
Figure 4-50. Negative Impulse Rates Plotted As a Function of C/N for Data Set 18
Figure 4-51. Positive (Negative) Impulse Rates
Plotted as a Function of C/N for a Sinusoidal Distribution
and a Peak Deviation of 5.4 MHz
Figure 4-52. Positive (Negative) Impulse Rates
Plotted as a Function of C/N for a Sinusoidal Distribution
and a Peak Deviation of 10.0 MHz
Figure 4-53. Positive (Negative) Impulse Rates Plotted as a Function of C/N for a Gaussian Distribution and a Peak Deviation of 5.4 MHz
Figure 4-54. Positive (Negative) Impulse Rates Plotted as a Function of C/N for a Gaussian Distribution and a Peak Deviation of 10.0 MHz
Odd-numbered data sets: flat
Even-numbered data sets: preemphasized
* Sinusoidal, $D_p = 5.4$ MHz
** Sinusoidal, $D_p = 10.0$ MHz
*** Gaussian, $D_p = 5.4$ MHz
**** Gaussian, $D_p = 10.0$ MHz

Figure 4-55. Impulse Rates for a Carrier-To-Noise Ratio of 10.0 dB
SECTION 5 - CONCLUSIONS

Several conclusions can be drawn from this study of the FM threshold. They are:

1. The balance of the FM spectrum around the center frequency of a symmetrical predetection filter affects the balance of positive and negative impulse rates. A balanced spectrum provides balanced impulse rates; whereas, an unbalanced spectrum may not. A spectrum having an expected frequency above the center frequency produces a higher negative impulse rate than positive. On the other hand, a spectrum having an expected frequency below the center frequency produces a higher positive rate than negative.

2. The impulse rates are higher for FM spectra having larger moments about the center frequency. For example, the spectrum of a sinusoidal modulating signal has most of its area away from its axis of symmetry, while the Gaussian has its area concentrated on its axis of symmetry. Thus, the sinusoidal modulating signal produces higher impulse rates than the Gaussian.

3. Sinusoidal modulation produces a total impulse rate (positive plus negative) which is a practical upper bound for the impulse rates of television signals providing the same peak deviation. Figure 4-55 shows that sinusoidal modulation at the highest peak deviation, namely 10.0 MHz, produces the highest total impulse rate of all the other cases considered.

4. It appears that the total impulse rate for television signals generally decreases with the inclusion of preemphasis. There was only one exception to this in the twelve pairs of cases examined in this study. Figure 4-55 shows this anomaly for data sets 15 and 16.
REFERENCES


APPENDIX A - PREDETECTION FILTER CALCULATIONS

A.1 INTRODUCTION

The radius of gyration is calculated for symmetric bandpass filters of the following types:

- Butterworth (1, 2, 3, and 4 pole)
- Chebyshev (1 and 2 pole)
- Gaussian
- Rectangular

These filters are assumed to have the same frequency response \( H(f) \) as the low pass equivalent except for a translation in frequency from zero to \( f_0 \).

The radius of gyration is defined by Equation (A-1) as follows:

\[
\begin{align*}
r & = \sqrt{\frac{I}{b}} \\
I & = \int_{-\infty}^{\infty} (f - f_0)^2 \left| H(f) \right|^2 \, df \\
b & = \int_{-\infty}^{\infty} \left| H(f) \right|^2 \, df
\end{align*}
\]

where

- \( I \) is the moment of inertia of \( \left| H(f) \right|^2 \) about the \( f = 0 \) axis and
- \( b \) is the noise bandwidth of the filter. Frequency is represented by \( f \) and \( H(f) \) is the frequency response of the filter. A summary of the results of the calculations herein are shown in Table A-1.
Table A-1. Noise Bandwidth, Moment of Inertia, and Radius of Gyration for Various Filter Types

<table>
<thead>
<tr>
<th>Filter Type</th>
<th>Noise Bandwidth</th>
<th>Moment of Inertia</th>
<th>Radius of Gyration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butterworth (1)</td>
<td>( \frac{\pi}{2} B )</td>
<td>( \infty )</td>
<td>( \infty )</td>
</tr>
<tr>
<td>Butterworth (2)</td>
<td>( \frac{\pi}{2\sqrt{2}} B )</td>
<td>( \frac{\pi}{2} B^3 )</td>
<td>( 2^{1/4} B )</td>
</tr>
<tr>
<td>Butterworth (3)</td>
<td>( \frac{\pi}{3} B )</td>
<td>( \frac{\pi}{24} B^3 )</td>
<td>( \frac{1}{2\sqrt{2}} B )</td>
</tr>
<tr>
<td>Butterworth (4)</td>
<td>( \frac{\pi}{8} \left[ \sqrt{2 + \sqrt{2 + \sqrt{2 - \sqrt{2}}} \right] B )</td>
<td>( \frac{\pi}{32} \left[ \sqrt{2 + \sqrt{2 - \sqrt{2}}} - \sqrt{2 - \sqrt{2}} \right] B^3 )</td>
<td>( \frac{\sqrt{2 - 1}}{2} B )</td>
</tr>
<tr>
<td>Chebyshev (1)</td>
<td>( \frac{\pi}{2\epsilon} B_\epsilon )</td>
<td>( \infty )</td>
<td>( \infty )</td>
</tr>
<tr>
<td>Chebyshev (2)</td>
<td>( \frac{\pi}{4} \sqrt{\frac{1}{\epsilon} \frac{1}{1 + \epsilon^2} + \frac{1}{1 + \epsilon^2}} B_\epsilon )</td>
<td>( \frac{\pi}{32\epsilon^2} \sqrt{\epsilon \frac{1}{1 + \epsilon^2} + \epsilon^2} B_\epsilon^3 )</td>
<td>( \frac{1 + \epsilon^2}{2\sqrt{2\epsilon}} )</td>
</tr>
<tr>
<td>Gaussian</td>
<td>( \frac{1}{2} \sqrt{\frac{\pi}{\ln 2}} B )</td>
<td>( \frac{\sqrt{\pi}}{16 (\ln 2)^{3/2}} B^3 )</td>
<td>( \frac{1}{2\sqrt{2 \ln 2}} B )</td>
</tr>
<tr>
<td>Rectangular</td>
<td>( B )</td>
<td>( \frac{1}{12} B^3 )</td>
<td>( \frac{1}{\sqrt{12}} B )</td>
</tr>
</tbody>
</table>
A.2 BUTTERWORTH FILTERS

The Butterworth filter is assumed to have a frequency response defined by

\[ \left| H(f) \right|^2 = \frac{1}{1 + \left(\frac{f - f_0}{B/2}\right)^{2n}} \quad (A-4) \]

where \( f \) represents frequency

\( B \) is the half-power bandwidth

\( n \) is the number of poles associated with the filter.

The moment of inertia is calculated by

\[ I = \int_{-\infty}^{\infty} \frac{(f - f_0)^2}{1 + \left(\frac{f - f_0}{B/2}\right)^{2n}} \, df \quad (A-5) \]

which can be simplified by a change of variable to

\[ I = \frac{B^3}{8} \int_{-\infty}^{\infty} \frac{x^2 \, dx}{1 + x^{2n}} \quad (A-6) \]

Because the integrand is an even function, it can be simplified further to

\[ I = \frac{B^3}{4} \int_{0}^{\infty} \frac{x^2 \, dx}{1 + x^{2n}} \quad (A-7) \]

The noise bandwidth for the Butterworth filter becomes

\[ b = \int_{-\infty}^{\infty} \frac{df}{1 + \left(\frac{f - f_0}{B/2}\right)^{2n}} \quad (A-8) \]

which can be simplified to

\[ d = B \int_{0}^{\infty} \frac{dx}{1 + x^{2n}} \quad (A-9) \]
Thus, the radius of gyration can be found by first evaluating Equations (A-7) and (A-9) for I and b and then substituting into Equation (A-1) for r.

A.2.1 Single-Pole Filter

First, the noise bandwidth is found to be

\[ b = B \int_{0}^{\infty} \frac{dx}{1 + x^2} = \frac{\pi B}{2} \quad (A-10) \]

but the moment of inertia

\[ I = \frac{B^3}{4} \int_{0}^{\infty} \frac{x^2 dx}{1 + x^2} = \infty \quad (A-11) \]

is not defined. Thus, the radius of gyration is also undefined.

A.2.2 Double-Pole Filter

The noise bandwidth of the two-pole filter is

\[ b = B \int_{0}^{\infty} \frac{dx}{1 + x^4} = \frac{\pi B}{2 \sqrt{2}} \quad (A-12) \]

and the moment of inertia is

\[ I = \frac{B^3}{4} \int_{0}^{\infty} \frac{x^2 dx}{1 + x^4} = \frac{\pi}{2} B^3 \quad (A-13) \]

Thus, the radius of gyration is found to be

\[ r = 2^{1/4} B \quad (A-14) \]

A-4
A.2.3 Triple-Pole Filter

The noise bandwidth is

\[ b = B \int_0^\infty \frac{dx}{1 + x^6} = \frac{\pi B}{3} \]  \hspace{1cm} (A-15)

and the moment of inertia is

\[ I = \frac{B^3}{4} \int_0^\infty \frac{x^2 \, dx}{1 + x^6} = \frac{\pi B^3}{24} \]  \hspace{1cm} (A-16)

Substitution of \( b \) and \( I \) into Equation (A-1) yields a radius of gyration of

\[ r = \frac{B}{2 \sqrt{2}} \]  \hspace{1cm} (A-17)

A.2.4 Quadruple-Pole Filter

The noise bandwidth is given by

\[ b = B \int_0^\infty \frac{dx}{1 + x^8} = \frac{\pi}{8} \left[ \sqrt{2 + \sqrt{2}} + \sqrt{2 - \sqrt{2}} \right] B \]  \hspace{1cm} (A-18)

and the moment of inertia is

\[ I = \frac{B^3}{4} \int_0^\infty \frac{x^2 \, dx}{1 + x^8} = \frac{\pi}{32} \left[ \sqrt{2 + \sqrt{2}} - \sqrt{2 - \sqrt{2}} \right] B^3 \]  \hspace{1cm} (A-19)

Thus, the radius of gyration is

\[ r = \frac{\sqrt{2} - 1}{2} B \]  \hspace{1cm} (A-20)

by substitution of \( I \) and \( b \) into Equation (A-1).
A.3 CHEBYSHEV FILTERS

The Chebyshev filter is assumed to have a frequency response defined by

\[
\left| H(f) \right|^2 = \frac{1}{1 + \epsilon^2 T_n 2 \left( \frac{f - f_0}{B_\epsilon / 2} \right)^2}
\]  

(A-21)

where \( \epsilon \) is the ripple factor
\( f \) represents frequency
\( B_\epsilon \) is the ripple bandwidth
\( n \) is the number of poles associated with the filter
\( T_n \) is a Chebyshev polynomial of order \( n \).

For \( n = 1 \) and \( 2 \) the Chebyshev polynomials are

\[
T_1(x) = x
\]

(A-22)

\[
T_2(x) = 2x^2 - 1
\]

(A-23)

For Chebyshev filters with more than two poles, it is better to use the computer in calculating the radius of gyration, because the expressions required in the calculations are very complicated.

The noise bandwidth of Chebyshev filters is given by

\[
b = \int_{-\infty}^{\infty} \frac{df}{1 + \epsilon^2 T_n 2 \left( \frac{f - f_0}{B_\epsilon / 2} \right)^2}
\]

(A-24)

which can be simplified by a change of variable and use of the symmetry of the integrand. The simplified form becomes

\[
b = B_\epsilon \int_{0}^{\infty} \frac{dx}{1 + \epsilon^2 T_n 2 \left( x \right)}
\]

(A-25)
Similarly, the moment of inertia can be simplified from

\[ I = \int_{-\infty}^{\infty} \frac{(f - f_0)^2 df}{1 + \epsilon^2 \frac{T_n^2(f - f_0)}{B \epsilon/2}} \]  

(A-26)

to

\[ I = \frac{B^3 \epsilon}{4} \int_{0}^{\infty} \frac{x^2 dx}{1 + \epsilon^2 T_n^2(x)} \]  

(A-27)

A.3.1 Single Pole Chebyshev Filter

The noise bandwidth is found by substituting the expression for \( T_1(x) \), given in Equation (A-22), into Equation (A-25). Thus the noise bandwidth becomes

\[ b = B \epsilon \int_{0}^{\infty} \frac{dx}{1 + \epsilon^2 x^2} \]  

(A-28)

By a change of variable, the noise bandwidth can be simplified further and evaluated as follows:

\[ b = \frac{B \epsilon}{\epsilon} \int_{0}^{\infty} \frac{dx}{1 + x^2} = \frac{\pi}{2\epsilon} B \epsilon \]  

(A-29)

Written in terms of the half-power bandwidth \( B \), the noise bandwidth becomes

\[ b = \frac{\pi}{2} B \]  

(A-30)

The moment of inertia, \( I \), is now found by evaluating the expression in Equation (A-27) with \( T_1(x) \). Then

\[ I = \frac{B^3 \epsilon}{4} \int_{0}^{\infty} \frac{x^2 dx}{1 + \epsilon^2 x^2} = \infty \]  

(A-31)

which does not converge. Therefore, the radius of gyration is also undefined.
A.3.2 Double-Pole Chebyshev Filter

The noise bandwidth is found by substituting the expression for \( T_2(x) \) given in Equation (A-23) into Equation (A-25). Thus, the noise bandwidth is

\[
b = B_\epsilon \int_0^\infty \frac{dx}{1 + \epsilon^2 \left(2x^2 - 1\right)^2}
\]

which can be evaluated by residue theory to yield

\[
b = \frac{\pi}{4} \sqrt{\frac{1}{\epsilon \sqrt{1 + \epsilon^2} + \frac{1}{1 + \epsilon^2}}} B_\epsilon
\]

(A-33)

Since the ripple bandwidth \( B_\epsilon \) can be written in terms of the half-power bandwidth as

\[
B_\epsilon = \sqrt{\frac{2 \epsilon}{1 + \epsilon}} B
\]

(A-34)

this expression for \( B_\epsilon \) can be substituted into Equation (A-33) to express the noise bandwidth as

\[
b = \frac{\pi}{4} \sqrt{\left(\frac{2}{1 + \epsilon}\right) \left(\frac{1}{\sqrt{1 + \epsilon^2}} + \frac{1}{1 + \epsilon^2}\right)} B
\]

(A-35)

in terms of the half-power bandwidth.

The moment of inertia can be found by using Equations (A-23) and (A-27) as follows:

\[
I = \frac{B_\epsilon^3}{4} \int_0^\infty \frac{x^2 \ dx}{1 + \epsilon^2 \left(2x^2 - 1\right)^2}
\]

(A-36)

This can be evaluated by the use of residue theory to yield the following result

\[
I = \frac{\pi}{32 \epsilon^2} \sqrt{\epsilon \sqrt{1 + \epsilon^2} + \epsilon^2} \frac{3}{B_\epsilon}
\]

(A-37)
By use of Equation (A-34) again, Equation (A-37) can be rewritten in terms of the half-power bandwidth as

\[ I = \frac{\pi}{4} \sqrt{\frac{2}{1 + \epsilon^2}} \left( \frac{1}{\sqrt{1 + \epsilon^2}} + \frac{1}{1 + \epsilon^2} \right) B^3 \]  

(A-38)

The expressions for the noise bandwidth and the moment of inertia given in Equations (A-33) and (A-37) can be substituted into Equation (A-1) to find the radius of gyration which is

\[ r = \frac{(1 + \epsilon^2)^{1/4}}{2 \sqrt{2 \epsilon}} B \]  

(A-39)

in terms of the ripple factor and the ripple bandwidth. This can also be written as

\[ r = \frac{(1 + \epsilon^2)^{1/4}}{2 \sqrt{\epsilon (1+\epsilon)}} B \]  

(A-40)

in terms of the ripple factor and the half-power bandwidth.

### A.4 GAUSSIAN FILTER

The Gaussian filter has a frequency response defined by

\[ |H(f)| = \exp \left[-\left(\frac{f - f_0}{B/2}\right)^2 \ln 2 \right] \]  

(A-41)

where B is the half-power bandwidth. According to Equation (A-3), the noise bandwidth can be calculated by evaluation of

\[ b = \int_{-\infty}^{\infty} \exp \left[-\left(\frac{f - f_0}{B/2}\right)^2 \ln 2 \right] \, df \]  

(A-42)

By a change of variables in Equation (A-42), \( b \) can be evaluated as follows:

\[ b = \frac{1}{2} \sqrt{\frac{\pi}{\ln 2}} B \]  

(A-43)

The moment of inertia can be calculated in accordance with Equation (A-2) as shown below.
\[ I = \int_{-\infty}^{\infty} \left( f - f_0 \right)^2 \exp \left[ - \left( \frac{f - f_0}{B/2} \right)^2 \ln 2 \right] df \quad (A-44) \]

This can be evaluated readily by a change in variables with the result,

\[ I = \frac{\sqrt{\pi}}{16 \left( \ln 2 \right)^{3/2}} B^3 \quad (A-45) \]

Finally, the radius of gyration is evaluated by Equation (A-1) as

\[ r = \frac{B}{2\sqrt{2} \ln 2} \quad (A-46) \]

A.5 RECTANGULAR FILTER

The simplest of the calculations is for the rectangular filter. The noise bandwidth is identical with the half-power bandwidth, since the response is flat in the pass band. Thus,

\[ b = B \quad (A-47) \]

The moment of inertia is expressed in accordance with Equation (A-2) as

\[ I = \int_{-\infty}^{\infty} \left( f - f_0 \right)^2 \text{rect} \left( \frac{f - f_0}{B} \right) df \quad (A-48) \]

which is equivalent to

\[ I = \int_{-\frac{B}{2}}^{\frac{B}{2}} x^2 dx \quad (A-49) \]

This is readily evaluated as

\[ I = \frac{B^3}{12} \quad (A-50) \]

Thus, the radius of gyration is calculated by substituting b and I into Equation (A-1). The result is

\[ r = \frac{B}{\sqrt{12}} \quad (A-51) \]
A. 6 SUMMARY OF RESULTS

The results of calculations in the previous paragraphs are summarized in Table A-1. The noise bandwidths, moments of inertia, and radii of gyration are presented. It is interesting to note upon evaluation of the Butterworth parameters that they approach those of the ideal rectangular filter as the number of poles increases. This is not surprising when one realizes that the rectangular frequency response is the limiting case of the Butterworth filter response as the number of poles increases without bound.
APPENDIX B - COMPUTER PROGRAM LISTING

DEFINE ERFC(X) = (1.+ 0.0705230784*X + 0.0422820123*X**2 + 0.000430638*X**6)**(-16)
DEFINE ERF(X) = 1. - (1.+ 0.0705230784*X + 0.0422820123*X**2 + 0.000430638*X**6)**(-16)
DIMENSION NHPDAT(1024), HPUAT(1024), PROB(1024)

IF DPNUM1 & DPNUM2 ARE SET TO ZERO IN FILE 17, THEN THEY WILL BE CALCULATED
READ (17,*) AMODX, PCPHOB, FMODMX, CONDH1, CONDB2, CONDB1, & DPNUM1, DPNUM2
PRINT *, *
PRINT *, *DATA SET:*
PRINT *, *MODULATION INDEX:*, AMODX
PRINT *, *PERCENT PROB OF EXCEEDING PEAK DEVIATION:*, PCPHOB
PRINT *, *MAX MODULATING FREQ (HZ):*, FMODMX
NOINC = 5E4
DP = AMODX * FMODMX
PRINT *, *PEAK DEVIATION (HZ):*, DP
PRINT *, *NO OF INTEGRATION INCREMENTS:*, NOINC
% CALCULATE PUF FROM NHPDAT
READ (19,*) NHPDAT
% FIND FIRST NONZERO DATA SUBSCRIPT N1
DO 5100 I = 1, 1024
IF (NHPDAT(I) .EQ. 0) GO TO 5100
N1 = I
GO TO 5150
5100 CONTINUE
% FIND LAST NONZERO DATA SUBSCRIPT N2
5150 DO 5200 I = 1, 1024
J = 1025 - I
IF (NHPDAT(J) .EQ. 0) GO TO 5200
N2 = J
GO TO 5250
5200 CONTINUE
5250 SUMNUM = 0.
SUMDEN = 0.
DO 5300 I = 1, 1024
HPDAT(I) = FLOAT(NHPDAT(I))
SUMNUM = SUMNUM + HPDAT(I) * I
SUMDEN = SUMDEN + HPDAT(I)
5300 CONTINUE
AMEAN = SUMNUM / SUMDEN
DO 5500 I = 1, 1024
PROB(I) = HPDAT(I) / SUMDEN
5500 CONTINUE
IF(DPNUM1 .NE. 0. .AND. DPNUM2 .NE. 0.) GO TO 6000

&FIND LOW NUMBER CORRESPONDING TO DP
PTAIL=PCPROB/200.
I=N1
PRBSUM=PROB(I)/2.
IF (PRBSUM .GE. PTAIL) GO TO 5750
5625 I=I+1
DPRS$UM=(PROB(I-1)+PROB(I))/2.
PRBSUM=PRBSUM+DPRS$UM
IF (PRBSUM .LT. PTAIL) GO TO 5625
ATEMP=PROB(I)-PROB(I-1)
CTEMP=-2.*(PTAIL-PRBSUM+DPRS$UM)
IF(NHPDAT(I) .EQ. NHPDAT(I-1)) GO TO 5700
RTEMP=-2.*PROB(I-1)
PTDISC=SQRT(BTEMP**2-4.*ATEMP*CTEMP)
XTEMP=(-BTEMP+PTDISC)/2./ATEMP
IF(XTEMP .GT. 0. .AND. XTEMP .LT. 1.0) GO TO 5650
XTEMP=(-BTEMP-PTDISC)/2./ATEMP
5650 DPNUM1=XTEMP-1.I
GO TO 5800
5700 DPNUM1=CTEMP/PROB(I)/2.+I-1.
GO TO 5800
5750 DPNUM1=SQRT(2.*PTAIL/PROB(I))-1.+I

&FIND UPPER NUMBER CORRESPONDING TO DP
5800 I=N2
PRBSUM=PROB(I)/2.
IF (PRBSUM .GE. PTAIL) GO TO 5950
5825 I=I-1
DPRSUM=(PROB(I)+PROB(I+1))/2.
PRBSUM=PRBSUM+DPRSUM
IF (PRBSUM .LT. PTAIL) GO TO 5825
ATEMP=PROB(I)-PROB(I+1)
CTEMP=-2.*(PTAIL-PRBSUM+DPRSUM)
IF(NHPDAT(I) .EQ. NHPDAT(I+1)) GO TO 5900
RTEMP=-2.*PROB(I+1)
PTDISC=SQRT(BTEMP**2-4.*ATEMP*CTEMP)
XTEMP=(-BTEMP+PTDISC)/2./ATEMP
IF (XTEMP .GT. 0. .AND. XTEMP .LT. 1.0) GO TO 5850
XTEMP=(-BTEMP-PTDISC)/2./ATEMP
5850 DPNUM2=XTEMP+I+1
GO TO 6000
5900 DPNUM2=-XTEMP+I+1
GO TO 6000
5950 DPNUM2=-SQRT(2.*PTAIL/PROB(I))+1.+I
6000 CPNUM=(DPNUM1+DPNUM2)/2.
DPNUM=DPNUM2-CPNUM
DELTAN=FLOAT(N2-N1+2)/FLOAT(NOINC)
PRINT **FIRST NONZERO SUBSCRIPT:** N1
PRINT **LAST NONZERO SUBSCRIPT:** N2
PRINT **MEAN SUBSCRIPT:** AMEAN

B-2
PRINT **, SUBSCRIPTS CORRESPONDING TO PEAK DEV: DPNUM1, DPNUM2
PRINT **, CENTER SUBSCRIPT: CTHNUM
PRINT **, **************
PRINT ** *
FOVN=DP/DPNUM
100 READ (18, *, END=9000) NFTYP, BANDW
PRINT ** *
GO TO (1000, 2000, 3000, 4000), NFTYP
* CALCULATE RADIUS OF GYRATION THEN 6010
* BUTTERWORTH
1000 READ (18, *) NPOLES
PRINT **, BUTTERWORTH FILTER - NO OF POLES: NPOLES
GO TO (1010, 1020, 1030, 1040), NPOLES
1010 WRITE(6, 1015)
1015 FORMAT(3X, • BUTTERWORTH NOT VALID FOR ONE POLE•)
GO TO 100
* 2 POLE BUTTER
1020 RADGYR=1.18921*BANDW
GO TO 6010
* 3 POLE BUTTER
1030 RADGYR=.353553*BANDW
GO TO 6010
* 4 POLE BUTTER
1040 RADGYR=.321797*BANDW
GO TO 6010
* CHERYSHEV
2000 READ (18, *) NPOLES, RIPLDH
PRINT **, CHERYSHEV FILTER WITH NPOLES POLES AND RIPLDB DB RIPPLE
FPSLON=SQRT(10**((RIPLDB/10.)-1.))
GO TO (2100, 2200, 2300, 2400), NPOLES
2100 PRINT **, CHERYSHEV NOT VALID FOR ONE POLE
2110 FORMAT(3X, • CHERYSHEV NOT VALID FOR ONE POLE•)
GO TO 100
* 2 POLE CHERY RADGYR
2200 RADGYR=SQRT(SQRT(1.0/EPSLON**2)/EPSLON/(1.0/EPSLON)) * BANDW/2.0
GO TO 6010
* 3 POLE CHERY RADGYR
* USE RESIDUES TO CALCULATE RADGYR
2300 E1=1.0/EPSLON
F2=E1/E1
F3=SQRT(E2+1.0)
F4=(E3+E1)**(1.0/3.0)
H=(E4-1.0/E4)/2.0
A=(E4+1.0/E4)/2.0
C=B/A
R3=A*A*(3.0+C*C)/4.0
X1=1.0
10 T=4.0*X1**3-3.0*X1-(1.0/EPSLON)
DT=12.0*X1**2-3.0
X2=X1-(T/DT)
X3=ABS(X1-X2)
TF (X3 .LT. 0.0001) GOTO 20
X1=X2
GOTO 10
20 W=X1

HEP=BANDW/W
RADGYR=(HEP/2.0)*SQRT(R3)
GO TO 6010
* 4 POLE CHEBY RADGYR
*USE RESIDUES TO CALCULATE RADGYH
2400 E1=1.0/EPISON
E2=E1*E1
F3=SQRT(F2+1.0)
F5=(E3+E1)**0.25
H=(E5-1.0/E5)/2.0
A=(E5+1.0/E5)/2.0
C=B/A
C1=0.92388
S1=0.382683
Q=C1*C1-S1*S1
Q1=1.0+(1.0+4.0*S1*S1/Q)*C*C
Q2=1.0-(1.0-4.0*C1*C1/Q)*C*C
Q3=1.0+(1.0+4.0*C1*C1/Q)*C*C
Q4=1.0-(1.0-4.0*S1*S1/Q)*C*C
Q5=1.0+S1*S1*C*C/C1/C1
Q6=1.0*C1*C1*C*C/S1/S1
P1=A*A*(C1*Q1+S1*Q2)*Q5*Q6*S1*C1
P2=S1*Q6*Q3+C1*Q5*Q4
P4=P1/P2
w=SQRT(SQRT(2.0+2.0/EPSLON)+2.0)/2.0
HEP=BANDW/W
RADGYR=(HEP/2.0)*SQRT(R4)
GO TO 6010
* GAUSSIAN RADGYR
3000 RADGYR=.424661*BANDW
PRINT ** 'GAUSSIAN FILTER'
GO TO 6010
* RECT RADGYR
4000 RADGYR=.288675*BANDW
PRINT ** 'RECTANGULAR FILTER'
6010 FOVNR=FOVN/RADGYR
PRINT ** 'RF BANDWIDTH (HZ):',BANDW
PRINT ** 'RADIUS OF GYRATION (HZ):',RADGYR
COND=CONDB1-CONDB1
PRINT ** 'CONDB' CLICKP CLICKP
PRINT ** 'COND' CLICKP
CONDR = CONDB + CONDBI
IF (CONDB * GT. CONDR2) GO TO 100
COVRN = 10. * (CONDB/10.)
SUMP = 0.
SUMN = 0.
ANUM = N1 - 1
DO 6050 I = 1, NOINC
ANUM = ANUM + DELTAN
U = (ANUM - CTRNUM) * FOVNR
ABU = ABS(U)
USQ = U * U
ARGRFC = SURT(COVRN + COVRN * USQ)
IF (ARGRFC * GT. 6.0) GO TO 6030
VALRFC = ERFC(ARGRFC)
GO TO 6035
6030 VALRFC = 0.0
6035 HIU = SQRT(1 + USQ) * VALRFC
UEMR = U / EXP(COVRN)
ARGERF = ABU * SQRT(COVRN)
IF (ARGERF * GT. 6.0) GO TO 6040
VALERF = ERF(ARGERF)
GO TO 6045
6040 VALERF = 1.0
6045 ERRORF = U / ABU * VALERF
PANUM = PROB(INT(ANUM)) + (PROB(INT(ANUM + 1.)) - PROB(INT(ANUM)))
SUMP = SUMP + PANUM * (HIU - UEMR * (1. - ERRORF))
SUMN = SUMN + PANUM * (HIU + UEMR * (1. + ERRORF))
6050 CONTINUE
CLICKP = DELTAN * SUMP * RADGYR / 2.
CLICKN = DELTAN * SUMN * RADGYR / 2.
WRITE (*, 7000) CONDR, CLICKP, CLICKN
7000 FORMAT (1X, F4.1, E14.7, E14.7)
GO TO 6025
9000 PRINT *, *, *
PRINT *, *
PRINT *, DATA USED FOR RESULTS ABOVE!
PRINT *, *
PRINT *, NHPDAT
CALL EXIT
END
B-5
APPENDIX C - GLOSSARY OF COMPUTER PROGRAM VARIABLES

A A variable used to represent different expressions in calculating the radius of gyration for three- and four-pole Chebyshev predetection filters.

ABU Absolute value of U.

AMEAN The expected value of the data subscripts.

AMODX The modulation index specified in file 17.

ANUM The variable of integration to find the FM threshold impulse rates.

ARGERF An argument of the error function used in computing the FM threshold impulse rates.

ARGRFC An argument of the complement of the error function used in computing the FM threshold impulse rates.

ATEMP A temporary value of differences in probabilities.

B A variable used to represent different expressions in calculating the radius of gyration for three- and four-pole Chebyshev predetection filters.

BANDW Half-power bandwidth of the RF predetection filter.

BEP The ripple bandwidth of the Chebyshev predetection filter.

BTEMP A temporary value of two times one of the elements in the probability vector.

C A variable defined by the quotient of B divided by A in calculating the radius of gyration for three- and four-pole Chebyshev predetection filters.

CLICKN The negative FM threshold impulse rate.

CLICKP The positive FM threshold impulse rate.

CONDB Carrier-to-noise ratio in dB.

CONDBI The incremental dB carrier-to-noise ratio for which FM threshold impulse rates are calculated. It is specified in file 17.

CONDB1 The first dB value of carrier-to-noise ratio for which FM threshold impulse rates are calculated. It is specified in file 17.

CONDB2 The last dB value of carrier-to-noise ratio for which FM threshold impulse rates are calculated. It is specified in file 17.

COVRN A temporary value used in calculating the data subscripts corresponding to the peak deviations.

CTRNUM The data subscript midway between the subscripts corresponding to the peak deviations.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>A real constant used in calculating the radius of gyration for the four-pole Chebyshev predetection filter.</td>
</tr>
<tr>
<td>DP</td>
<td>The peak deviation in Hz.</td>
</tr>
<tr>
<td>DPNUM</td>
<td>The data subscript deviation corresponding to the peak frequency deviation.</td>
</tr>
<tr>
<td>DPNUM1</td>
<td>The data subscript corresponding to the peak frequency deviation on the low side of the carrier.</td>
</tr>
<tr>
<td>DPNUM2</td>
<td>The data subscript corresponding to the peak deviation on the high side of the carrier.</td>
</tr>
<tr>
<td>DPRSUM</td>
<td>An incremental probability used in calculating the data subscripts corresponding to the peak deviations.</td>
</tr>
<tr>
<td>DT</td>
<td>The derivative of the variable T, which represents the polynomial whose roots are to be determined by the Newton-Rapson method, in calculating the radius of gyration for the three-pole Chebyshev predetection filter.</td>
</tr>
<tr>
<td>EPSLON</td>
<td>The numerical ripple factor used in Chebyshev filter analysis.</td>
</tr>
<tr>
<td>ERRORF</td>
<td>A value of the error function used in calculating the FM threshold impulse rates.</td>
</tr>
<tr>
<td>E1</td>
<td>The reciprocal of the ripple factor for Chebyshev filters.</td>
</tr>
<tr>
<td>E2</td>
<td>The square of E1.</td>
</tr>
<tr>
<td>E3</td>
<td>A special expression involving the Chebyshev ripple factor.</td>
</tr>
<tr>
<td>E4</td>
<td>A special expression involving E1 and used to simplify mathematical expressions for calculating the radius of gyration of the three-pole Chebyshev filter.</td>
</tr>
<tr>
<td>E5</td>
<td>A special expression involving E1 and used to simplify mathematical expressions for calculating the radius of gyration of the four-pole Chebyshev filter.</td>
</tr>
<tr>
<td>FMODMX</td>
<td>The maximum modulating frequency specified in file 17.</td>
</tr>
<tr>
<td>FOVN</td>
<td>The ratio of frequency deviation to the corresponding subscript deviation.</td>
</tr>
<tr>
<td>FOVNR</td>
<td>The ratio of FOVN to the radius of gyration of the RF predetection filter.</td>
</tr>
<tr>
<td>HPDAT</td>
<td>A vector of order 1024 which is the floating form of the vector NHPDAT.</td>
</tr>
<tr>
<td>H1U</td>
<td>A value used in the integrand for calculating the threshold impulse rates.</td>
</tr>
<tr>
<td>I</td>
<td>An integer used as an index.</td>
</tr>
<tr>
<td>J</td>
<td>An integer used as an index.</td>
</tr>
</tbody>
</table>
NFTYP A number specified in file 18 designating the RF predetection filter type as follows:

1. Butterworth
2. Chebyshev
3. Gaussian
4. Rectangular

NHPDAT A vector of order 1024, the components of which make up the probability input data.

NOINC The number of increments to be used in integrating to determine the FM threshold impulse rates.

NPOLES The number of poles of the RF predetection filter specified in file 18.

N1 The subscript of the first nonzero element of the vector NHPDAT.

N2 The subscript of the last nonzero element of the vector NHPDAT.

PANUM The probability density associated with the continuous variable of integration.

PCPROB The percentage probability of the FM carrier deviation falling outside the range defined by the peak deviation. It is specified in file 17.

PRBSUM An accounting variable used to store the cumulative probability of integrating the tails of the probability density function.

PROB A vector of order 1024 which is the probability density function derived from the vector NHPDAT.

PTAIL The probability that the deviation of the FM carrier exceeds the peak deviation in one direction.

P1 The value of the expression in the numerator of the fraction for calculating R4, which is used in calculating the radius of gyration of the four-pole Chebyshev predetection filter.

P2 The value of the expression in the denominator of the fraction for calculating R4, which is used in calculating the radius of gyration of the four-pole Chebyshev predetection filter.

Q The value of an expression used in calculating the radius of gyration of the four-pole Chebyshev predetection filter.

Q1 The value of an expression used in calculating P1 during calculation of the radius of gyration of the four-pole Chebyshev predetection filter.

Q2 The value of an expression used in calculating P1 during calculation of the radius of gyration of the four-pole Chebyshev predetection filter.
Q3 The value of an expression used in calculating P2 during calculation of the radius of gyration of the four-pole Chebyshev predetection filter.

Q4 The value of an expression used in calculating P2 during calculation of the radius of gyration of the four-pole Chebyshev predetection filter.

Q5 The value of an expression used in calculating both P1 and P2 during calculation of the radius of gyration of the four-pole Chebyshev predetection filter.

Q6 The value of an expression used in calculating both P1 and P2 during calculation of the radius of gyration of the four-pole Chebyshev predetection filter.

RADGYR The radius of gyration of the RF predetection filter.

RIPLDB The dB value of the ripple specified in file 18 for the Chebyshev predetection filter.

RTDISC The square root of the discriminant used in calculating the continuous subscript number corresponding to the peak deviation of the RF carrier.

R3 A variable used to calculate the radius of gyration of the three-pole Chebyshev predetection filter.

R4 A variable used to calculate the radius of gyration of the four-pole Chebyshev predetection filter.

SUMDEN The sum of the components of the vector NHPDAT.

SUMN A summation used in calculating the negative FM threshold impulse rate.

SUMNUM A summation which is the first moment of the probability input data. It is used to calculate the expected value of the integral subscripts.

SUMP A summation used in calculating the negative FM threshold impulse rate.

Si A constant used in calculating the radius of gyration for the four-pole Chebyshev predetection filter.

T The value of the polynomial in the denominator of the three-pole Chebyshev filter transfer function.

U A variable of integration used in calculating FM threshold impulse rates. It is obtained by dividing frequency by the radius of gyration of the RF predetection filter.

UEMR A factor used in the integrand for calculating the FM threshold impulse rates.

USQ The square of U.

VALERF A value of the error function used in the integrand for calculating the FM threshold impulse rates.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VALRFC</td>
<td>A value of the complement of the error function used in the integrand for calculating the FM threshold impulse rates.</td>
</tr>
<tr>
<td>W</td>
<td>The values of the roots of the polynomials in the denominator of the three-pole and four-pole Chebyshev filters.</td>
</tr>
<tr>
<td>XTEMP</td>
<td>A temporary value used in calculating the continuous subscripts corresponding to the peak deviation.</td>
</tr>
<tr>
<td>X1</td>
<td>A variable used to approximate the root of a polynomial by the Newton-Raphson method in order to calculate the radius of gyration of the three-pole Chebyshev predetection filter.</td>
</tr>
<tr>
<td>X2</td>
<td>The iterated value of the root of the polynomial in the denominator of the three-pole Chebyshev transfer function.</td>
</tr>
<tr>
<td>X3</td>
<td>The absolute value of the difference between X1 and X2, used in calculating the radius of gyration of the three-pole Chebyshev predetection filter.</td>
</tr>
</tbody>
</table>
The probability data used in the computer program to calculate the threshold impulse rates for an FM transmission system are presented herein.

The data presented in Tables D-1 through D-24 are data measured by NASA at Goddard Space Flight Center. Each data set is a vector of order 1024. The first number in each line is a line number followed by ten components of the data vector in order from left to right, except for the last line which has only four components. Each component of a data vector represents a count of the number of samples in each of 1024 adjacent equal intervals of voltage of the modulating signal during the particular duration of measurement. The duration of measurement was not the same for all data sets. Each vector can be interpreted to represent some multiple of samples of the voltage probability density function of a particular modulating waveform. Thus, the data are referred to as probability data or probability density data.

Figures D-1 through D-24 are pictures of oscilloscope presentations of the data shown, respectively, in Tables D-1 through D-24. Thus, these figures represent the probability density functions of the modulating waveforms, and are approximations to the FM spectrum.

Tables D-25 and D-26 show simulated probability data for sinusoidal and Gaussian modulating signals. These computer-generated data vectors are presented in a slightly different format without line numbers.

Figures D-25 and D-26 show, respectively, sketches of the sinusoidal and Gaussian probability density functions corresponding to Tables D-25 and D-26.
Table D-1. Probability Data Set 01

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### Table D-2. Probability Data Set 02 (Cont'd)

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| 370 | 472 | 555 | 556 | 571 | 557 | 585 | 553 | 582 | 527 | 511 |
| 380 | 511 | 469 | 462 | 467 | 416 | 435 | 434 | 459 | 455 | 490 |
| 390 | 488 | 553 | 554 | 645 | 683 | 793 | 720 | 823 | 828 | 882 |
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| 410 | 8074 | 10089 | 11926 | 13867 | 15722 | 17292 | 18690 | 19704 | 20204 | 21089 |
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| 700 | 23619 | 23219 | 22602 | 22506 | 22590 | 21750 | 20997 | 20785 | 20161 | 19349 |
| 710 | 18296 | 17529 | 16494 | 15539 | 14702 | 13661 | 12642 | 11615 | 10744 | 9531  |
| 720 | 8400  | 7670  | 6567  | 5579  | 4662  | 4019  | 3313  | 2787  | 2281  | 1840  |
| 730 | 1614  | 1286  | 1058  | 898   | 754   | 708   | 498   | 450   | 386   | 327   |
| 740 | 252   | 189   | 139   | 96    | 83    | 58    | 33    | 33    | 11    | 15    |
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| 360 | 4526  | 4790  | 4845  | 5176  | 5257  | 5650  | 5691  | 5974  | 6212  | 6622  |
| 370 | 6874  | 7238  | 7403  | 7751  | 8364  | 8695  | 9052  | 9307  | 9795  | 10105 |
| 380 | 10696 | 11227 | 11692 | 12054 | 12668 | 13249 | 13862 | 14542 | 15193 | 15839 |
| 390 | 16635 | 17430 | 18157 | 18942 | 19873 | 20845 | 22000 | 22995 | 24165 | 25213 |
| 400 | 26835 | 28207 | 29986 | 31273 | 33114 | 35312 | 36572 | 38890 | 41026 | 43323 |
| 410 | 45971 | 48210 | 51494 | 54712 | 57436 | 61446 | 64762 | 68574 | 72803 | 76811 |
| 420 | 81155 | 85809 | 90192 | 95204 | 100181 | 105926 | 111197 | 116776 | 122886 | 129180 |
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| 480 | 409891 | 429128 | 449721 | 469848 | 491297 | 514234 | 536357 | 558240 | 580171 |
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| 700 | 22979 | 22448 | 22215 | 22002 | 22002 | 21629 | 21761 | 21414 | 21394 |
| 710 | 21447 | 21046 | 21013 | 21200 | 20896 | 21128 | 21146 | 20815 | 21098 |
| 720 | 21023 | 20838 | 20978 | 20953 | 21119 | 21028 | 21019 | 20994 | 21032 |
| 730 | 20966 | 21067 | 20962 | 21074 | 21123 | 21069 | 21127 | 20961 | 21418 |
| 740 | 21648 | 21584 | 21749 | 21556 | 21739 | 21429 | 21770 | 22155 | 22110 |
| 750 | 22427 | 22432 | 22663 | 22802 | 23216 | 23471 | 23202 | 23679 | 23557 |
| 760 | 24282 | 24697 | 24844 | 24854 | 25450 | 25612 | 25755 | 26213 | 26398 |
| 770 | 26784 | 27121 | 27308 | 27684 | 26990 | 27421 | 27494 | 27748 | 27546 |
| 780 | 27504 | 27610 | 27541 | 27456 | 27889 | 27953 | 27741 | 28293 | 28549 |
| 790 | 29442 | 29339 | 29876 | 30821 | 31336 | 31710 | 32022 | 33468 | 34498 |
| 800 | 37413 | 39483 | 41481 | 45098 | 48448 | 52018 | 55739 | 59049 | 61972 |
| 810 | 66674 | 69002 | 69732 | 69703 | 69117 | 69223 | 68175 | 67826 | 67352 |
| 820 | 66420 | 66336 | 65841 | 64565 | 63318 | 61754 | 58451 | 55133 | 52237 |
| 830 | 44380 | 40382 | 37060 | 33907 | 31106 | 29014 | 27084 | 25834 | 24520 |
| 840 | 22896 | 22152 | 21758 | 21067 | 20930 | 20307 | 20337 | 19995 | 19997 |
| 850 | 19396 | 19270 | 18917 | 18528 | 18483 | 18166 | 18019 | 17785 | 17272 |
| 860 | 16857 | 16723 | 16478 | 16288 | 16381 | 16432 | 16451 | 16806 | 16991 |
| 870 | 17876 | 18343 | 18930 | 19574 | 20273 | 20911 | 21953 | 22733 | 23924 |
| 880 | 25906 | 26818 | 28305 | 29961 | 32612 | 34237 | 35092 | 35881 | 36976 |
| 890 | 36507 | 36283 | 36564 | 35524 | 34876 | 33681 | 32586 | 31803 | 30854 |
| 900 | 28286 | 27395 | 25917 | 24337 | 22469 | 20546 | 18579 | 16304 | 13947 |
| 910 | 9366 | 7666 | 5934 | 4666 | 3528 | 2638 | 1931 | 1419 | 998 |
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| 680 | 390 | 375 | 359 | 330 | 330 | 290 | 288 | 292 | 265 | 265 | | | | | | | | | | | | | | | | | | | | |
| 690 | 246 | 203 | 266 | 209 | 221 | 185 | 202 | 176 | 144 | 157 | | | | | | | | | | | | | | | | | | | | |
| 700 | 154 | 163 | 150 | 141 | 160 | 136 | 115 | 124 | 113 | 116 | | | | | | | | | | | | | | | | | | | | |
| 710 | 127 | 99  | 89  | 100 | 82  | 85  | 75  | 84  | 83  | | | | | | | | | | | | | | | | | | | | |
| 720 | 63  | 78  | 63  | 71  | 69  | 59  | 56  | 51  | 55  | 38  | | | | | | | | | | | | | | | | | | | | |
| 730 | 47  | 38  | 42  | 40  | 40  | 26  | 27  | 32  | 29  | | | | | | | | | | | | | | | | | | | | |
| 740 | 24  | 24  | 22  | 14  | 26  | 12  | 7   | 10  | 14  | 15  | | | | | | | | | | | | | | | | | | | | |
| 750 | 10  | 12  | 12  | 10  | 8   | 17  | 10  | 6   | 6   | 5   | | | | | | | | | | | | | | | | | | | | |
| 760 | 8   | 5   | 3   | 2   | 1   | 3   | 2   | 3   | 2   | 0   | | | | | | | | | | | | | | | | | | | | |
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|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
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|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|   | 202807    | 197968    | 192788    | 188251    | 183208    | 178835    | 173053    | 169178    | 164483    | 159503    | 155409    | 152168    | 147345    | 142530    | 138758    | 134971    | 130860    | 127511    | 122652    | 119224    | 670       | 680       | 690       | 700       | 710       | 720       | 730       | 740       | 750       | 760       | 770       | 780       | 790       | 800       | 810       | 820       | 830       | 840       | 850       | 860       | 870       | 880       | 890       | 900       | 910       | 920       | 930       | 940       | 950       | 960       | 970       | 980       | 990       | 1000      | 1010      | 1020      |
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| 360| 6165| 6583| 7267| 7872| 8536| 9185| 9740| 10696| 11732| 12472|
| 370| 13515| 14483| 15764| 17196| 18222| 19786| 21729| 23026| 24713| 26450|
| 380| 28655| 30959| 33031| 35599| 37712| 40464| 42255| 4527| 4783| 50260|
| 390| 53088| 55229| 58686| 61633| 63796| 67334| 69578| 72686| 75397| 78273|
| 400| 81479| 84549| 89237| 90821| 92944| 96422| 99312| 102371| 105646| 108232|
| 410| 111945| 115521| 119309| 123140| 127383| 130434| 135318| 140337| 144057| 149396|
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| 430| 217947| 225062| 231719| 241181| 256264| 264496| 272954| 280552| 289032|    |
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Mathematically-Generated Probability Data for a Gaussian Signal

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Figure D-1. Oscilloscope Presentation of Probability Data Set 01

Figure D-2. Oscilloscope Presentation of Probability Data Set 02
Figure D-3. Oscilloscope Presentation of Probability Data Set 03

Figure D-4. Oscilloscope Presentation of Probability Data Set 04
Figure D-5. Oscilloscope Presentation of Probability Data Set 05

Figure D-6. Oscilloscope Presentation of Probability Data Set 06
Figure D-7. Oscilloscope Presentation of Probability Data Set 07

Figure D-8. Oscilloscope Presentation of Probability Data Set 08
Figure D-9. Oscilloscope Presentation of Probability Data Set 09

Figure D-10. Oscilloscope Presentation of Probability Data Set 10
Figure D-11. Oscilloscope Presentation of Probability Data Set 11

Figure D-12. Oscilloscope Presentation of Probability Data Set 12

D-85
Figure D-13. Oscilloscope Presentation of Probability Data Set 13

Figure D-14. Oscilloscope Presentation of Probability Data Set 14
Figure D-15. Oscilloscope Presentation of Probability Data Set 15

Figure D-16. Oscilloscope Presentation of Probability Data Set 16
Figure D-17. Oscilloscope Presentation of Probability Data Set 17

Figure D-18. Oscilloscope Presentation of Probability Data Set 18
Figure D-19. Oscilloscope Presentation of Probability Data Set 19

Figure D-20. Oscilloscope Presentation of Probability Data Set 20
Figure D-21. Oscilloscope Presentation of Probability Data Set 21

Figure D-22. Oscilloscope Presentation of Probability Data Set 22
Figure D-23. Oscilloscope Presentation of Probability Data Set 23

Figure D-24. Oscilloscope Presentation of Probability Data Set 24
Figure D-25. Probability Density Function of a Sinusoidal Signal

Figure D-26. Probability Density Function of a Gaussian Signal