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FREQUENCY RESPONSE, NOISE, AND PULSE TRANSMISSION IN AN FM/FM TELEMETRY SYSTEM

by C.F. Asquith

February 1965

U S ARMY MISSILE COMMAND
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by

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ABSTRACT

This report presents some experimental data taken in a study of a standard FM/FM telemetry system. The objective of the continuing study program is to assign each onboard missile measurement to an optimum telemetry channel. Taken into account are noise to be tolerated and frequency response characteristics, assuming a reasonable estimate of signal behavior. Pulses and repetitive waveforms are used to determine transmission capability.

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Section I. INTRODUCTION

This report is part of a continuing program by the Army Inertial Guidance and Control Laboratory to formulate a simple set of rules for assigning onboard missile measurements to telemetry channels. The information herein is experimental and deals with the transmission of pulses and repetitive waveforms through an FM/FM system. The results should be helpful not only to instrumentation engineers but to the users of data furnished by the instrumentation system.

The center frequencies and nominal data channel bandwidths of the standard FM/FM subchannels as specified by the Inter-Range Instrumentation Group (IRIG) are listed in Table I. Table II shows additional proposed channels which are not yet standard in operational ground receiving stations. A complete transmitting and receiving system is shown in block diagram form in Figure 1. Usually, at least one of the highest channels is commutated, or time-shared by several low frequency signals, but this is not germane to this report. The transmission capacity of the system is determined primarily by two factors: frequency response and noise. As in all communication systems, these two factors are related in a direct manner, but in an FM/FM multiplex system the relationship is more pronounced. In fact, the discriminator output filters shown in Figure 1 are a means of controlling the system noise by limiting the bandwidth of each subchannel. The term noise is used in the general sense, meaning anything which interferes with the signal. The nominal information bandwidths of Tables I and II are compromise frequency responses arbitrarily set by IRIG to give a reasonable frequency response at a low noise level. There is nothing in the telemetry system which limits the subchannels to these bandwidths except the output filters, which can be changed at will.

The amount of noise which can be tolerated is dependent upon that feature (amplitude, time of occurrence, etc.) of the signal which is of interest, the accuracy with which it must be known, and the noise rejection properties of the read-out device. Theoretically, if the factors mentioned plus a reasonable estimate of signal behavior are known, it should be possible to assign each measurement to an optimum telemetry channel. This is the ultimate objective of the study program of which this report is a part. This objective is still some distance away but it was decided to present the information which follows in the hope that it might be useful at this time.

Section II. FREQUENCY RESPONSE

As has been pointed out, in normal operation, the primary factor which determines the frequency response of each FM/FM subchannel is the discriminator output filter. The channel response exclusive of the output filter is much wider than the filter bandwidth. Some data were taken on this using the system shown in Figure 2 and the results for one channel are shown in Figure 3. Since the curves for all channels are essentially identical when normalized about their nominal IRIG bandwidths, Figure 3 can be made to represent any one of the 18 channels by multiplying the horizontal axis by the nominal bandwidth of that channel. The response of the nominal IRIG filter is shown for comparison. As can be seen, the inherent channel response is down 3 db at about 5 times its nominal bandwidth. Below this frequency there is nothing that limits the channel bandwidth except the noise that can be tolerated.

Sectio III. NOISE

The difficulty that is encountered in making noise measurements is the uncertainty about the conditions under which they should be made. It is desirable to have data taken under typical operating conditions, and one commonly used scheme for simulating such conditions is shown in Figure 4. It is a matter of opinion as to whether or not a random noise input to all channels represents typical operation. Examination of a few missile records will show nothing but dc on most channels a large percentage of the time. Some data were taken which indicated that the random noise modulation does not make a substantial contribution to the total intermodulation noise. Some curves were run using the system shown in Figure 5 in which the RMS noise output of each channel was checked at the center of its band and at one edge with the other channels having 0, 2.5, and 5 volts input. The 2.5-volt position is band center while 0 and 5 volts represent the two IRIG band limits. The results for one typical channel are shown in Figure 6. The noise output was recorded as a function of the channel output filter bandwidth normalized with respect to IRIG nominal response. Since a precise measure of the noise is impossible to predict under all conditions and unimportant anyway, the average curve of Figure 7 was derived from the data taken for all channels at all positions in the band. This curve will give a reasonable estimation of the RMS noise in percent of peak-to-peak full scale output as a function of output filter bandwidth for any channel.

Section IV. PULSE TRANSMISSION

The channel response required for the transmission of a pulse or a periodic signal is inversely proportional to the width of the pulse or the period of the signal. The necessary bandwidth is also directly proportional to the desired fidelity of reproduction. A general idea of the transmission capability of the TM system can be gotten from the oscillograms of Figures 8 through 11 which were made using the standard IRIG filters of Table I. Channels 1 and 15 were not wired into the system at the time the oscillograms were made. The pulse widths and waveform periods were chosen so that the channel responses ranged from inadequate to more than adequate. The results are general in the sense that similar waves of different widths or periods would be passed with the same results but shifted up or down the TM spectrum in inverse proportion to the width or period.

The pulse transmission capabilities can be presented by a set of curves which give the amplitude and width of the output pulse relative to the input. These curves are shown in Figure 12 for the standard IRIG filters. The amplitude was normalized by dividing the output pulse height, A, by the value A_o, approached at the highest TM channels, and the output width was normalized by dividing the measured width, W, of the output pulse at its half-amplitude point by the input pulse width, W_o. The horizontal scale was normalized by multiplying the channel bandwidth, f_o, by the true pulse width, W_o. The shaded portion of Figure 12 is a transition zone, which occurs in Figure 9 at about channel 8, where overshoot is beginning to appear but cannot be distinguished as such. The results of Figures 9 through 12 are very similar to those obtained using IRIG Gaussian output filters, except that Gaussian filters do not exhibit overshoot or ringing. It can be seen that any channel such that the product of its response and the pulse width is 1.5 or greater will give accurate amplitude and width data. Values of W_of_o between 1.0 and 1.35 should be avoided by using standard filters because of amplitude uncertainty. In cases where adequate bandwidth is not available and the true pulse width, W_o, is known, the factor to be applied in determining the true amplitude can be read from the curve. When bandwidth is insufficient and the true pulse width is uncertain, the curve labeled "Measured Pulse Width (Wf_o)" can be used. This curve is a plot of the channel bandwidth, f_o, times the measured half-amplitude pulse width, W, versus the normalized channel bandwidth, W_of_o. Since Wf_o is known, this curve is entered from the vertical scale and the amplitude and width factors read on a vertical line through the point on the Wf_o curve. For example, a measured half-amplitude width of 0.375 milliseconds and 1-volt amplitude on channel 18 (1050 cps filter) gives $Wf_o = 0.394$. This point corresponds to $W_of_o = 0.32$ and a vertical line through this point gives $A/A_o = 0.865$ and $W/W_o = 1.23$. Therefore, $A_o = 1.16$ volts and $W_o = 0.461$ milliseconds. The Wf_o curve is useless below W_of_o of about 0.25 or Wf_o of 0.375 where the normalized measured pulse width becomes a constant. W_of_o of 0.25 corresponds to a pulse width of 238 microseconds through a 1050 cps filter. The W_of_o values are shown on Figure 8. A general idea can be obtained of what pulse transmission capability is signified by this parameter.

Channel delays and rise times are shown in Figure 13 as a function of output filter bandwidth. Plotted on log-log paper, these curves should be straight lines and are so within the limits of experimental error. Delay time and rise time are inversely proportional to bandwidth. From the slope of these lines it was found that the delay is

$$T_D = \frac{530}{f_o} \text{ milliseconds}$$

and the rise time is

$$T_R = \frac{430}{f_o} \text{ milliseconds}$$

in which f_o is again the output filter bandwidth as specified by IRIG. The delay time is about half the reciprocal of the channel bandwidth and the rise time is about 80 percent of the delay time. The results are somewhat different from those that would be expected using textbook rules for filters of the same "bandwidth." The IRIG telemetry filter bandwidth does not conform to the 3 db bandwidth in common usage, but has unity gain at the bandwidth frequency. The 3 db point is about 1.3 times the nominal IRIG bandwidth.

Section V. CONCLUSIONS

Frequency response, noise, and pulse transmission characteristics of a standard FM/FM telemetry system have been presented. The frequency response and noise data should be useful when it is necessary to make a compromise between noise and bandwidth to accommodate the maximum number of high frequency signals. The effect of noise, which is dependent upon the read-out device, must be estimated by the user at present. The effect of channel response on dynamic error has been discussed in a previous report.[1] Further information on the relation between the frequency and time domains is given by the pulse transmission data which should be useful in monitoring such signals as squib firings and time-of-events.

[1] W. F. Baxter, and C. F. Asquith, Assigning Measurements to Telemetry Channels to Meet Error Specifications, U. S. Army Missile Command Report No. RG-TR-63-13.

Table I. IRIG FM/FM Subchannels

Subchannel Number	Center Frequency (cps)	Nominal Intelligence Bandwidth (cps)
1	400	6
2	560	8
3	730	11
4	960	14
5	1,300	20
6	1,700	25
7	2,300	35
8	3,000	45
9	3,900	60
10	5,400	80
11	7,350	110
12	10,500	160
13	14,500	220
14	22,000	330
15	30,000	450
16	40,000	600
17	52,500	790
18	70,000	1050

Table II. Proposed FM/FM Subchannels

Subchannel Number	Center Frequency (cps)	Nominal Intelligence Bandwidth (cps)
19	93,000	1400
20	124,000	1900
21	165,000	2500

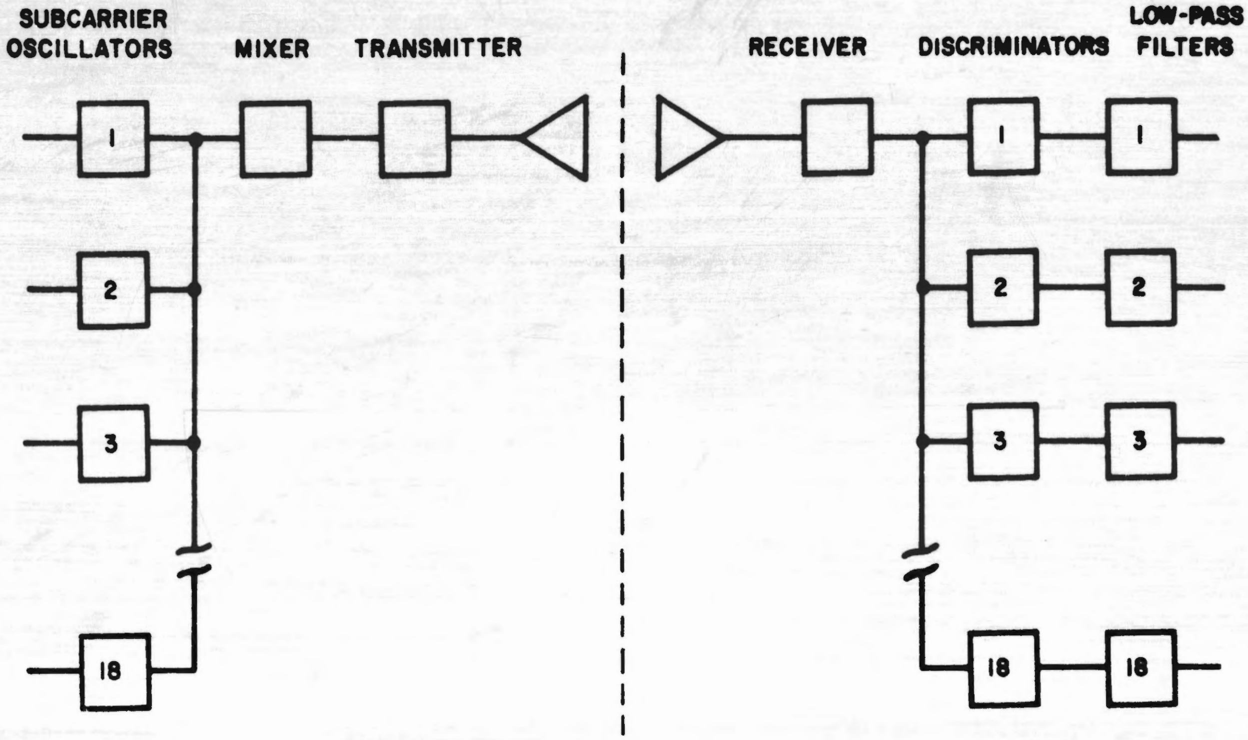

Figure 1. FM/FM Telemetry System

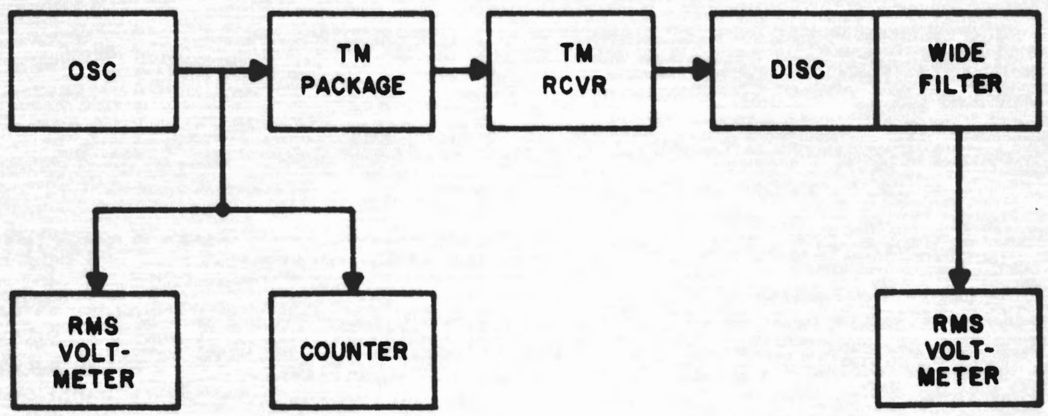

Figure 2. System Used for Taking Frequency Response Data

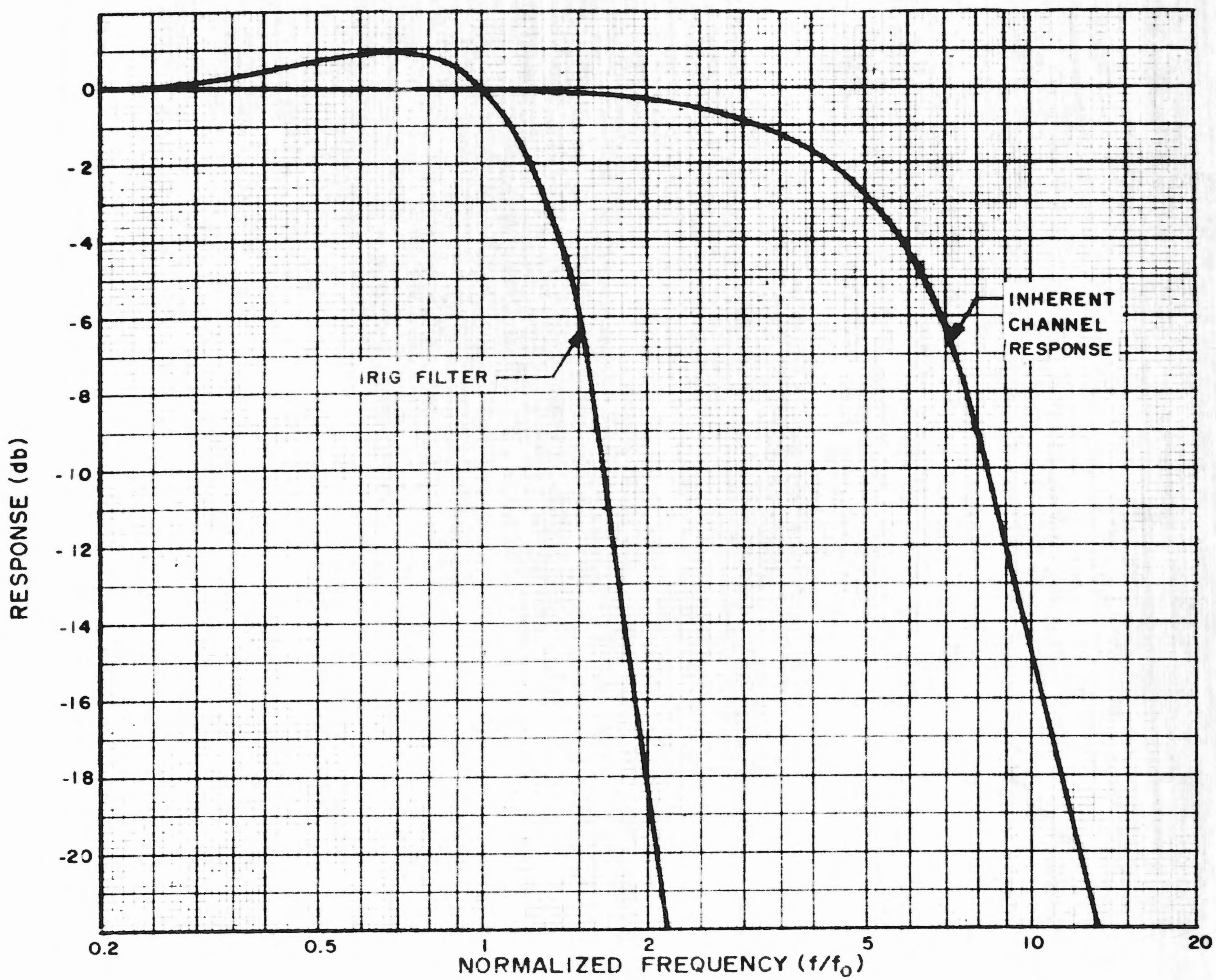

Figure 3. Frequency Response of an FM/FM Telemetry Channel.

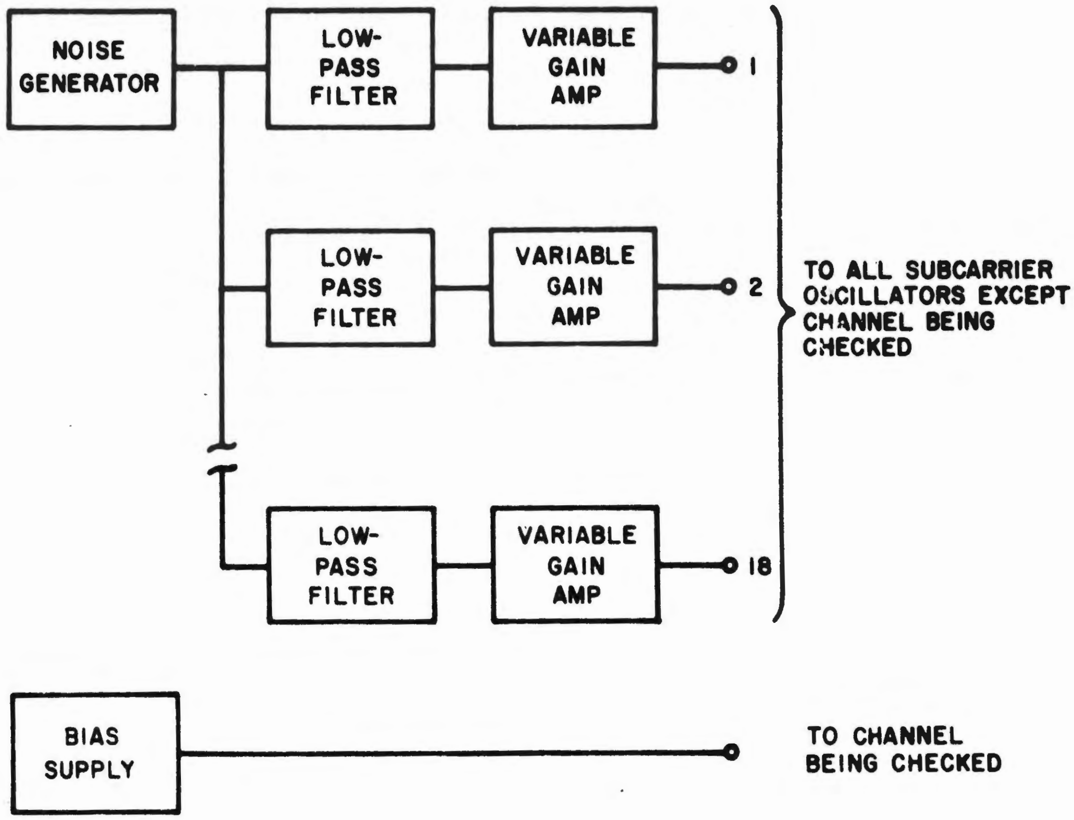

Figure 4. Noise Generator System Recommended for Taking FM/FM Intermodulation Data

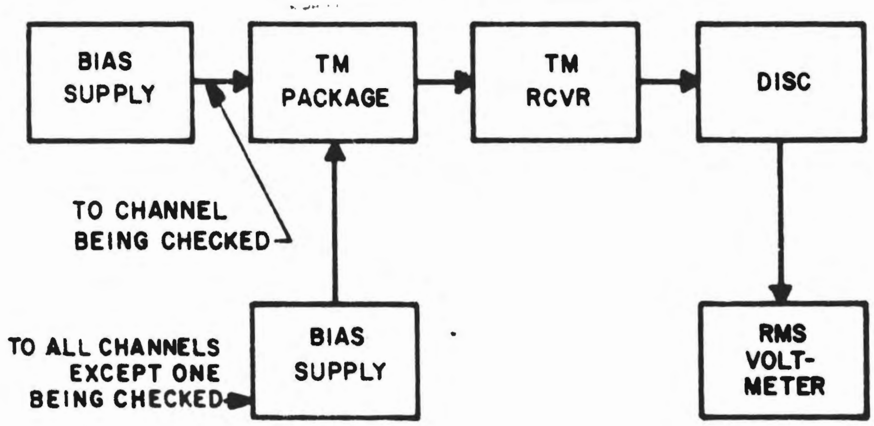

Figure 5. System Used for Taking FM/FM Noise and Intermodulation Data

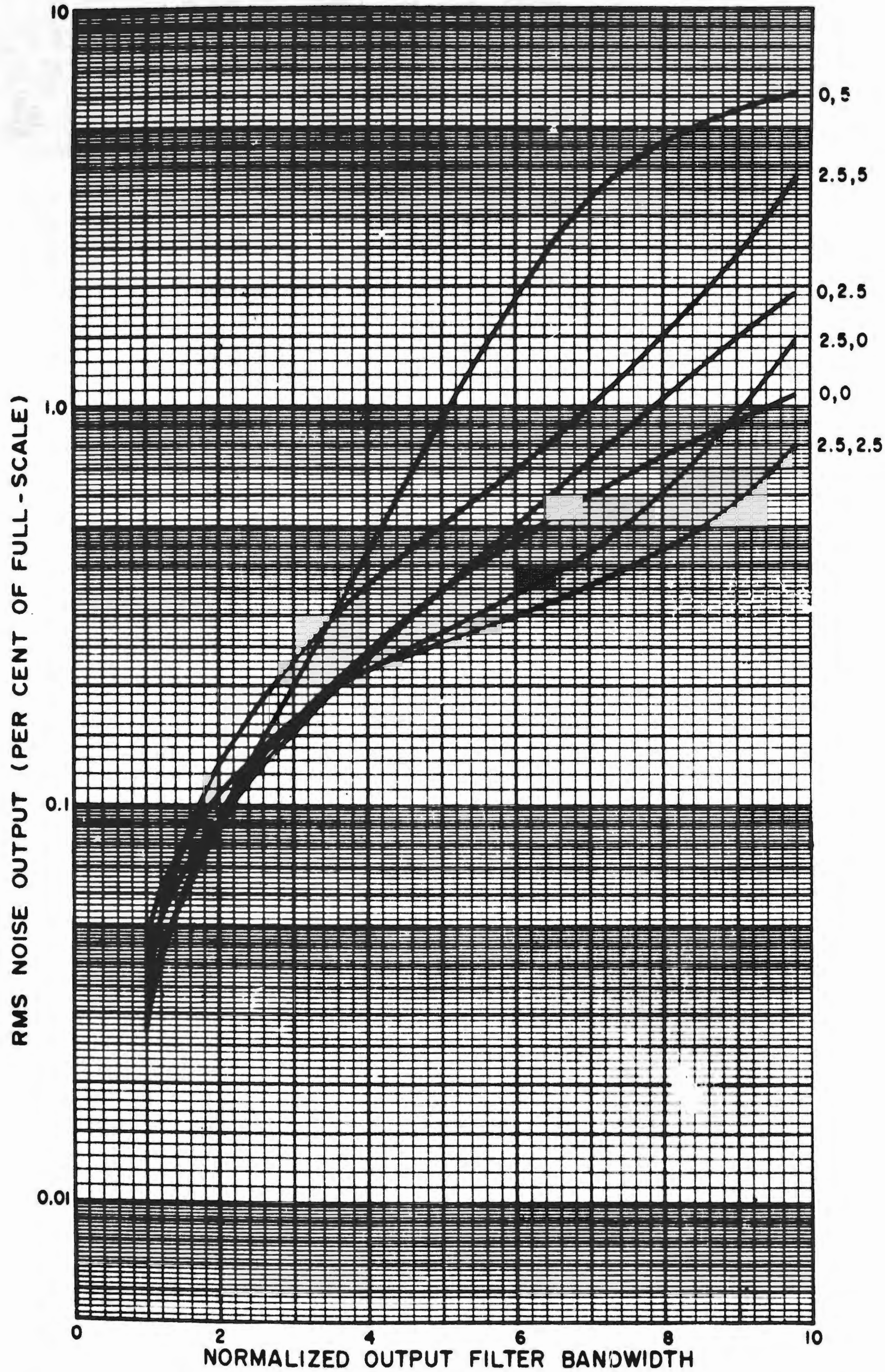

Figure 6. Noise Output for One Channel Using System of Figure 5.

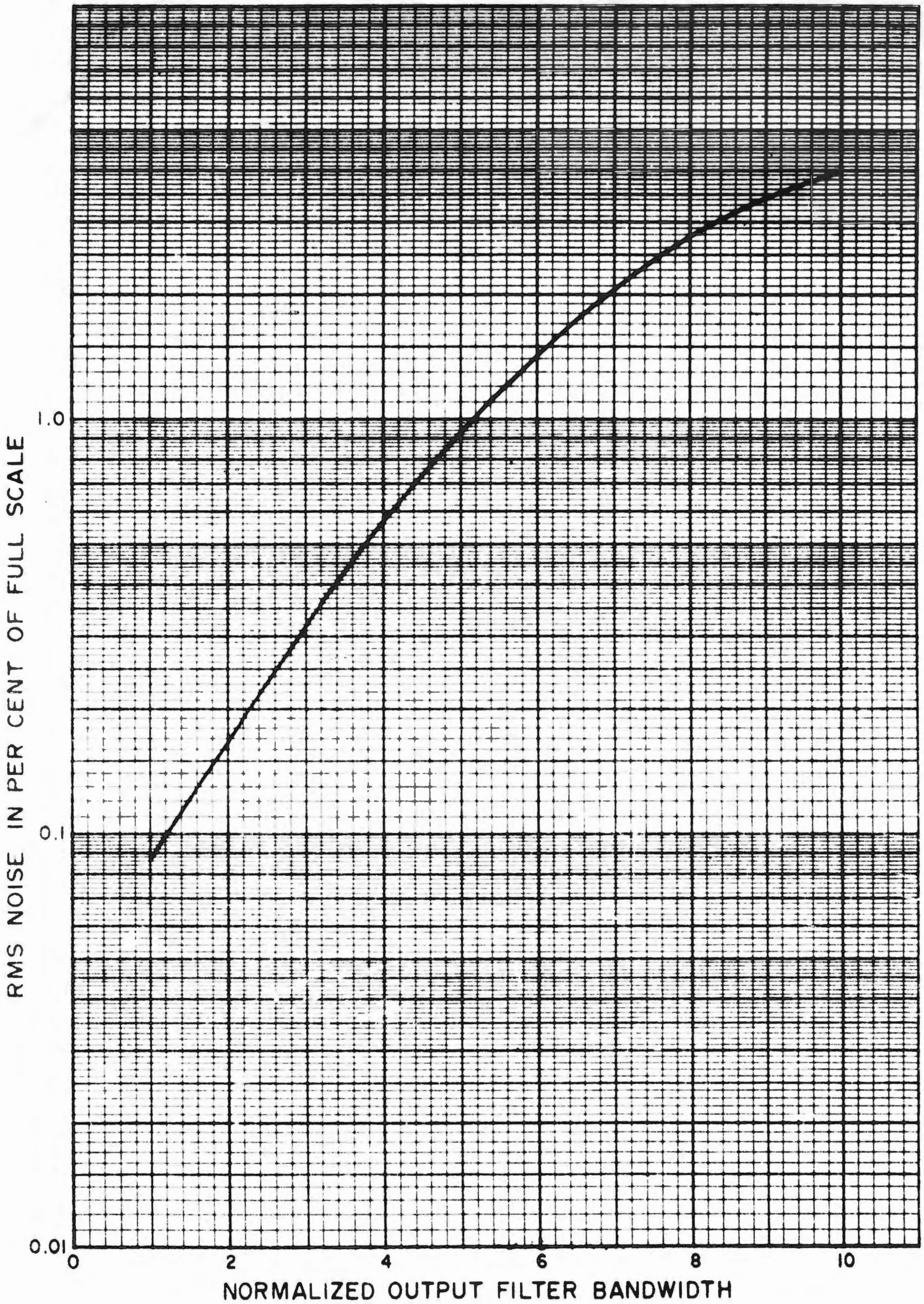

Figure 7. Average Noise Output for all Channels
Using System of Figure 5

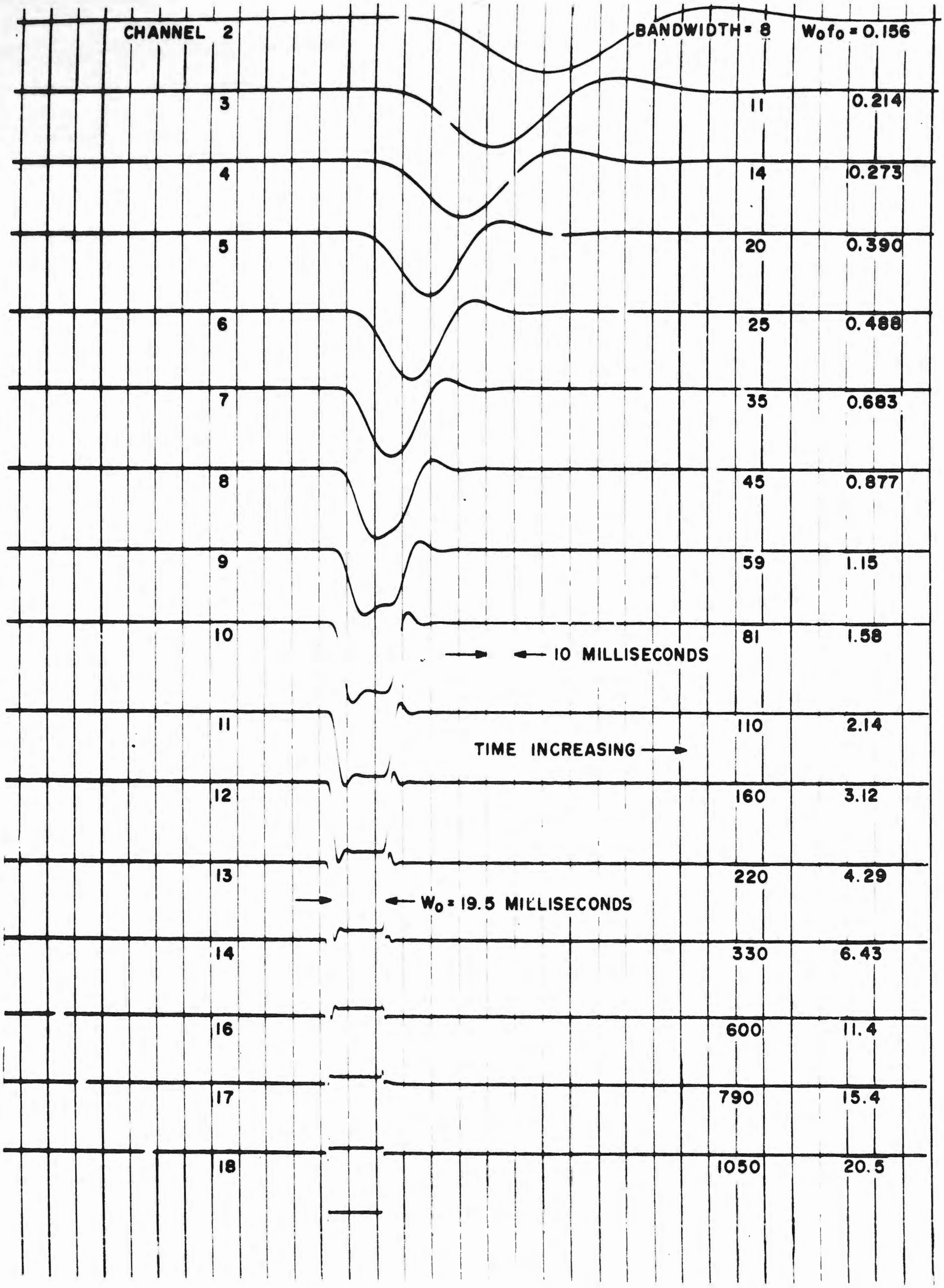

Figure 8. FM/FM System Square Pulse Transmission

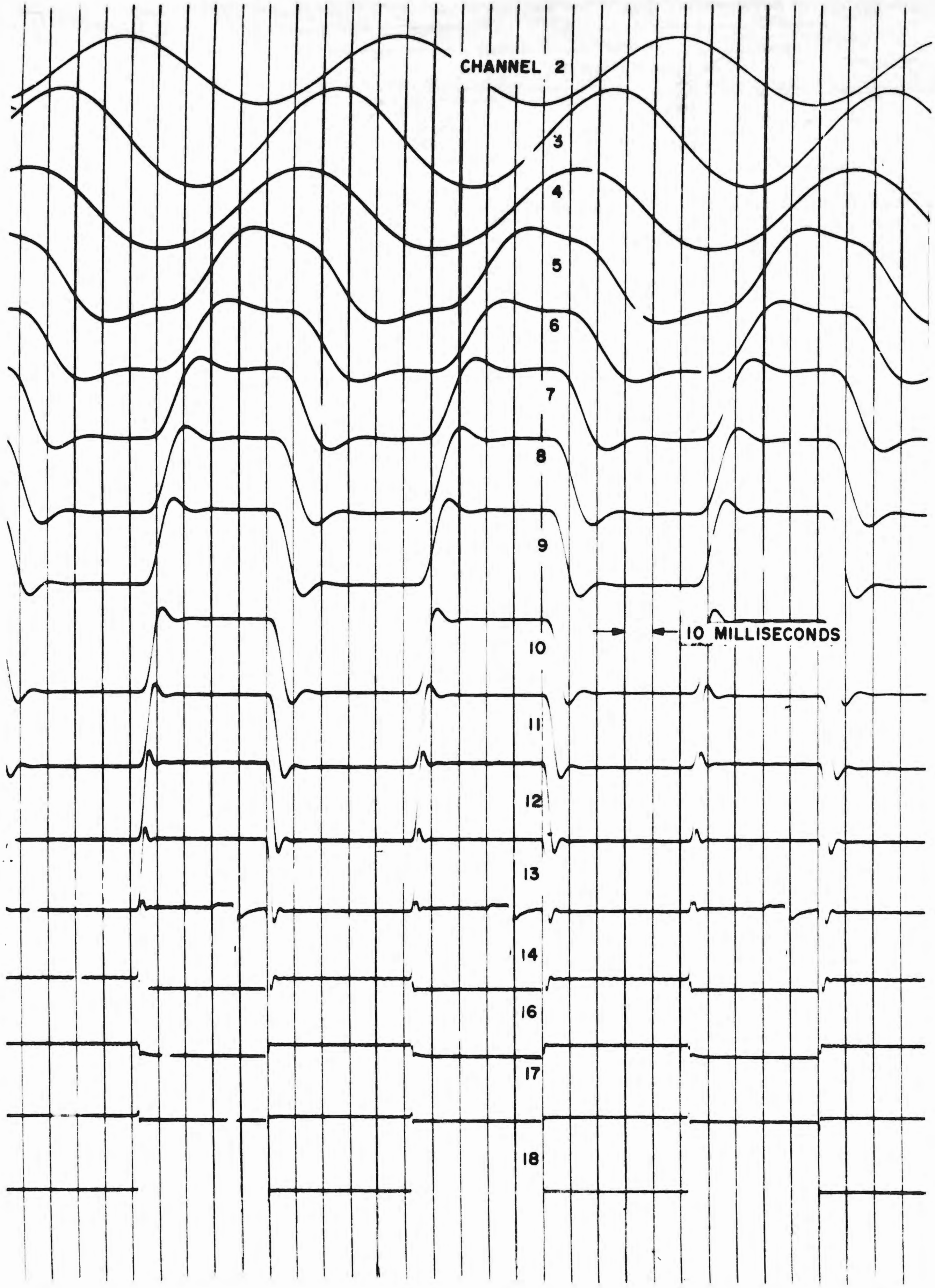

Figure 9. FM/FM System Square Wave Transmission

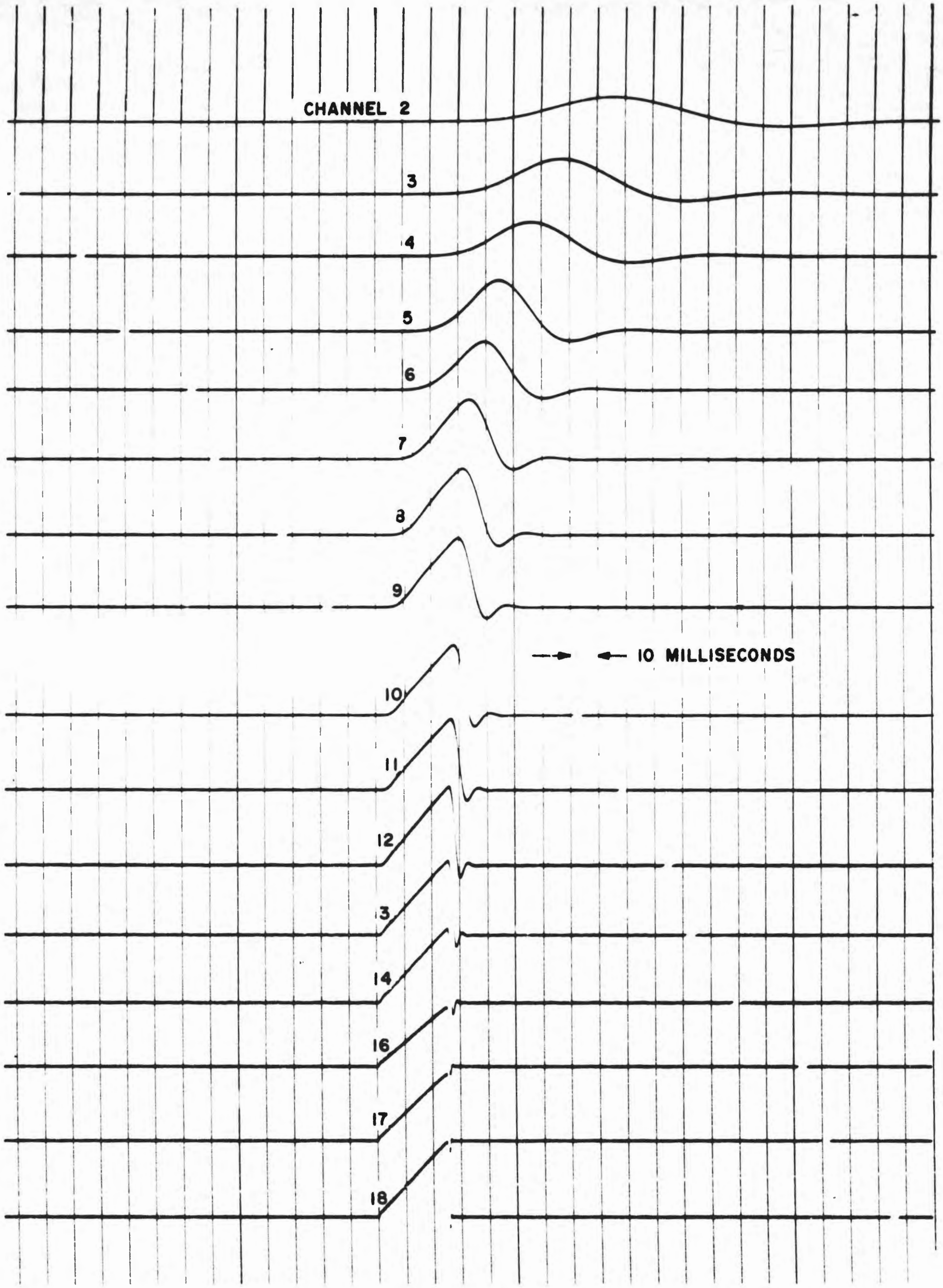

Figure 10. FM/FM System Triangular Pulse Transmission

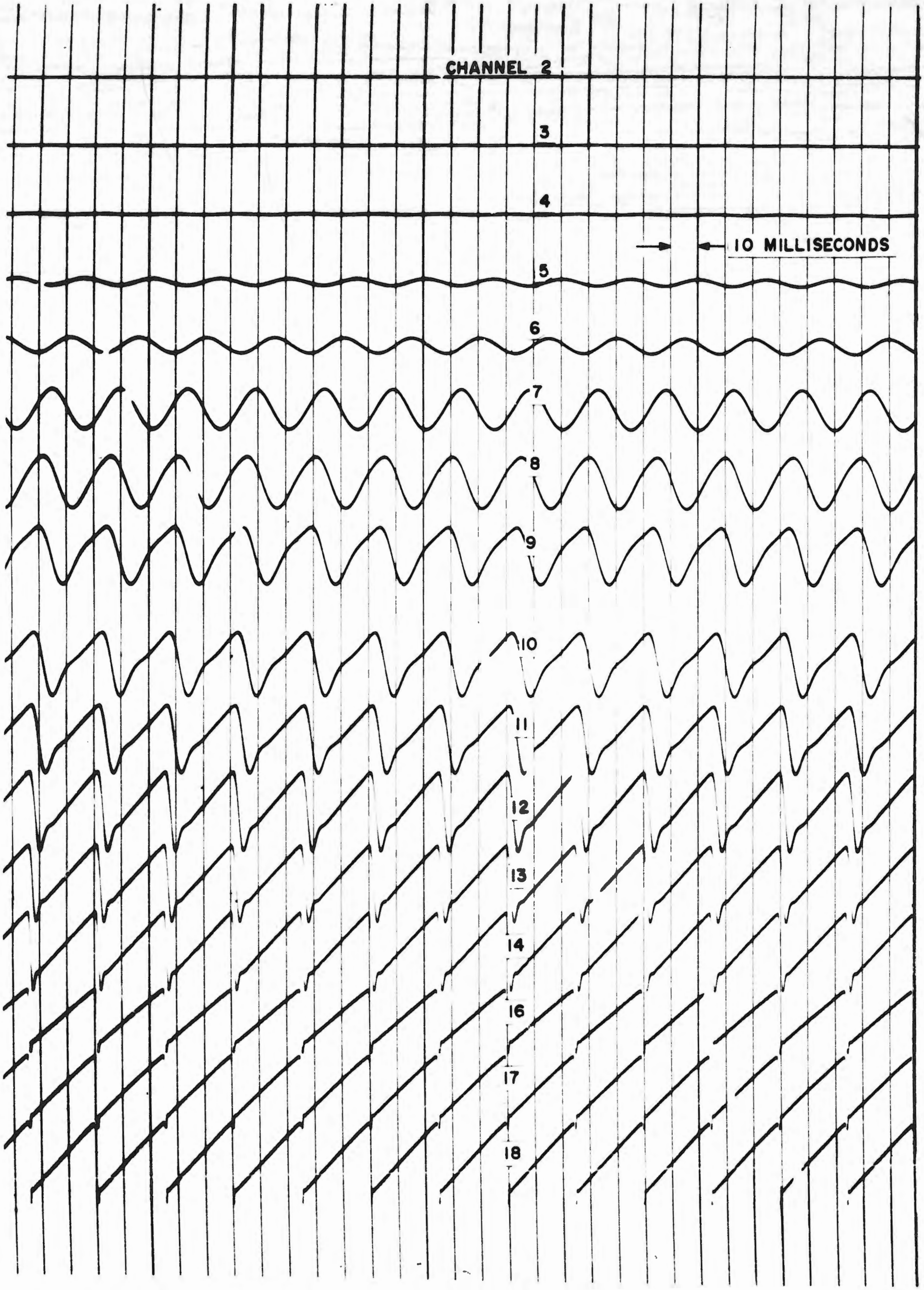

Figure 11. FM/FM System Triangular Wave Transmission

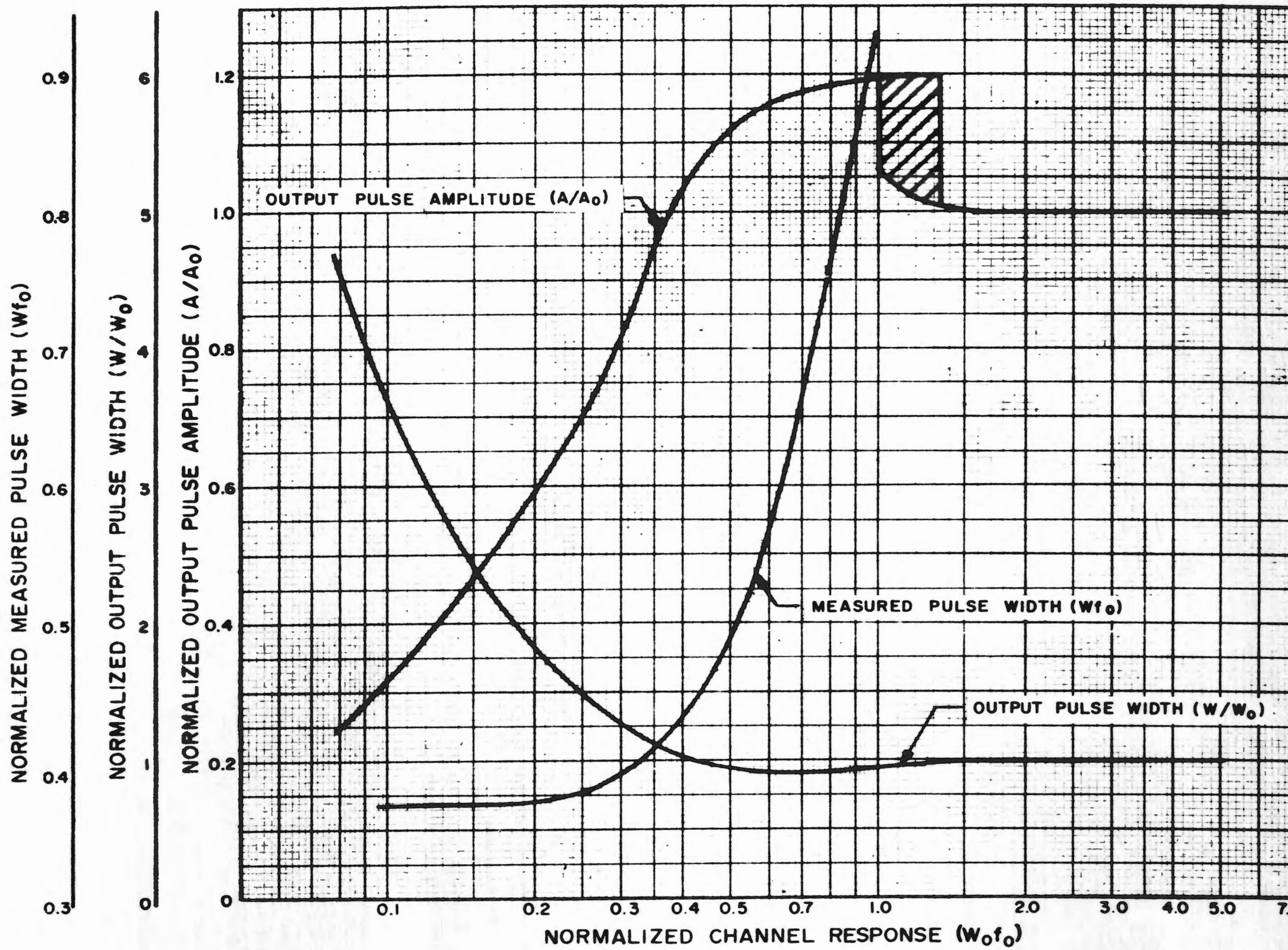

Figure 12. Pulse Width and Amplitude Transmission Curves for an FM/FM System

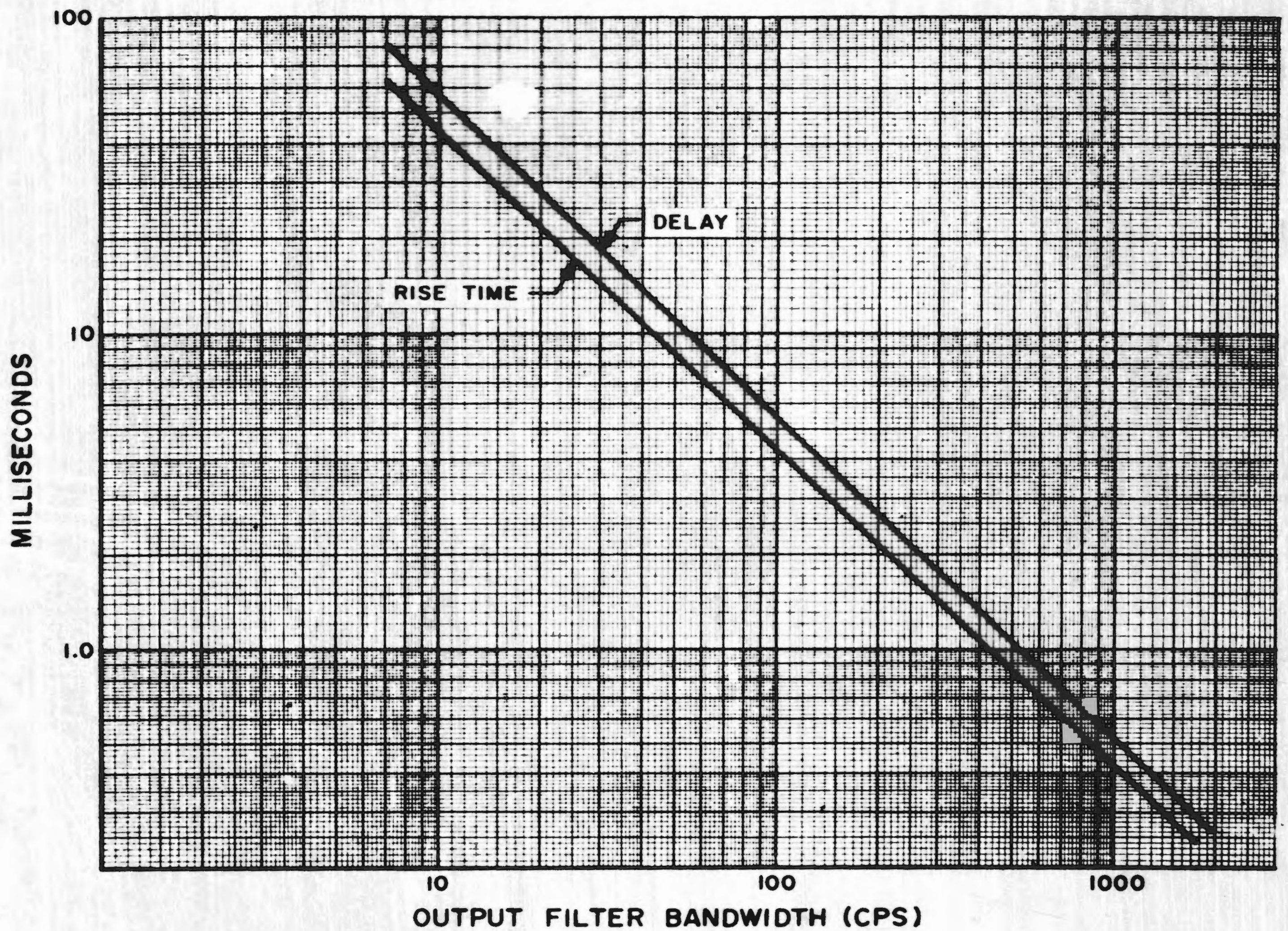

Figure 13. Channel Delay and Rise Time for an FM/FM System

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Telemetry Compromise Frequency Response at Low Noise Level						
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