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A METHOD FOR MORE EFFICIENT USE OF THE 4B VOICE/DATA LINES WITH APPLICATION TO THE PROPOSED AAP TELEPRINTER

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16. ABSTRACT

This document presents a technique for transmitting digital data within the unused spectrum on voice communications channels. The channels may be used simultaneously for both voice and digital data. Necessary equipment to frequency share the channel is shown, and test results that demonstrate the feasibility of the technique are shown.

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A METHOD FOR MORE EFFICIENT USE OF THE 4B VOICE/DATA LINES WITH APPLICATION TO THE PROPOSED AAP TELEPRINTER

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SUMMARY

The present proposal for transmitting data to the Apollo Applications Program teleprinter is to use the universal command system. An alternate technique is to bypass the command system entirely and to transmit the teleprinter data in dot-matrix form on a frequency-shared voice line. The voice and teleprinter data can be transmitted on existing voice lines to the remote sites by limiting the frequency spectrum of each signal. The remote site would simply throughput the information to the spacecraft where filters would be used to separate the voice and data. On board, the data could be routed to several audio jacks where a portable teleprinter could be used. This document contains the results of a study conducted by the Systems Engineering Branch, Flight Support Division, Manned Spacecraft Center, to prove the feasibility of this method. An actual teleprinter was not used, but the waveform of the bits was recognizable on an oscilloscope. Generally, the results were very favorable. Most of the difficulties encountered were caused by the use of variable frequency filters which had low rolloffs.

INTRODUCTION

The present proposal for transmitting data to the Apollo Applications Program (AAP) teleprinter is to use the universal command system (UCS). This method is very complex and includes many error protection checks. As a result of this complexity, it is proposed that the command system be bypassed entirely and that the data be transmitted on a frequency-shared voice line. This document contains the results of a study conducted to determine the feasibility of frequency multiplexing voice and teleprinter data at different bit rates within the same voice line.

In this method, the teleprinter data and the voice will be transmitted within the same voice line by limiting the frequency spectrum of each signal. A dot-matrix form of transmission will be used for the teleprinter data. This method allows both text and pictures to be transmitted with a relatively high accuracy because the loss of one dot within the dot matrix will not seriously degrade the information.

To fit the teleprinter data in the bandwidth available, it is proposed that the digital data amplitude modulate a carrier set at one side of the available channel bandwidth. In this manner, the signal on the line will consist of the carrier and a single sideband caused by the modulation. Then, the bit rate that can be accepted in the teleprinter channel depends on the channel bandwidth, the signal-to-noise ratio at the receiver, and the acceptable error rate (ref. 1).

The principal advantages of this system are its versatility, simplicity, and low cost. Both text and pictures may be transmitted within the same message by use of the dot-matrix scheme. The data can be throughput at the remote site on the existing voice circuits to the onboard teleprinter. The onboard package can be designed to interface with the audio system through standard audio jacks and will be small enough to enable it to be transported easily from jack to jack. The accuracy obtained by using the dot-matrix technique is high enough to obtain good data definition but still retain a basically simple system, as opposed to the command system. This simplicity results in a much lower cost than the proposed method of using the UCS.

SYMBOLS

f_c	center frequency
f_{ch}	high cut-off frequency
f_{c1}	low cut-off frequency
Q-1, Q-2, Q-3	transistors
V_{OUT}	voltage output
V_{p-p}	volts, peak to peak
V-1, V-2, V-3	voltages

CONFIGURATION

The circuit shown in figure 1 was assembled so that the voice and teleprinter data could be mixed and transmitted on the same circuit. The teleprinter data were simulated by a carrier which was turned on or off at the desired bit rate by a square wave input to the modulator. The voice data were generated either by using a headset or a sine wave generator.

To limit the spectrum of each signal, both the voice and teleprinter data were filtered before they were mixed. The frequency settings of each piece of equipment and the actual band pass of each filter or group of filters will be discussed in the following section. An amplifier was used at test point (TP) 5 and TP-6 (fig. 1) to interface the unbalanced equipment used in the experiment with the balanced voice/data line. A type 4B voice/data line was used to route the data to the Goddard Space Flight Center (GSFC) and to return the data to the Manned Spacecraft Center (MSC) to simulate the actual transmission of the data to a remote site for up link. Then, the returned signal was separated by filtering. The teleprinter data were displayed on an oscilloscope, and the voice was routed to a telephone handset.

Special Circuits

The circuit shown in figure 2 was used to simulate the various bit rates. This was accomplished by using a square wave to turn the sine-wave-carrier signal on and off at the desired bit rate. Stages Q-1, Q-2, and Q-5 are emitter followers that were used for impedance buffering purposes. The actual modulator Q-3 was biased at cutoff so that the square wave would turn the transistor either on or off to pass or stop the sine wave carrier. A summing amplifier stage Q-4 was used to add a fractional part of the square wave input (controlled by 200 kΩ potentiometer) to the output of the modulator to obtain the desired shape of the output bit train.

The circuit shown in figure 3 was used to mix the voice and teleprinter data. The mixer channel V-1 input was used for teleprinter data; the mixer channel V-2 input was used for voice data. The two 10-kΩ potentiometers were used to control the amplitude of the teleprinter data and voice inputs. The Q-1, Q-3, and Q-6 stages are emitter-follower stages used for impedance buffering; Q-2 and Q-4 are amplifier stages, and Q-5 is the mixer stage. The V-1 and V-2 mixer channels were set at 0-dBm gain nominally (figs. 4 and 5).

Measurements

To meet the level specifications for the 4B voice/data line (-6 dBm/600 Ω nominal with peaks not to exceed 0 dBm), the teleprinter signal level was set at -10 dBm at TP-5 on figure 1; therefore, when this signal was added with the voice, the signal level did not exceed the specifications.

To obtain consistent measurements, three pieces of equipment were used as standards throughout the tests.

Parameter	Equipment	NASA no.
Signal level	rms voltmeter	46371
Frequency	Function generator	69267
Wave analysis	Wave analyzer	105532

CIRCUIT CHARACTERISTICS

The test point references throughout this section are to figure 1. The signal levels used did not cause clipping at any point in a particular test.

Voice Line

The purpose of this test was to determine the band pass of the 4B voice/data line in use. The procedure used to obtain the band pass of the voice/data line is as follows.

1. Break the circuit at TP-5 and TP-6.

2. Terminate TP-6 with 620 Ω.

3. Set the amplifier to 0-decibel gain.

4. Connect the sine wave generator at TP-5. Set the input level to -10 dBm.

5. Record the signal-level readings at TP-6 for the incremental frequency settings from 100 to 5000 hertz.

The point-to-point gain of the voice line was as follows.

1. Input signal level = -10 dBm at 1 kilohertz at TP-5.

2. From TP-5 to TP-6, the gain = -7.5 decibels.

The band pass of the 4B voice/data line tested was from 167 to 3300 hertz (bandwidth equals 3133 hertz), as seen in figure 6. The rolloff on the low frequency end is approximately 53 dB/octave, and the rolloff on the high frequency end is greater than 60 dB/octave. The 7.5-decibel loss observed from TP-5 to TP-6 is because of line loss between the test bench and the Facilities Control System (FACS) area of the Mission Control Center (MCC) at MSC.

Voice and Data Filters

The purpose of this test was to determine the separation of the voice and teleprinter data before they were mixed.

The procedure used to obtain the teleprinter channel data is as follows.

1. Break the circuit at TP-1 and TP-2.

2. Set the high-pass filters for f_{c1} = 3.0 kilohertz. Set the band-pass filter for f_{c1} = 3.0 kilohertz and f_{ch} = 3.2 kilohertz with 20 dBm gain.

3. Connect the sine wave generator at TP-1. Set the input level so that the maximum output at TP-2 is 0 dBm.

4. Record the output-signal-level readings at TP-2 for the incremental frequency readings from 1000 to 10 000 hertz.

The point-to-point gain of the teleprinter channel was as follows.

1. The input signal level = -10.5 dBm at 3.7 kilohertz at TP-1.

2. From TP-1 to TP-2, the gain = 10.5 decibels.

The procedure used to obtain the voice channel data is as follows.

1. Break the circuit at TP-3 and TP-4.

2. Set the band-pass filters for f_{ch} = 2.2 kilohertz and f_{c1} = 150 hertz.

3. Connect the sine wave generator at TP-3. Set the input level so that the maximum output at TP-4 is 0 dBm.

4. Record the output-signal-level readings for the incremental frequency settings from 100 to 6000 hertz.

The point-to-point gain of the voice channel was as follows.

1. The input signal level = -1.7 dBm at 300 hertz at TP-3.

2. From TP-3 to TP-4 the gain = 1.7 decibels.

The band pass of the voice filters was from 180 to 1850 hertz (bandwidth equals 1670 hertz), as seen in figure 7. The high end rolloff is 53 dB/octave. The band pass of the teleprinter data filters is from 3100 to 4300 hertz (bandwidth equals 1200 hertz). The low end rolloff is approximately 60 dB/octave. The crossover point of the voice and teleprinter channels occurs at 2500 hertz and is 14 decibels down at that point.

Characteristics of input filters and the voice line (from TP-1 to TP-6 and from TP-3 to TP-6). - The purpose of this experiment was to determine the separation of the voice and teleprinter data on the voice line. The procedure used to obtain the teleprinter channel data on the voice line is as follows.

1. Break the circuit at TP-1 and TP-6.

2. Set the amplifier for 0-decibel gain.

3. Terminate TP-6 with 620 Ω.

4. Disconnect the V-2 mixer input at TP-4.

5. Set the high-pass filters for f_{c1} = 3.0 kilohertz.

6. Set the band-pass filter for f_{c1} = 3.0 kilohertz and f_{ch} = 3.2 kilohertz with 20-decibel gain.

7. Connect the sine wave generator at TP-1. Set the input level so that the maximum output at TP-5 is -10 dBm.

8. Record the output-signal-level readings at TP-6 for incremental frequency settings from 1000 to 5000 hertz.

The point-to-point gain of the teleprinter channel was as follows.

1. The input signal level = -18.75 dBm at 3.3 kilohertz at TP-1.

2. From TP-1 to TP-2, the gain = 8.25 decibels.

3. From TP-2 to TP-5, the gain = -0.5 decibel.

4. From TP-5 to TP-6, the gain = -10.5 decibels.

The procedure used to obtain the voice channel data on the voice line is as follows.

1. Break the circuit at TP-3 and TP-6.

2. Terminate TP-6 with 620 Ω.

3. Set the amplifiers for 0-decibel gain.

4. Disconnect the V-1 mixer input at TP-2.

5. Set the band-pass filters for f_{c1} = 150 hertz and f_{ch} = 2.2 kilohertz.

6. Connect the sine wave generator at TP-3. Set the input level so that the maximum output level at TP-5 is -10 dBm.

7. Record the output-signal-level readings at TP-6 for incremental frequency settings from 100 to 5000 hertz.

The point-to-point gain of the voice channel was as follows.

1. The input signal level = -2.7 dBm at 300 hertz at TP-3.

2. From TP-3 to TP-4, the gain = 1.7 decibels.

3. From TP-4 to TP-5, the gain = -9 decibels.

4. From TP-5 to TP-6, the gain = -7.5 decibels.

The band pass of the voice filters was from 185 to 1800 hertz (bandwidth equals 1615 hertz) with a high end rolloff of 53 dB/octave, as seen in figure 8. The gain observed between TP-5 and TP-4 is variable, adjusted by the V-2 potentiometer setting on the mixer. The band pass of the teleprinter data was from 2.9 to 3.4 kilohertz (bandwidth equals 500 hertz) with a low end rolloff of greater than 60 dB/octave. The voice line limited the high cut-off on the teleprinter data to 3.4 kilohertz, as seen in figure 6. Crossover occurred at 2550 hertz and was 13 decibels down from the voice at that point.

Characteristics of output filters. - The purpose of this test was to determine the separation of the output filters.

The procedure used to obtain the teleprinter channel data on the output filters is as follows.

1. Break the circuit at TP-6 and TP-7.

2. Set the high-pass filter for f_{c1} = 3000 hertz.

3. Connect the sine wave generator at TP-6. Set the input level so that the maximum output at TP-7 is 0 dBm.

4. Record the output-signal-level readings at TP-7 for the incremental frequency settings from 1000 to 6000 hertz.

The point-to-point gain of the teleprinter channel was as follows.

1. The input signal level at TP-6 = +0.2 dBm at 4000 hertz.

2. From TP-6 to TP-7, the gain = -0.5 decibel.

The procedure used to obtain the voice channel data on the output filters is as follows.

1. Break the circuit at TP-6 and TP-8.

2. Set the low-pass filter for f_{ch} = 2.2 kilohertz.

3. Connect the sine wave generator at TP-6. Set the input level so that the maximum output level at TP-8 is 0 dBm.

4. Record the output-signal-level readings at TP-8 for the incremental frequency settings from 100 to 5500 hertz.

The point-to-point gain of the voice channel was as follows.

1. The input signal level at TP-6 = -0.5 dBm at 1400 hertz.

2. From TP-6 to TP-8, the gain = +0.5 decibel.

The high frequency cut-off of the low-pass filter was 1900 hertz with a rolloff of 39 dB/octave. The low frequency cut-off of the high-pass filter was 3100 hertz with a rolloff of 38 dB/octave. Crossover occurred at 2500 hertz and was 10 decibels down at that point. The results are presented in figure 9.

End-to-end channel characteristics (from TP-1 to TP-7 and from TP-3 to TP-8). - The purpose of this test was to show the total separation of the voice and teleprinter data channels.

The procedure used to obtain the teleprinter channel data is as follows.

1. Break the circuit at TP-1 and TP-7.

2. Disconnect the V-2 input to the mixer at TP-4.

3. Terminate the output amplifier with 620 Ω at TP-6.

4. Set the input high-pass filters for f_{c1} = 3000 hertz.

5. Set the input band-pass filter for f_{c1} = 3000 hertz, f_{ch} = 3200 hertz, and 20-decibel gain.

6. Set the output high-pass filter for f_{c1} = 3000 hertz.

7. Set the input and output amplifiers to 0-decibel gain.

8. Connect the sine wave generator at TP-1. Set the input level so that the maximum output at TP-5 is -10 dBm.

9. Record the output-signal-level readings at TP-7 for the incremental frequency settings from 1000 to 5000 hertz.

The point-to-point gain of the teleprinter channel was as follows.

1. The input signal level at TP-1 = -18.75 dBm at 3.3 kilohertz.

2. From TP-1 to TP-2, the gain = 8.25 decibels.

3. From TP-2 to TP-5, the gain = 0 decibel.

4. From TP-5 to TP-6, the gain = -11.5 decibels.

5. From TP-6 to TP-7, the gain = -2.5 decibels.

The procedure used to obtain the voice channel data is as follows.

1. Break the circuit at TP-3 and TP-8.

2. Disconnect the V-1 input to the mixer.

3. Parallel the output amplifier with 620 Ω at TP-6.

4. Set both amplifiers to 0-decibel gain.

5. Set the input band-pass filters for f_{c1} = 150 hertz and f_{ch} = 2.2 kilohertz.

6. Set the output low-pass filter for f_{ch} = 2.2 kilohertz.

7. Connect the sine wave generator at TP-3. Set the input level so that the maximum level at TP-5 is -10 dBm.

8. Record the output-signal-level readings at TP-8 for the incremental frequency settings from 100 to 4000 hertz.

The point-to-point losses of the voice channel were as follows.

1. The input signal level at TP-3 = 2.7 dBm at 1500 hertz.

2. From TP-3 to TP-4, the gain = 0.5 decibel.

3. From TP-4 to TP-5, the gain = -8.9 decibels.

4. From TP-5 to TP-6, the gain = -8.5 decibels.

5. From TP-6 to TP-8, the gain = 0.4 decibel.

The results are presented in figure 10. The band pass of the voice data was from 190 to 1750 hertz (bandwidth equals 1560 hertz) with an upper rolloff of 41 dB/octave. The band pass for the teleprinter data was from 3000 to 3400 hertz with a lower rolloff of 60 dB/octave. Crossover occurred at 2600 hertz and was 21 decibels down from the voice at that point, as seen in figure 10. The 400-hertz band pass for the teleprinter data was 100 hertz narrower than was desired in the optimum case for 500 bps.

Channel Crosstalk

Teleprinter and voice channels (from TP-1 to TP-8 and from TP-3 to TP-7). - The purpose of this test was to determine the amount of crosstalk between the input to one channel and the output of the other channel. The procedure used to determine the teleprinter-to-voice channel crosstalk is as follows.

1. Break the circuit at TP-1, TP-3, TP-7, and TP-8.

2. Terminate the output amplifier with 620 Ω. Set the gain of both amplifiers to 0 decibel.

3. Set the input high-pass filter for f_{cl} = 3.0 kilohertz. Set the band-pass filter for f_{cl} = 3.0 kilohertz and f_{ch} = 3.4 kilohertz with 20-decibel gain.

4. Set the output low-pass filter (from TP-6 to TP-8) for f_{ch} = 2.2 kilohertz.

5. Connect the sine wave generator at TP-1. Set the input signal level so that the maximum output signal level at TP-5 is 0 dBm. (The input level was -9.5 dBm.)

6. Record the output-signal-level readings at TP-8 for the incremental frequency settings from 100 to 5000 hertz.

The procedure used to determine the voice-to-teleprinter channel crosstalk is as follows.

1. Break the circuit at TP-1, TP-3, TP-7, and TP-8.

2. Terminate the output amplifier with 620 Ω. Set both amplifiers to 0-decibel gain.

3. Set the input band-pass filters for f_{ch} = 2.2 kilohertz and f_{c1} = 150 hertz.

4. Set the output high-pass filter (from TP-6 to TP-7) for f_{c1} = 3000 hertz.

5. Connect the sine wave generator at TP-3. Set the input signal so that the maximum output at TP-5 is 0 dBm. (The input level was -2 dBm.)

6. Record the output-signal-level readings for the incremental frequency settings from 100 to 4000 hertz.

The plot of the crosstalk between the voice and teleprinter channels is shown in figure 11. The signal levels shown are approximately 10 decibels higher than they were in the actual case because the input signal level at TP-5 was -10 dBm nominally. In this case, 0 dBm was used. Therefore, the only significant crosstalk occurred between 1000 and 3500 hertz for TP-3 to TP-7. This crosstalk peaked at 2300 hertz. This peak occurred very near the crossover point of the teleprinter and voice channels shown in figure 10 and is 9 decibels down from the teleprinter data.

Mixer input crosstalk (from TP-2 to TP-4). - The purpose of this test is to determine the crosstalk between the two mixer inputs.

The procedure used to determine the amount of crosstalk between the two mixer inputs is as follows.

1. Break the circuit at TP-2, TP-4, and TP-5.

2. Set both mixer channels (from TP-2 to TP-5 and from TP-4 to TP-5) to 0-decibel gain with the potentiometers.

3. Terminate TP-5 with 620 Ω.

4. Connect the sine wave generator at TP-2. Set the input level at 0 dBm.

5. Record the output-signal-level readings at TP-4 for the incremental frequency settings from 100 to 10 000 hertz.

The crosstalk is plotted in figure 12. The crosstalk mainly interfered with the voice channel as the level was down 45 decibels in the band pass of the teleprinter channel. The level would be down an additional 10 decibels in the actual case because the nominal signal level at TP-2 was -10.5 dBm. The crosstalk within the voice band pass affected the voice clarity (discussed in the following section) because there was a spurious signal, equal to the square wave modulator frequency, occurring within the voice band pass.

Wave Analysis

Mixer output (TP-5). - The purpose of this test was to determine the frequency spectrum of the simulated teleprinter data at the mixer output.

The procedure used to determine the frequency spectrum is as follows.

1. Set the input level to -6 dBm (1.6 V_{p-p}).
2. Connect the wave analyzer at TP-5.
3. Set the carrier frequency at 3350 hertz.
4. Set the modulating square wave frequency at either 250 or 500 hertz.
5. Record all signal-level readings above -50 dBm (arbitrary).

A wave analysis made at a modulating frequency of 500 hertz is shown in figure 13 and that for 250 hertz is shown in figure 14. In either case, the modulating frequency appears as a sideband within the voice band pass because the spectrum was not completely cut off by the high-pass filter shown in figure 7. The double row of spikes which appear at the harmonic frequency plus 30 and 60 hertz, shown in figure 14, are because of a nonideal band pass on the wave analyzer notch filter and because of intermodulation products of the modulator and square wave outputs. This same explanation holds for figure 13.

Modulator output (TP-1). - The purpose of this test was to determine the frequency spectrum of the simulated teleprinter data at the mixer output.

The procedure used to determine the frequency spectrum is as follows.

1. Set the input level to -6 dBm (1.6 V_{p-p}).
2. Connect the wave analyzer at TP-1.
3. Set the carrier frequency at 3350 hertz.
4. Set the modulating square wave frequency at either 250 or 500 hertz.
5. Record all signal-level readings above -50 dBm (arbitrary).

The frequency spectrum at the modulator output for modulating square wave frequencies of 250 and 500 hertz is shown in figures 15 and 16, respectively. Again, the modulating square wave is present on each plot, as are the odd harmonic frequencies. The harmonic frequency plus 30- and 60-hertz spikes, shown in figure 14, are seen more easily here before they are filtered. These spikes are also shown in figure 16.

TESTS

Bit Rate Simulation

The purpose of this test was to show the carrier, modulating signal, bit train, and distortion of the bit train, if any. Oscillograms were taken of the bit train at various points in the circuit (fig. 1). The TP-4 input to the mixer was disconnected.

The modulator and carrier frequencies are shown in figure 17. The upper trace shows the modulating signal at 500 hertz. The lower trace is the 3350-hertz carrier. Both of these signals were used as inputs to the modulator to generate a certain bit rate. The square wave frequency controls the bit rate.

The modulator output and mixer input are shown in figure 18. The upper trace is the modulator output (TP-1) at 1000 bps. The lower trace is the same bit train at TP-2 after being filtered. The filters distort the bit train somewhat.

The mixer input and voice line output are shown in figure 19. The upper trace shows 1000 bps at TP-2. The lower trace is the same signal at TP-6. The voice line also distorts the signal, but it is still recognizable. This distortion is caused mainly by the 500-hertz band pass of the filters between TP-1 and TP-6, as shown in figure 8.

The mixer input and final teleprinter filter output are shown in figures 20 to 26. The upper trace in each figure shows different bit rates at the mixer input (TP-2). The lower trace in each figure is at the output of the final data filter (TP-7). The carrier frequency is 3200 hertz in figure 25; in all the other oscillograms, it is 3350 hertz. The total band pass of the data filters now has been reduced to 400 hertz, as shown in figure 10. This bandwidth causes some distortion of the output signal, but in all cases, the bits are easily distinguishable. The input and output signals are better shaped at the lower bit rates because the relatively wider band pass of the filters causes the bandwidth-signal-distortion trade-off to favor minimum distortion.

Voice Interference

The purpose of this test was to determine the audiofrequencies that will interfere with the data.

Oscillograms were taken at various points within the circuit shown in figure 1.

Voice and data inputs are shown in figure 27. The upper trace is 300 hertz, which was entered at TP-3. The lower trace is 1000 bps, entered at TP-2.

A voice distortion test is shown in figures 28 and 29. The upper trace in figure 28 is the 300-hertz voice at TP-8 with the data input at TP-2 disconnected. The upper trace in figure 29 is the same as in figure 28 except the data shown in the lower trace are again being input at TP-2. Because the two upper traces are identical with or without the data input, the probable cause of the voice distortion is in the filters and the mixer.

Voice and data intermodulation is shown in figures 29 to 42. The upper trace in each figure shows varying frequencies of the voice signal (entered at TP-3) which were entered at TP-8. The lower trace is the data at 1000 bps. The data in figure 34 are the same as the dots in figure 33 except that the data input was removed at TP-2 to illustrate further that the data do not cause the voice distortion. As illustrated in figures 17 to 42, the voice does not seriously interfere with the data definition until a frequency of approximately 1850 hertz is reached. This interference begins to occur at the upper 3-decibel point of the voice band-pass filters. Most of this crosstalk occurs because of crosstalk between the voice and teleprinter channels (fig. 11). As previously mentioned, the interference becomes increasingly worse above a frequency of 1850 hertz.

The configuration of the equipment used in the study is shown in figure 43. The equipment description is given in table I.

CONCLUSIONS

The tests performed during this study indicated that voice and teleprinter data could be transmitted in the same voice line. However, there were several limitations in the particular setup used.

The rolloffs obtained with the variable filters were not as good as was desired. These rolloffs caused more restrictions on the voice band pass and the teleprinter data band pass than was absolutely necessary because of the separation required between the two channels. As a result, the upper cut-off frequency of the voice band pass was 1750 hertz. Also, the teleprinter band pass was limited to 400 hertz. By using fixed filters with sharper cut-offs, it is thought that the upper cut-off frequency on the voice band-pass filter can be raised to 2.4 kilohertz and that the lower cut-off frequency on the teleprinter data band pass can be lowered to 2.7 kilohertz; thus, the data band pass can be extended to 700 hertz if the line cut-off is at 3.4 kilohertz, or will drop to 300 hertz if the line cut-off is at 3.0 kilohertz. A wider band pass will eliminate most of the distortion caused by transmitting 1000 bps through a 400-hertz bandwidth. Also, the interference from high-frequency voice inputs will be essentially eliminated. In addition, this will aid in the reduction of the tone (a composite of the carrier and modulating frequencies) heard at TP-8. These sharper rolloffs would also result in a greater channel separation at the crossover point. Presently, this level is 14 decibels down from the 3-decibel point of data band pass.

The various bit rate tests indicated that digital data can be transmitted simultaneously with voice on a 4B line at bit rates determined by the bandwidth available for the digital data. Because the test data were transmitted through only a 400-hertz band pass, it is thought that in the worst case, where only a 300-hertz band pass is available, there will be no trouble in decoding at least 500 bps. By assuming a minimum solid-lock acquisition time of 6 minutes over a site per pass, 7.15 pages can be up linked to a vehicle. This figure was determined as follows.

$$(500 \text{ bps})(60 \text{ sec/min})\left(\frac{1}{180} \text{ rows/bit}\right)\left(\frac{1}{10} \text{ line/row}\right)\left(\frac{1}{14} \text{ page/line}\right) = 1.19 \text{ pages/min}$$

$$(1.19 \text{ pages/min})(6 \text{ min/pass}) = 7.15 \text{ pages/pass}$$

These numbers were based on existing page-size definitions and a bit rate of 500 bps.

REFERENCE

Oliver, B. M.; Pierce, J. R.; and Shannon, C. E.: The Philosophy of PCM. Proceedings of I.R.E., vol. 36, Nov. 1948, pp. 1324-1331.

TABLE I. - EQUIPMENT LISTING

Equipment no.	Equipment	NASA no.
1	Function generator	69267
2	Modulator	
3	Wide range oscillator	P18747
4	Filter (dual section)	43070
5	Variable filter	50180
6	Mixer	
7	Variable filter	49792
8	Variable filter	49791
9	ac amplifier	46358
10	Headset battery feed card	
11	Amplifier	
12	Amplifier	
13	ac amplifier	46359
14	Filter (dual section)	43068
15	Oscilloscope	48712 53759
16	Power supply	44911
17	Power supply	75891
	rms voltmeter	46371
	Wave analyzer	105532

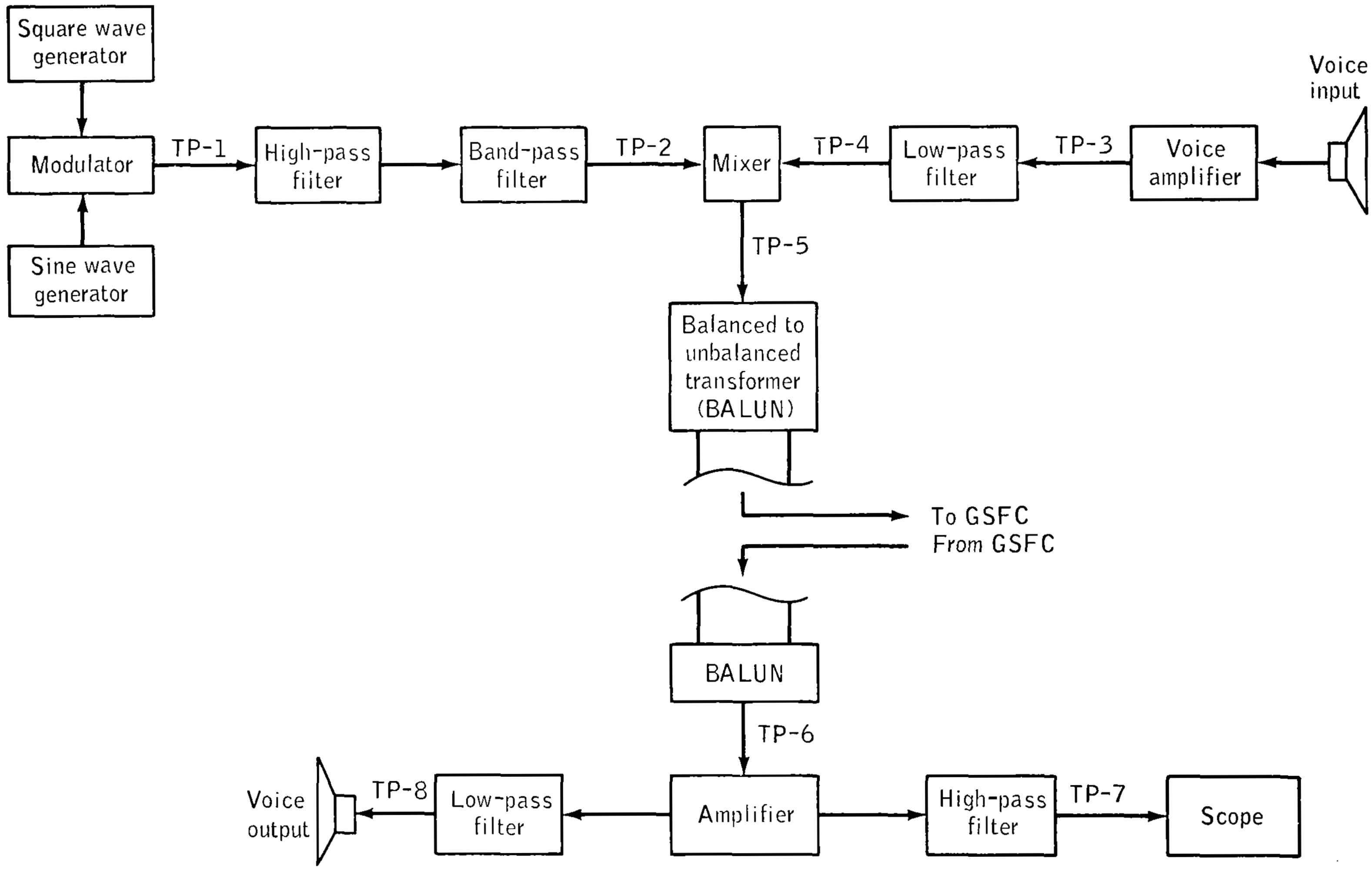

Figure 1. - Test configuration.

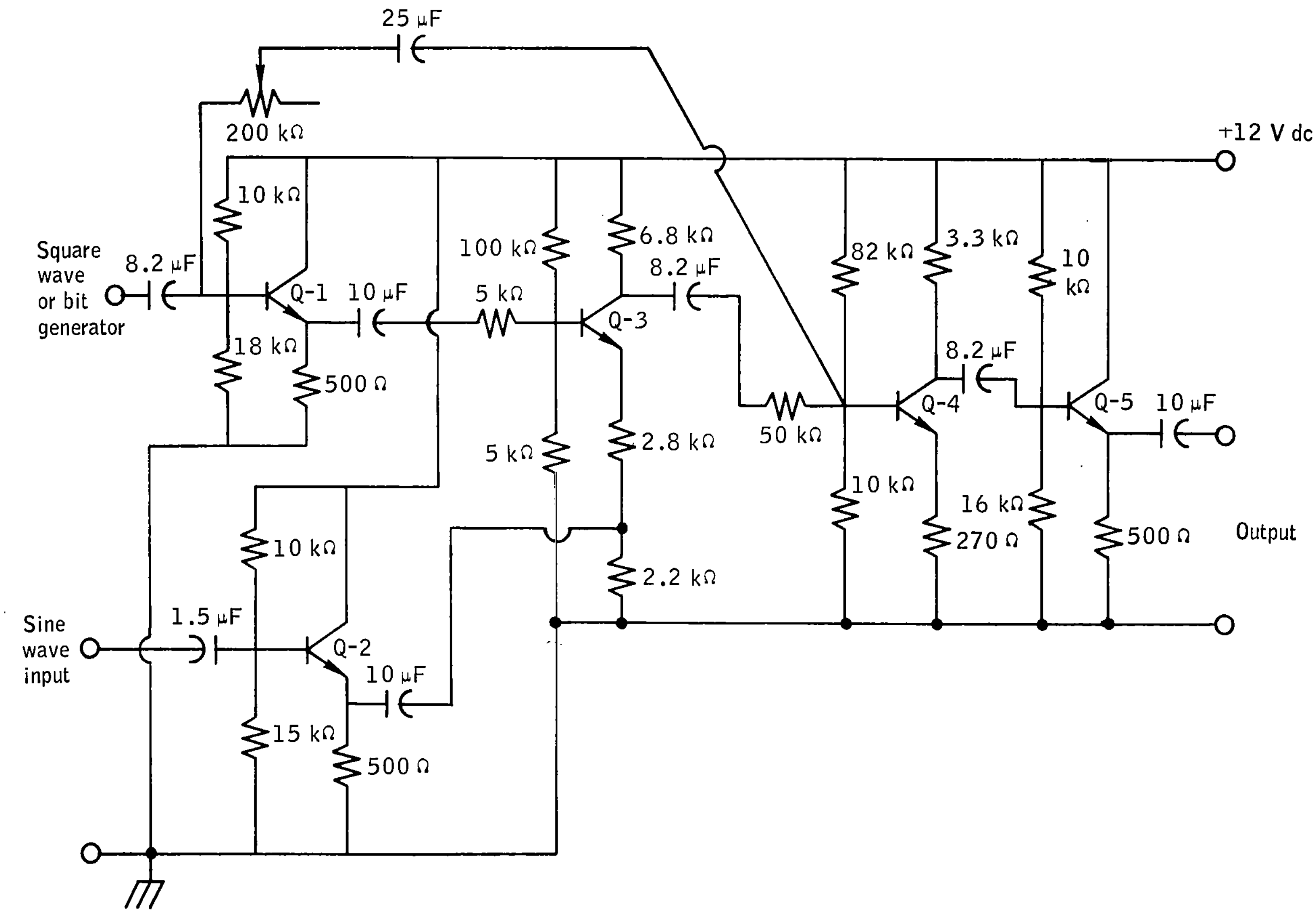

Figure 2. - Modulator circuit.

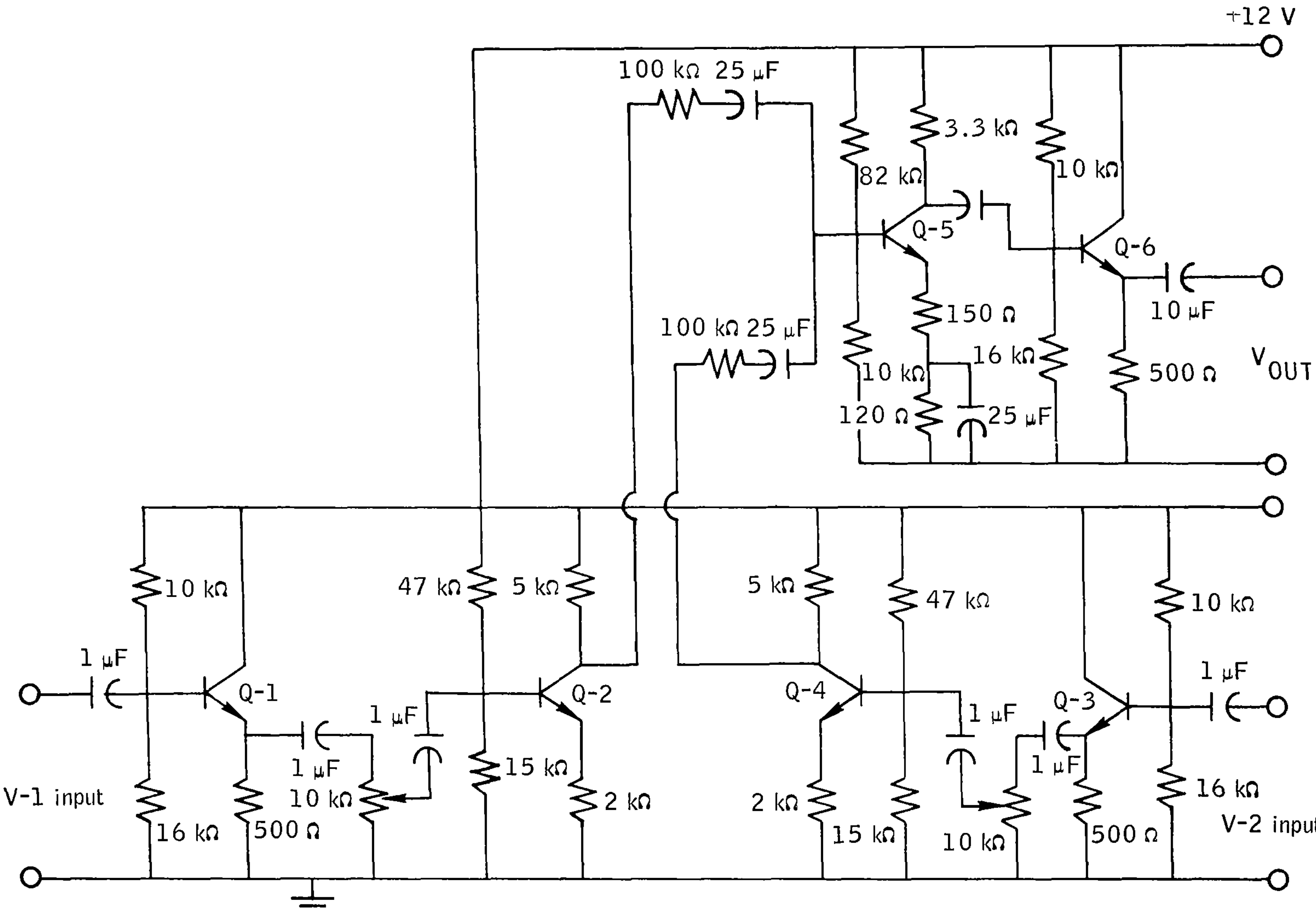

Figure 3. - Mixer circuit.

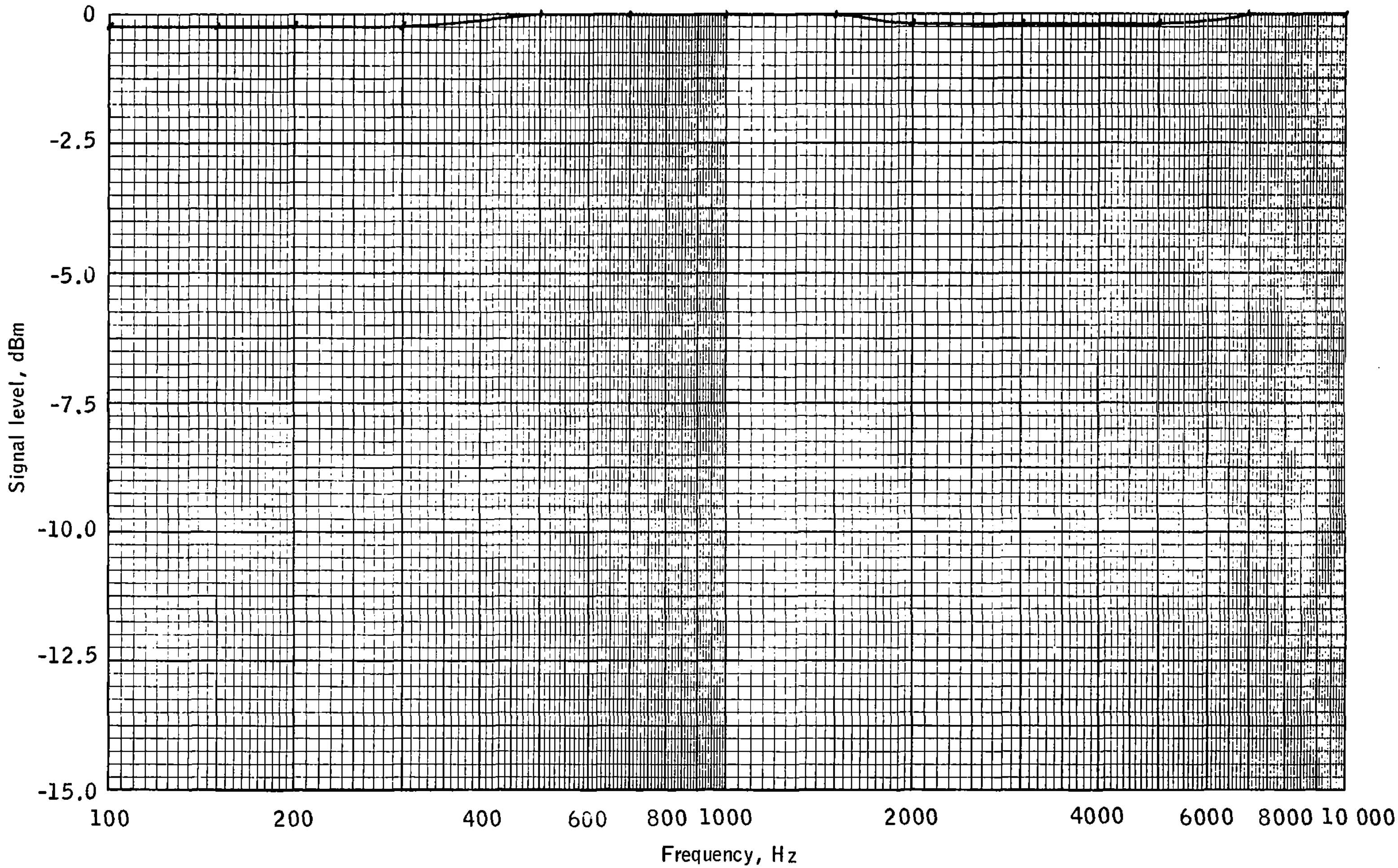

Figure 4. - Mixer channel 1 response (from TP-2 to TP-5).

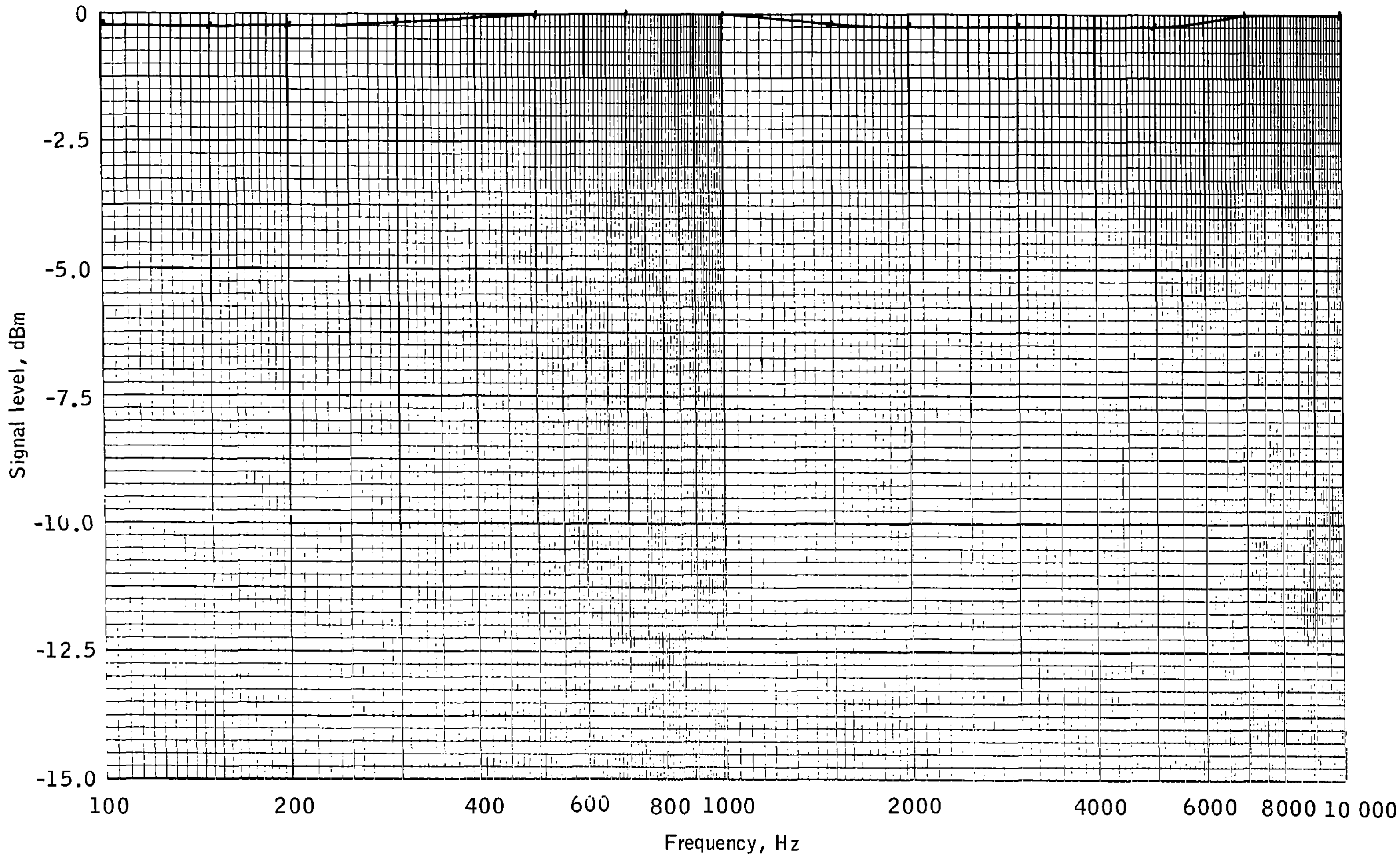

Figure 5. - Mixer channel 2 response (from TP-4 to TP-5).

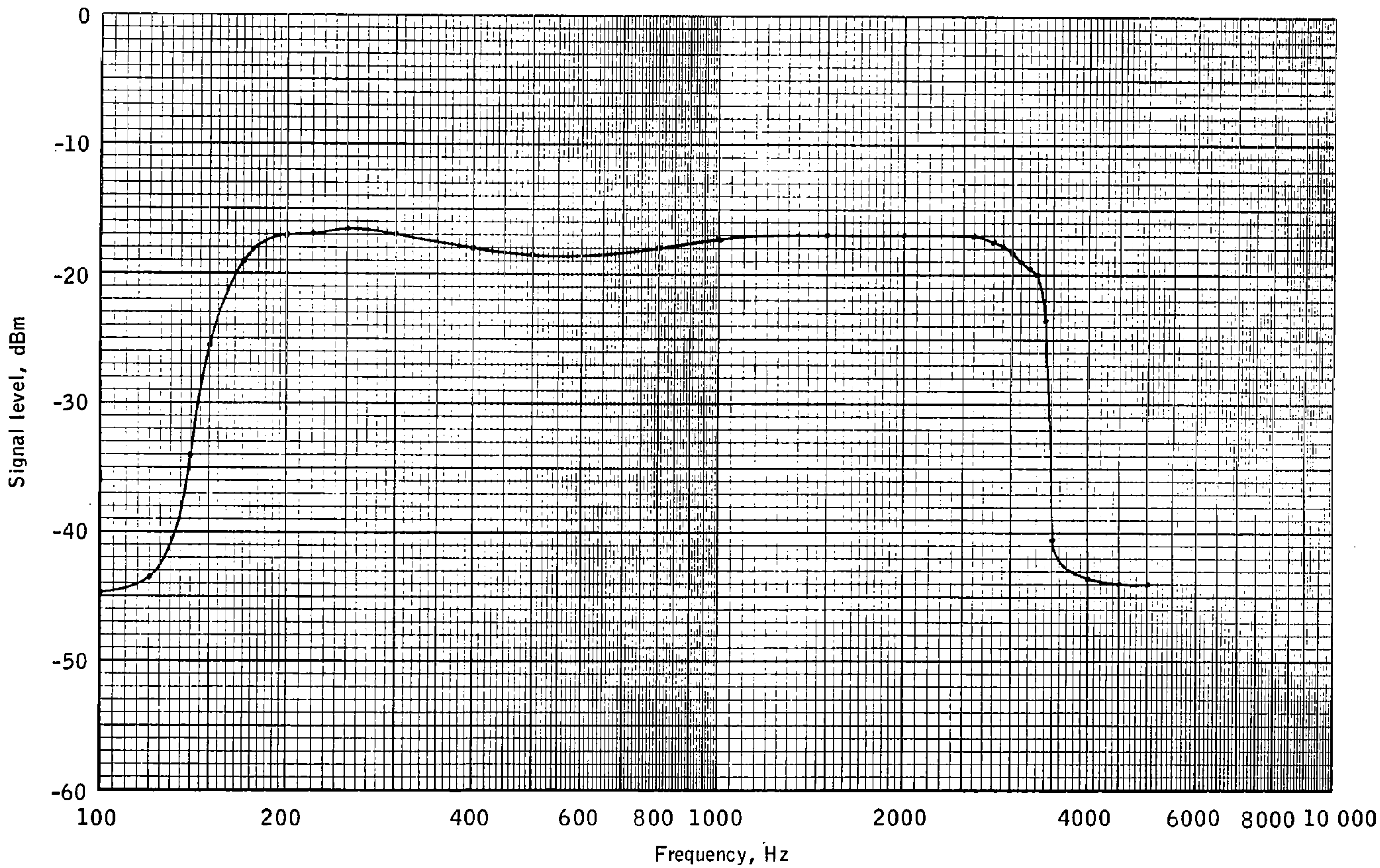

Figure 6. - Voice line response (from TP-5 to TP-6).

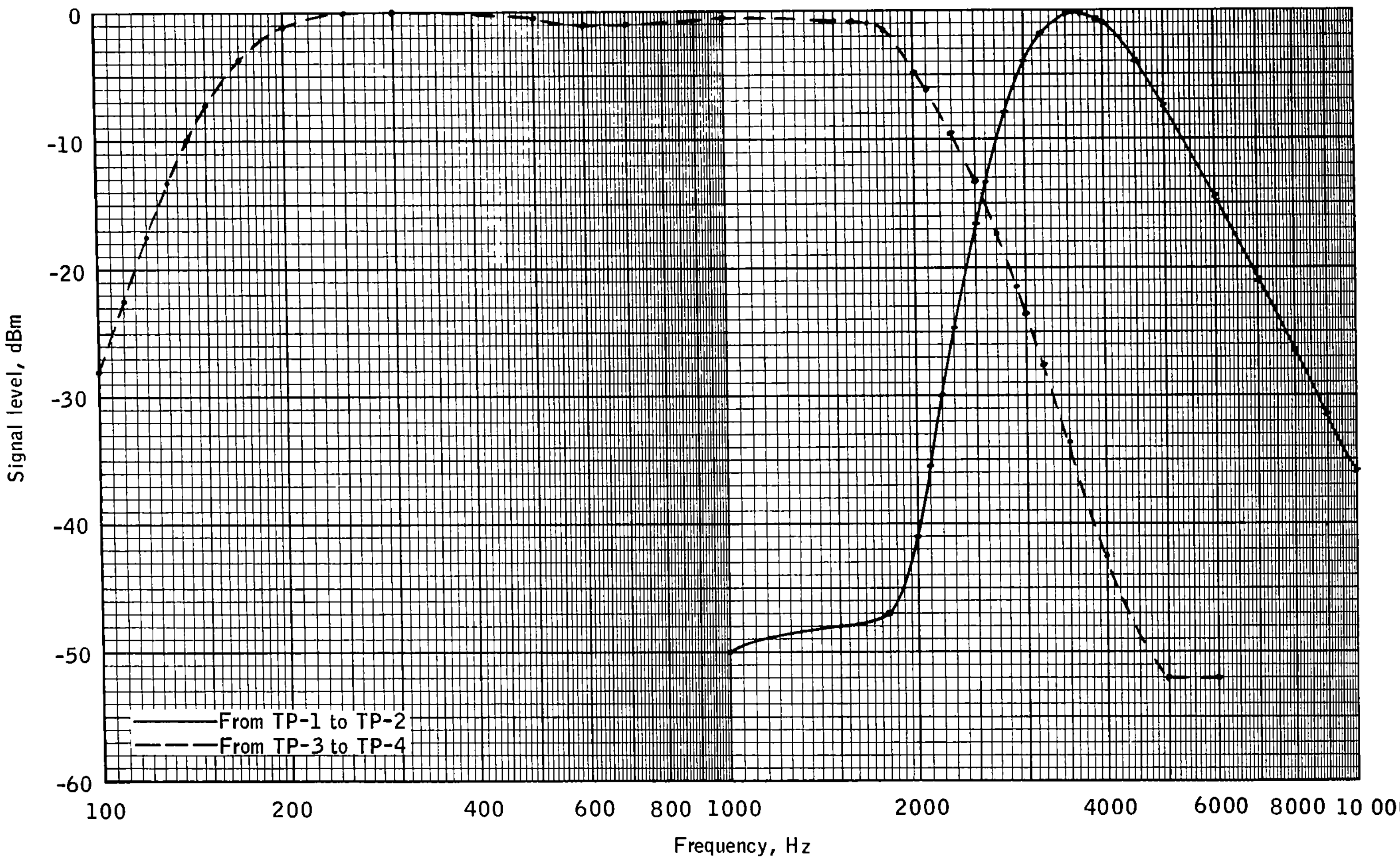

Figure 7. - Input separation of teleprinter and voice (from TP-1 to TP-2 and from TP-3 to TP-4).

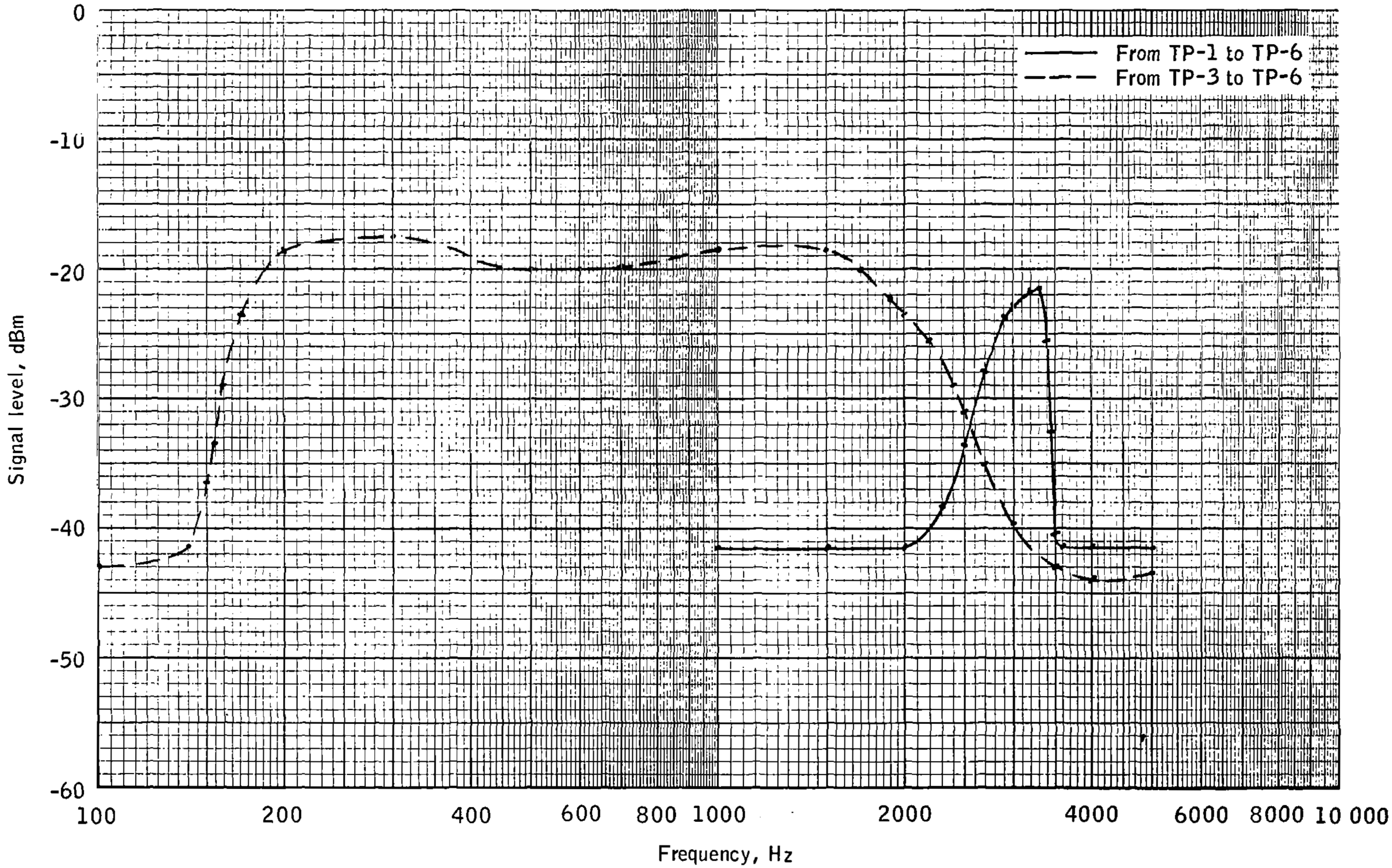

Figure 8. - Combined response of input filters and voice line (from TP-1 to TP-6 and from TP-3 to TP-6).

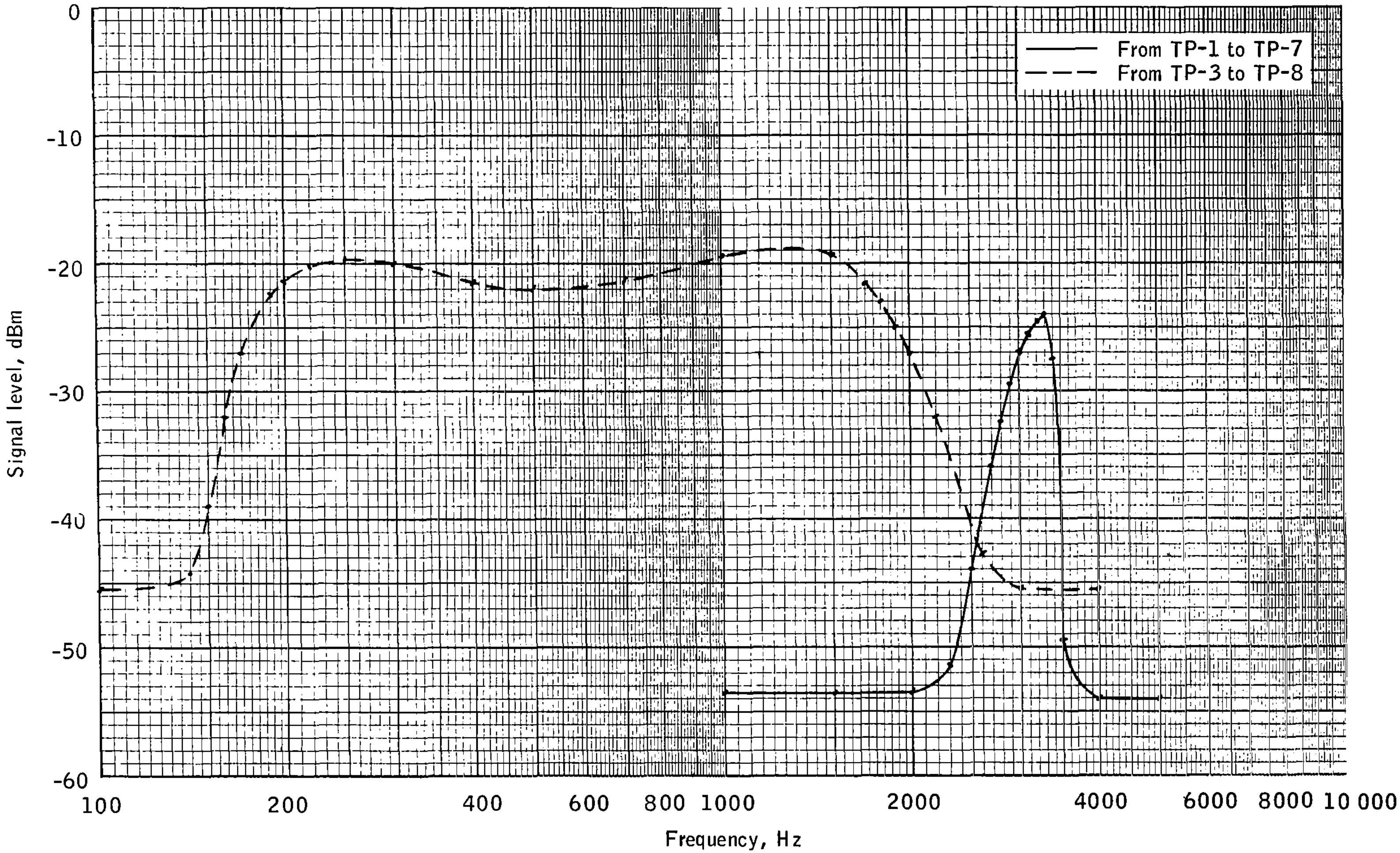

Figure 9. - Channel separation including all filters (from TP-1 to TP-7 and from TP-3 to TP-8).

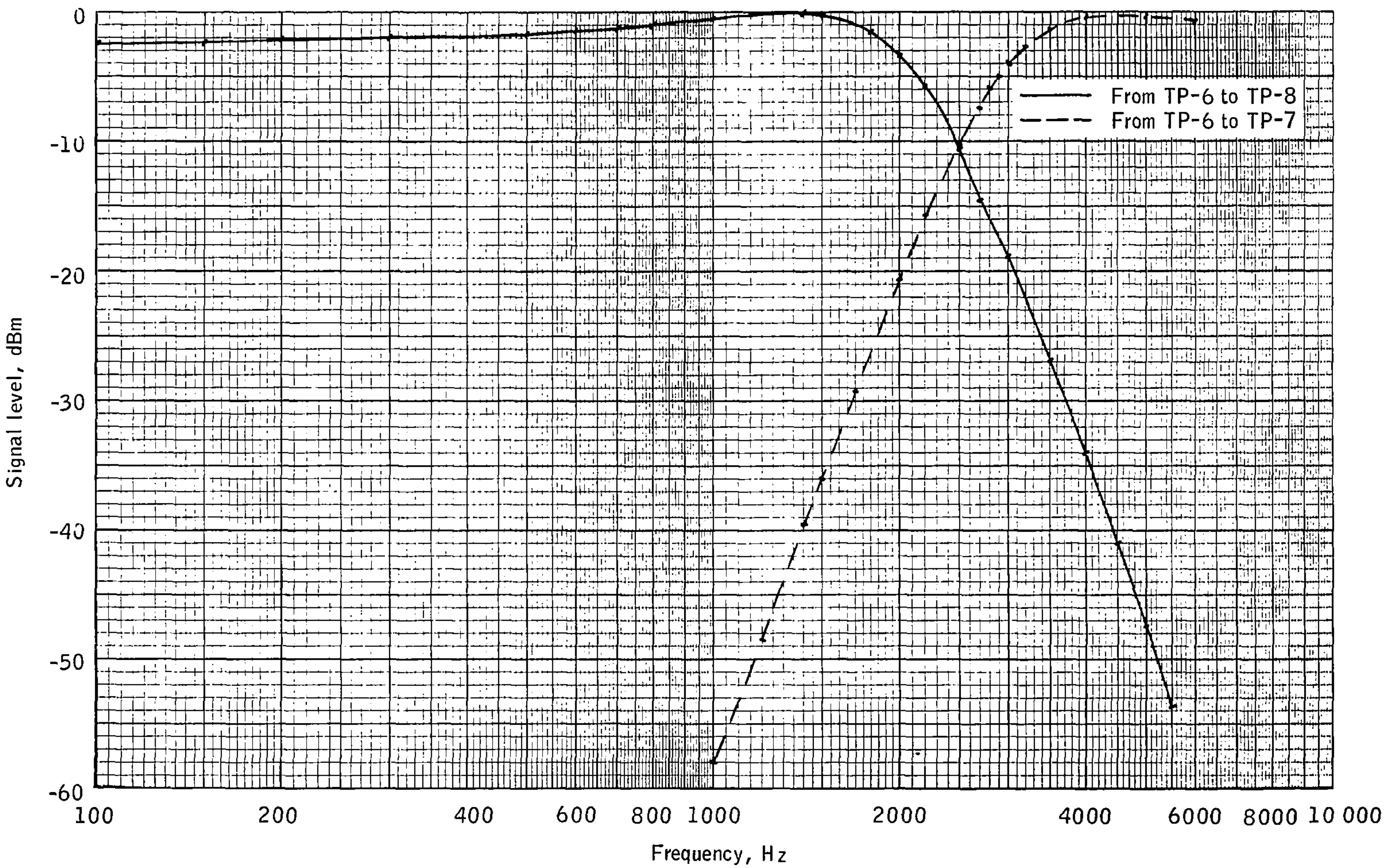

Figure 10. - Output separation of teleprinter and voice (from TP-6 to TP-7 and from TP-6 to TP-8).

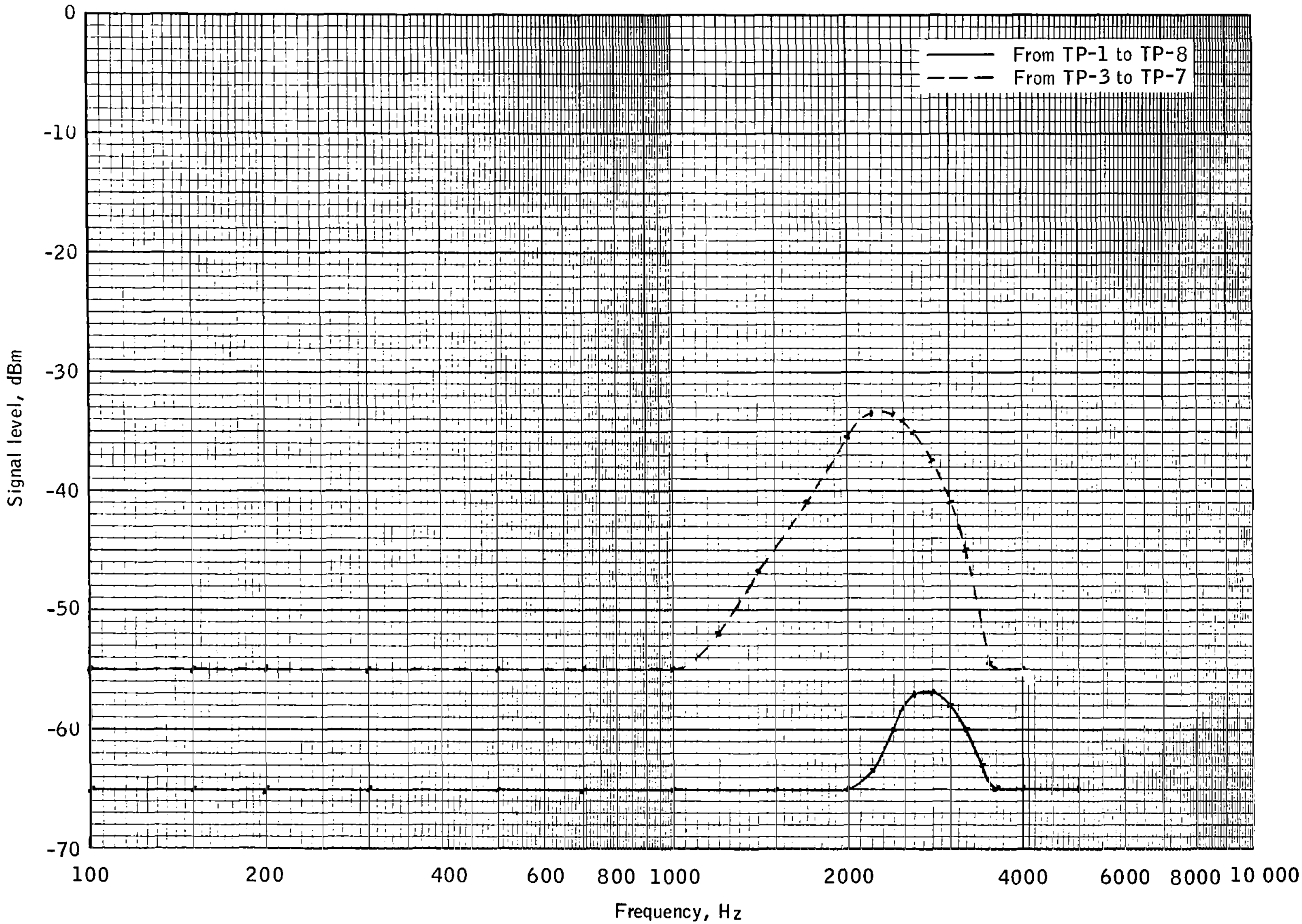

Figure 11. - Crosstalk between teleprinter and voice channels (from TP-1 to TP-8 and from TP-3 to TP-7).

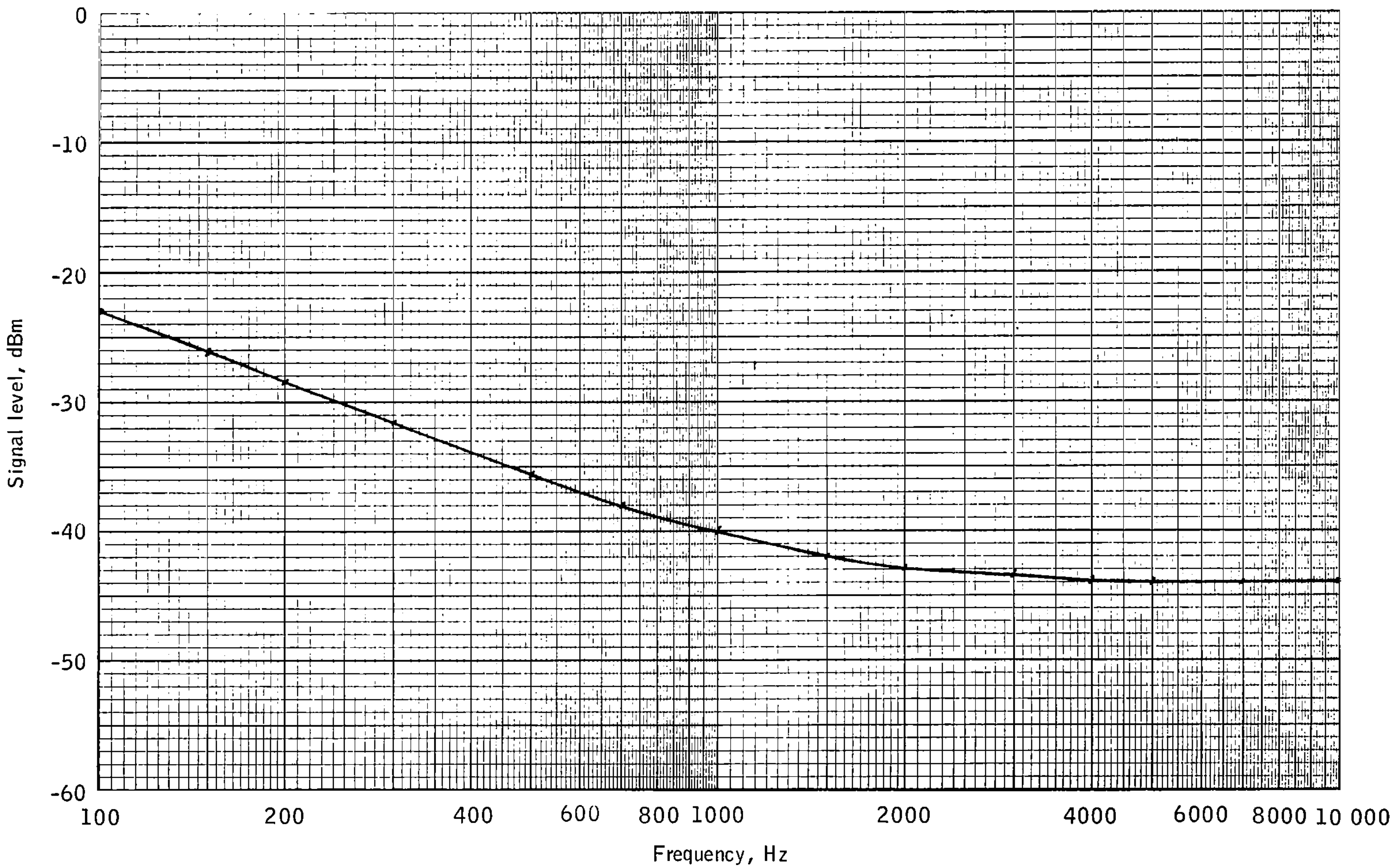

Figure 12. - Crosstalk between the two mixer inputs (from TP-2 to TP-4).

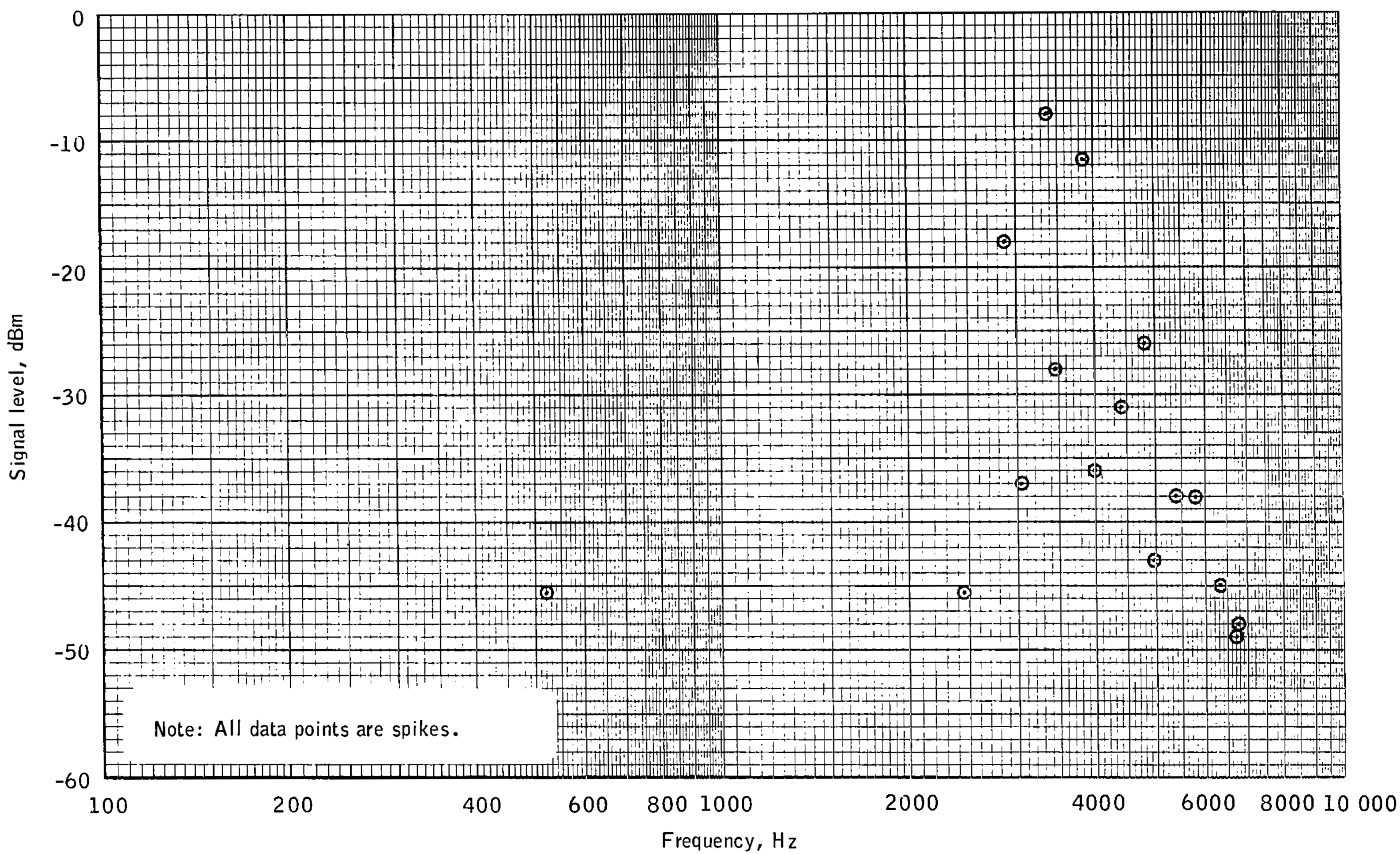

Figure 13. - Signal spectrum at TP-5 with modulator set at 500 hertz.

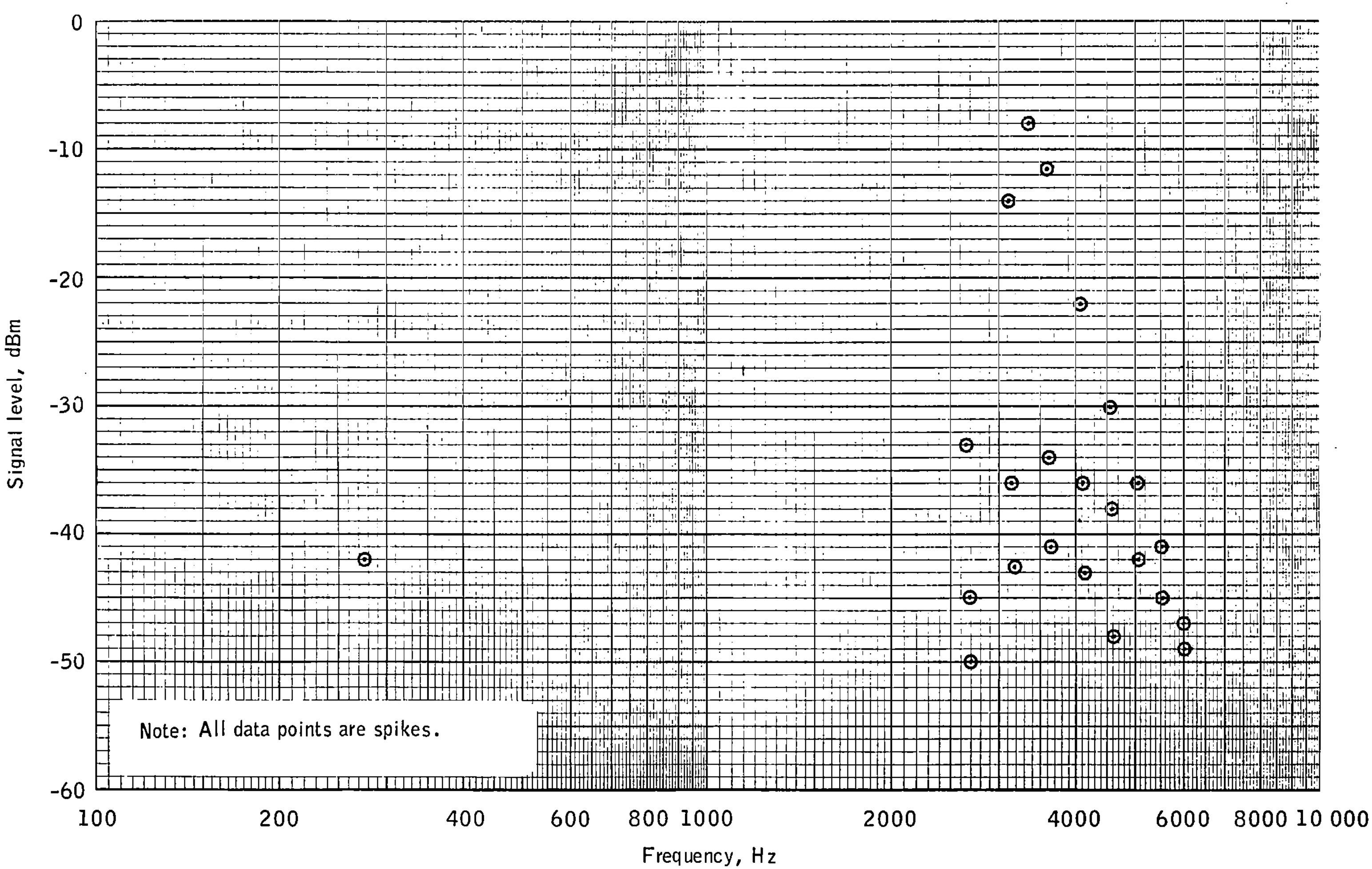

Figure 14. - Signal spectrum at TP-5 with modulator set at 250 hertz.

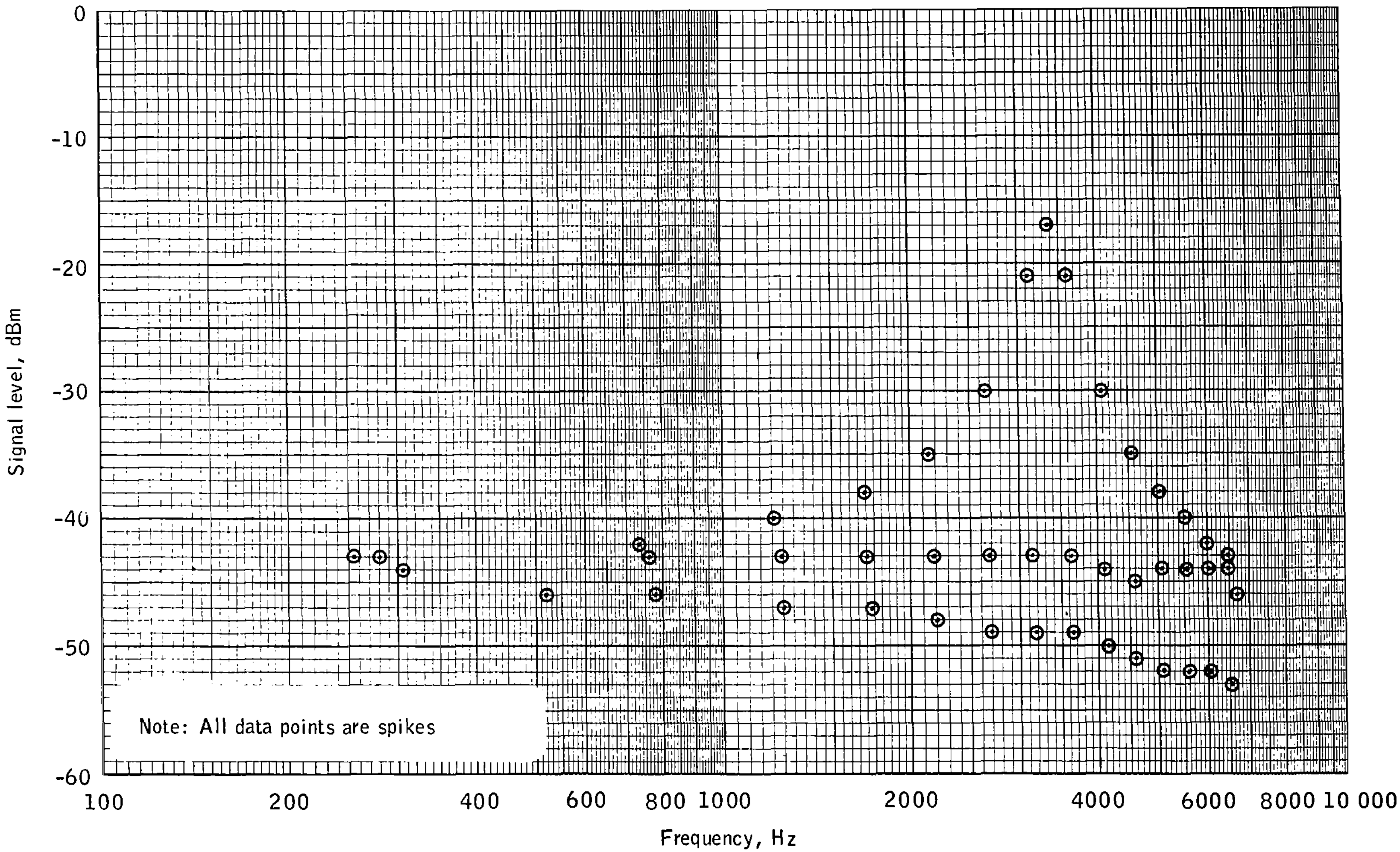

Figure 15. - Signal spectrum at TP-1 with modulator set at 250 hertz.

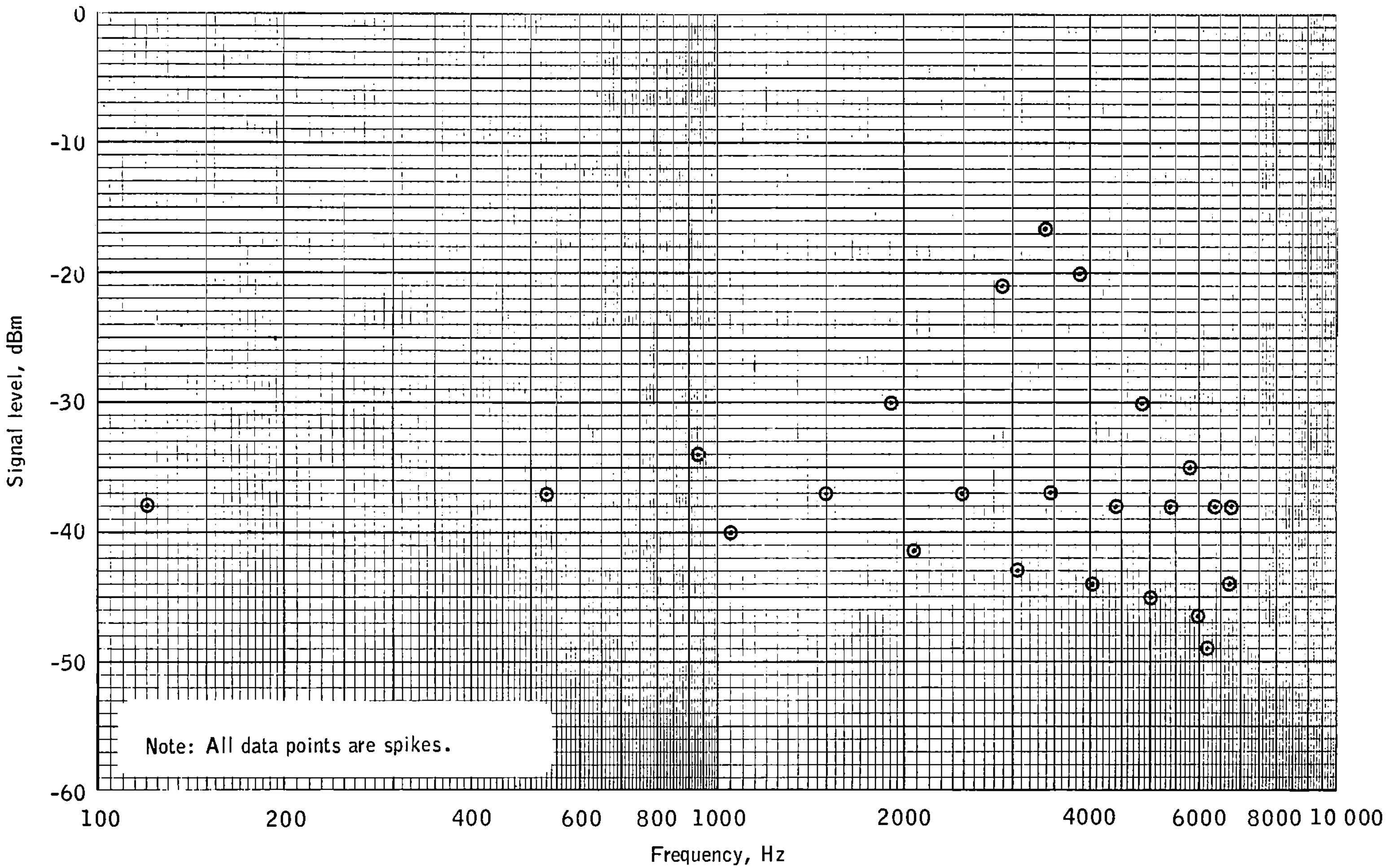

Figure 16. - Signal spectrum at TP-1 with modulator set at 500 hertz.

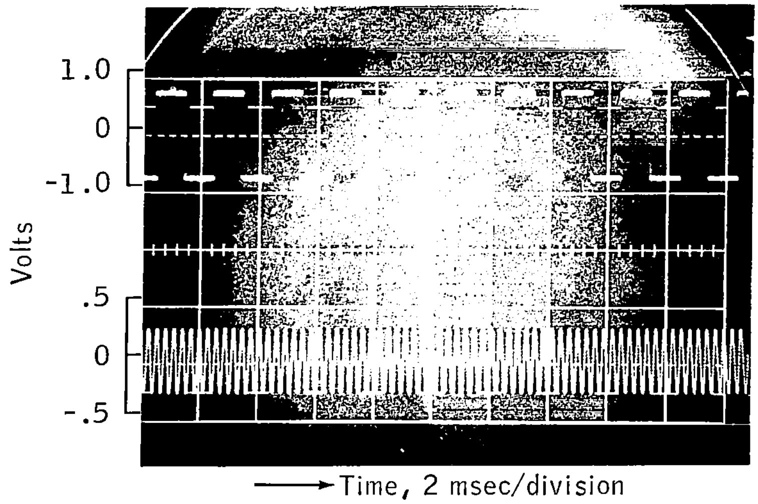

Figure 17. - Upper trace: 500-hertz modulating square wave; lower trace: 3350-hertz carrier signal.

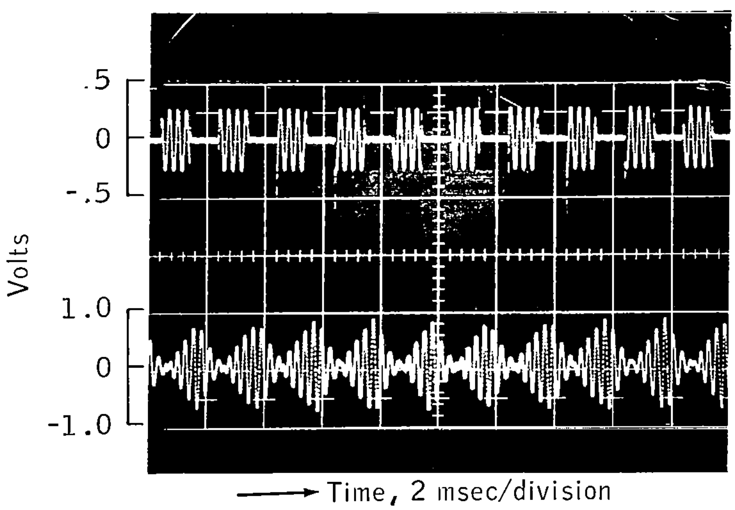

Figure 18. - Upper trace: 1000 bps at modulator output (TP-1); lower trace: 1000 bps at mixer input (TP-2). Carrier frequency of 3350 hertz.

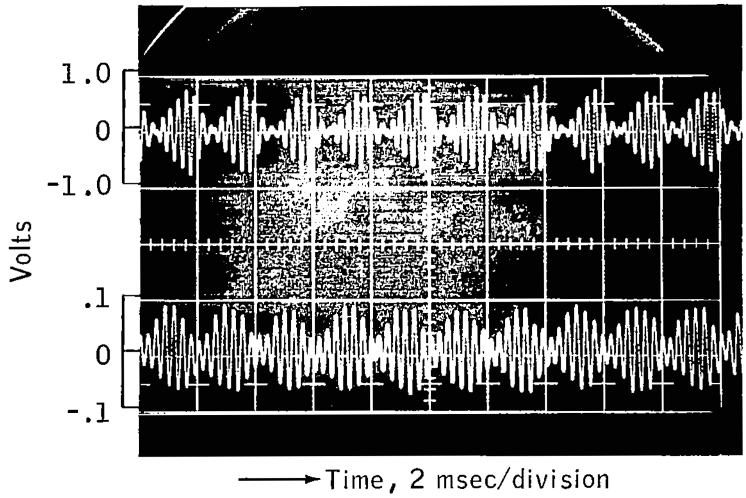

Figure 19. - Upper trace: 1000 bps at mixer input (TP-2); lower trace: 1000 bps at voice line output (TP-6). Carrier frequency of 3350 hertz.

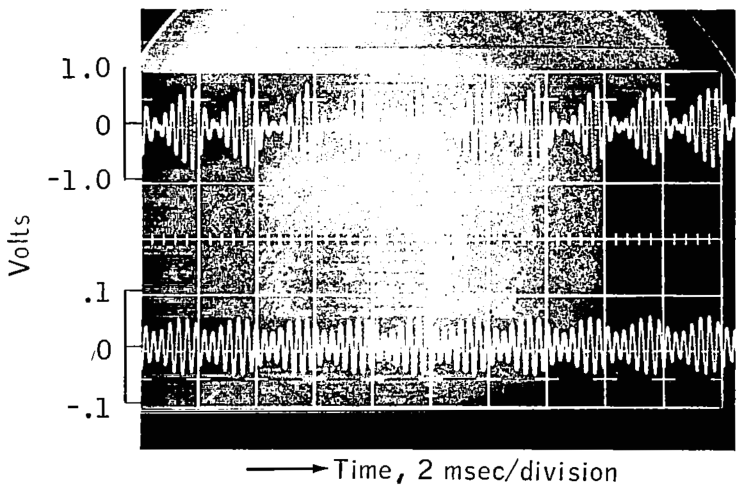

Figure 20. - Upper trace: 1000 bps at mixer input (TP-2); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

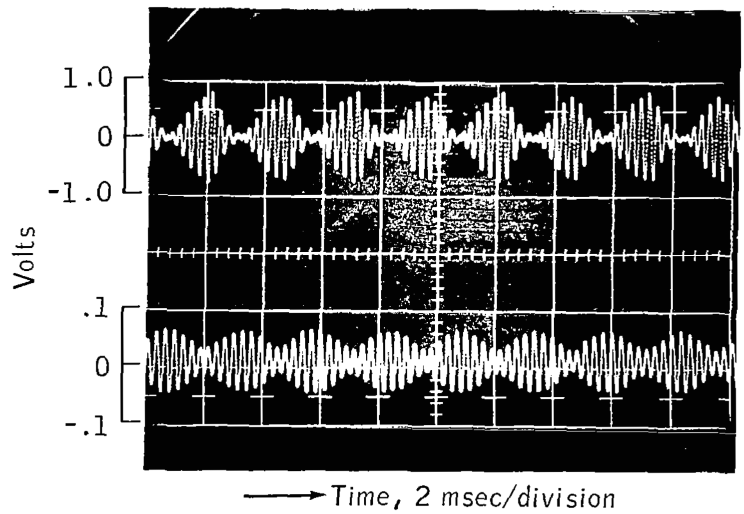

Figure 21. - Upper trace: 800 bps at mixer input (TP-2); lower trace: 800 bps at data output (TP-7). Carrier frequency of 3350 hertz.

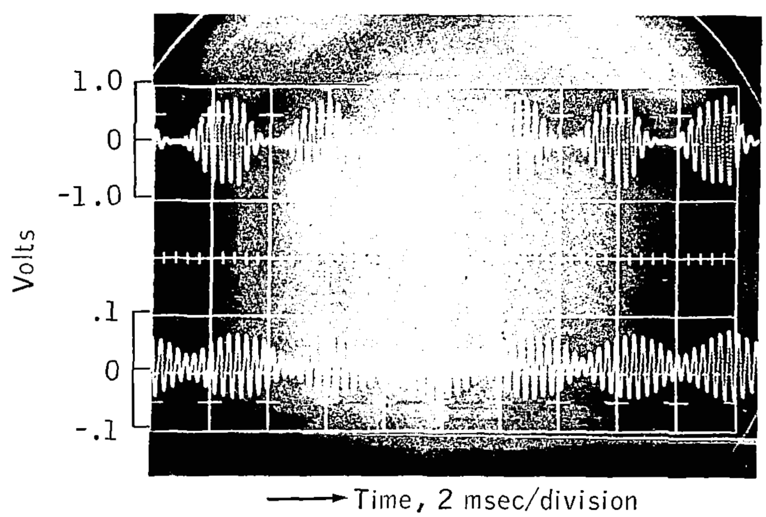

Figure 22. - Upper trace: 600 bps at mixer input (TP-2); lower trace: 600 bps at data output (TP-7). Carrier frequency of 3350 hertz.

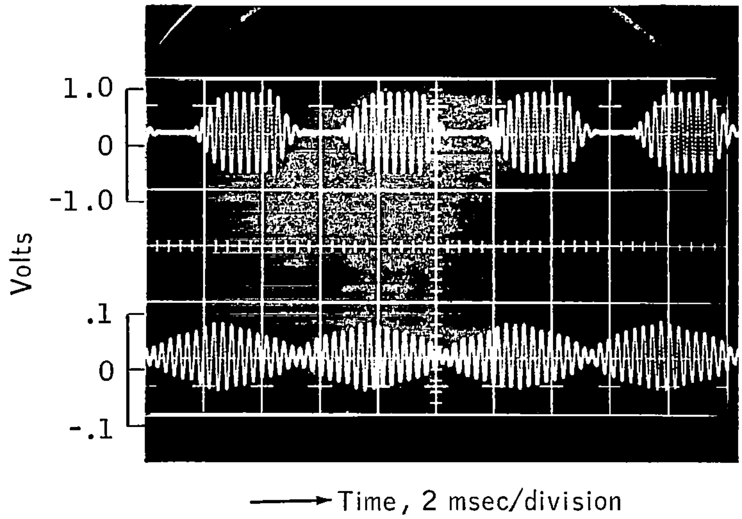

Figure 23. - Upper trace: 500 bps at mixer input (TP-2); lower trace: 500 bps at data output (TP-7). Carrier frequency of 3350 hertz.

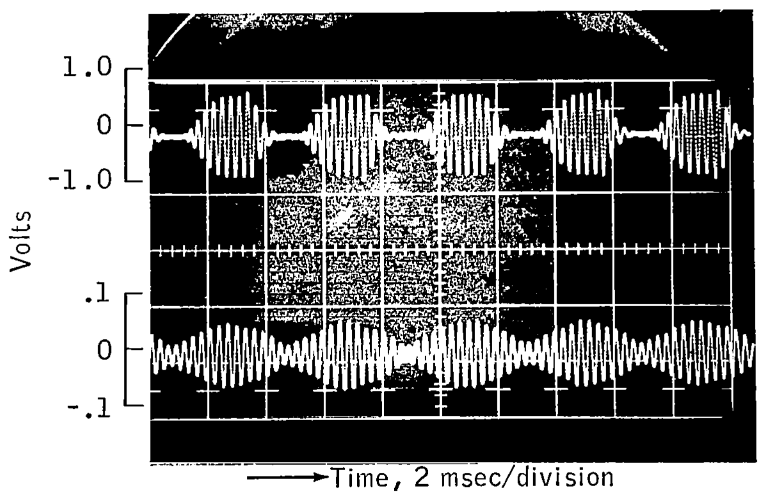

Figure 24. - Upper trace: 400 bps at mixer input (TP-2); lower trace: 400 bps at data output (TP-7). Carrier frequency of 3350 hertz.

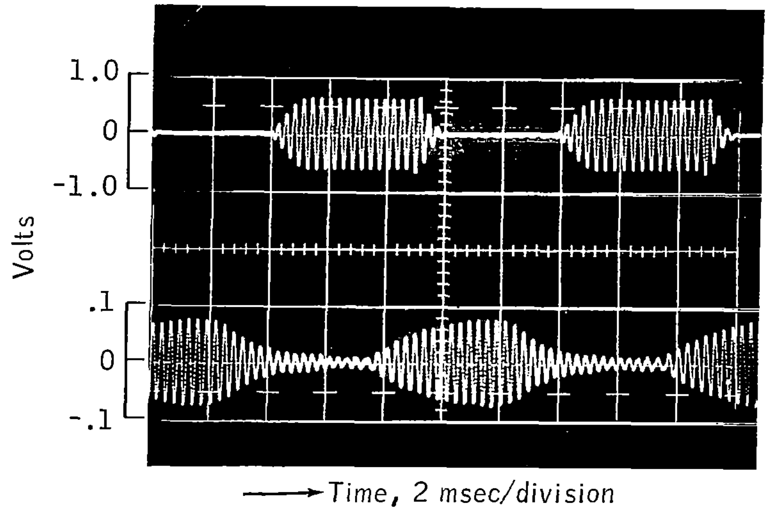

Figure 25. - Upper trace: 200 bps at mixer input (TP-2); lower trace: 200 bps at data output (TP-7). Carrier frequency of 3200 hertz.

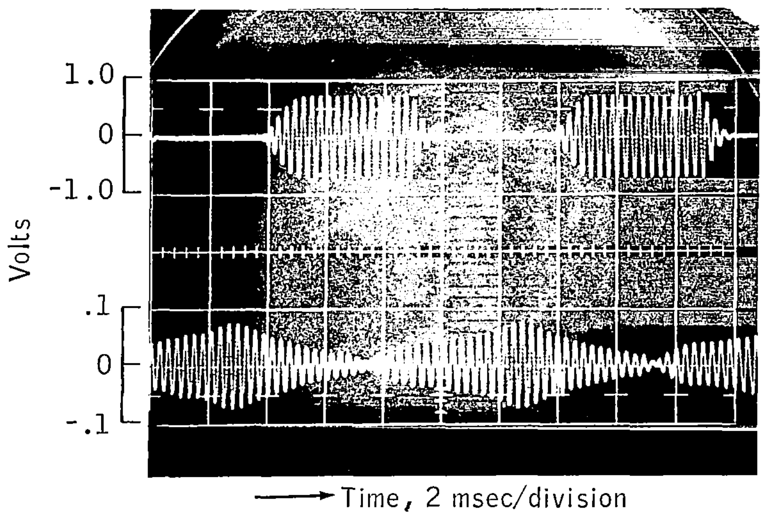

Figure 26. - Upper trace: 200 bps at mixer input (TP-2); lower trace: 200 bps at data output (TP-7). Carrier frequency of 3350 hertz.

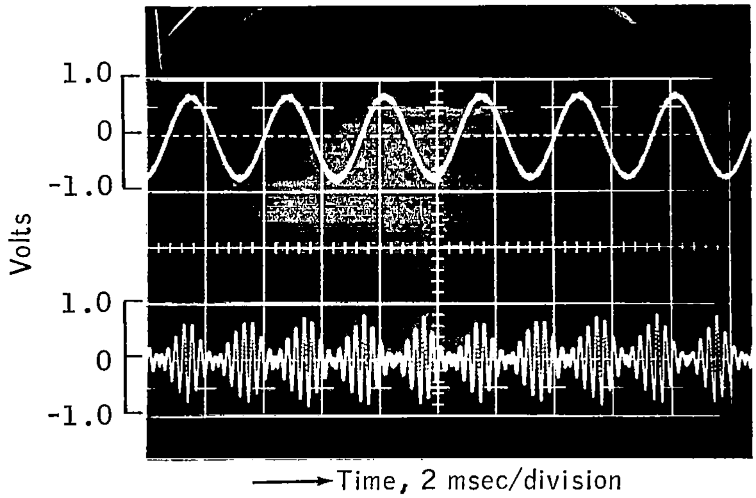

Figure 27. - Upper trace: 300-hertz audio at mixer input (TP-4); lower trace: 1000 bps at mixer input (TP-2). Carrier frequency of 3350 hertz.

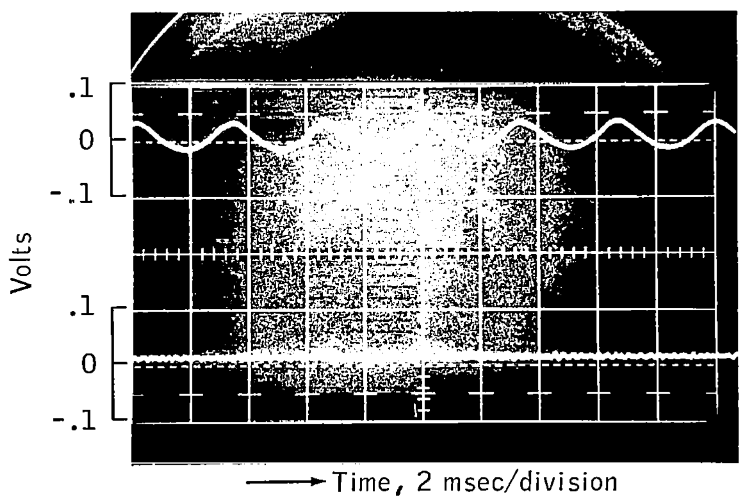

Figure 28. - Upper trace: 300-hertz audio at audio output (TP-8); lower trace: no data input at mixer input (TP-7).

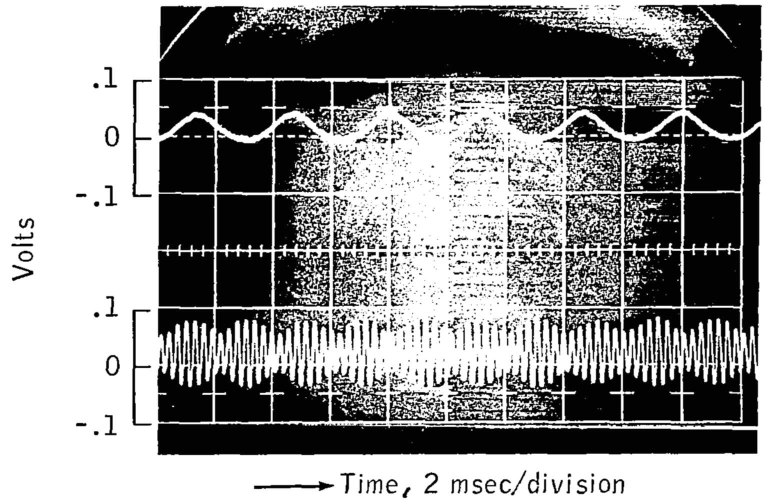

Figure 29. - Upper trace: 300-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

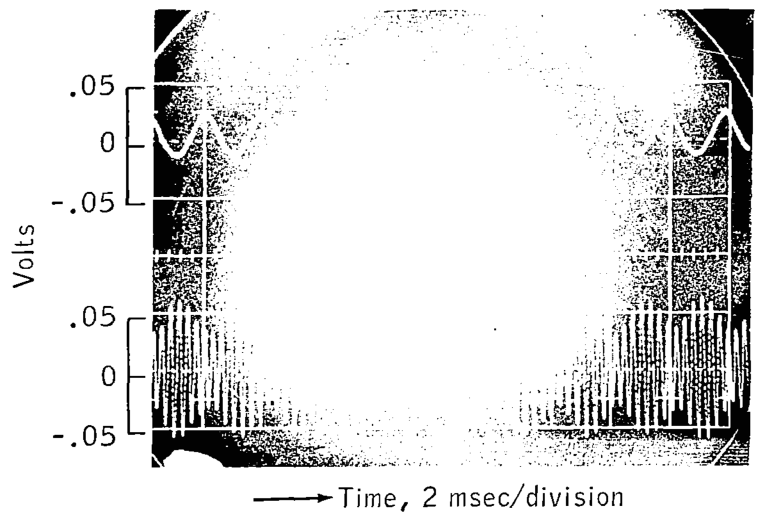

Figure 30. - Upper trace: 500-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

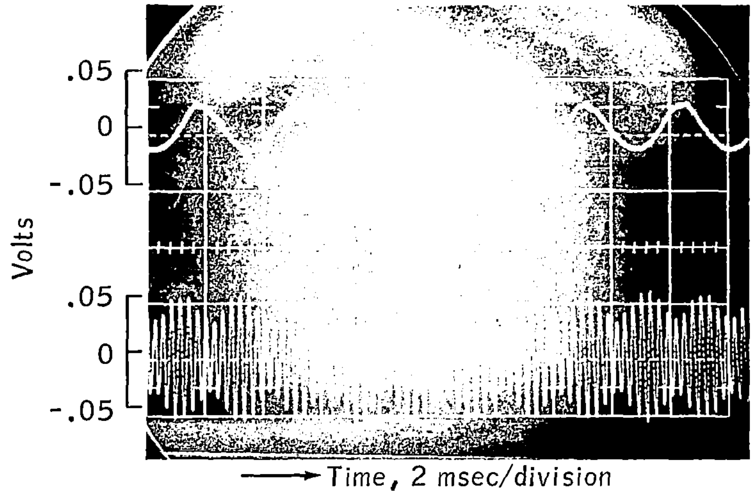

Figure 31. - Upper trace: 300-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz; expanded scale.

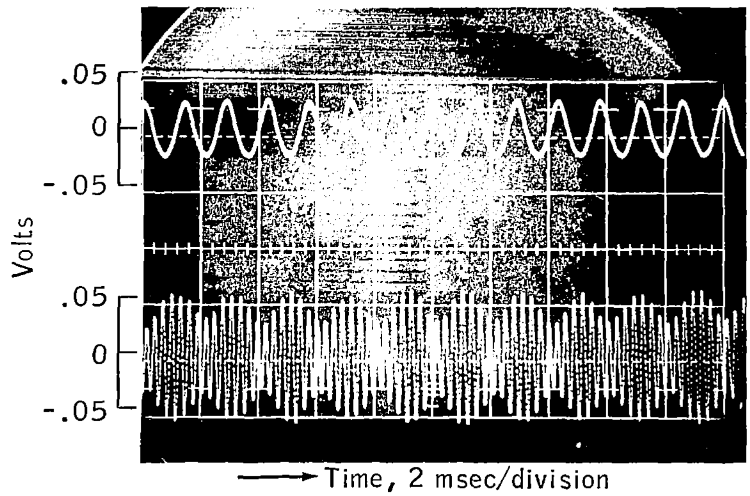

Figure 32. - Upper trace: 700-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

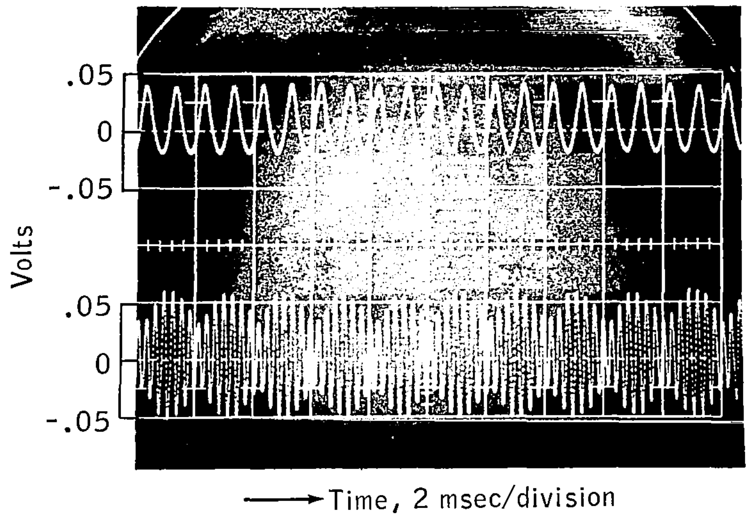

Figure 33. - Upper trace: 1000-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

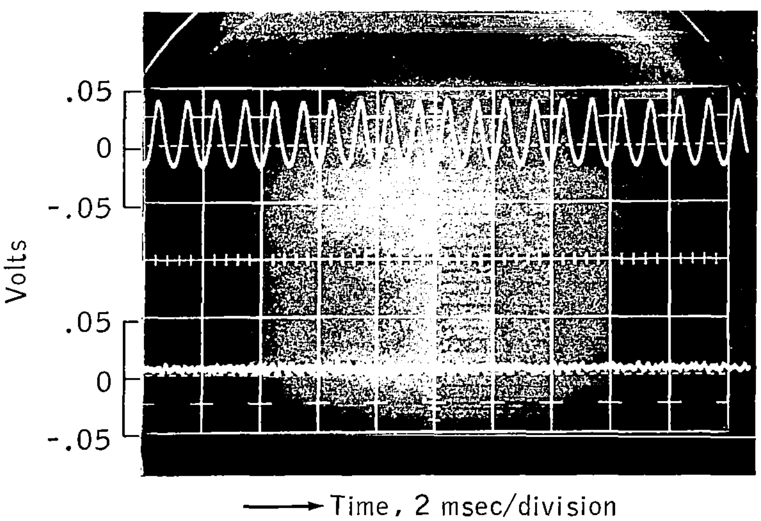

Figure 34. - Upper trace: 1000-hertz audio at audio output (TP-8); lower trace: no data input at mixer (TP-7).

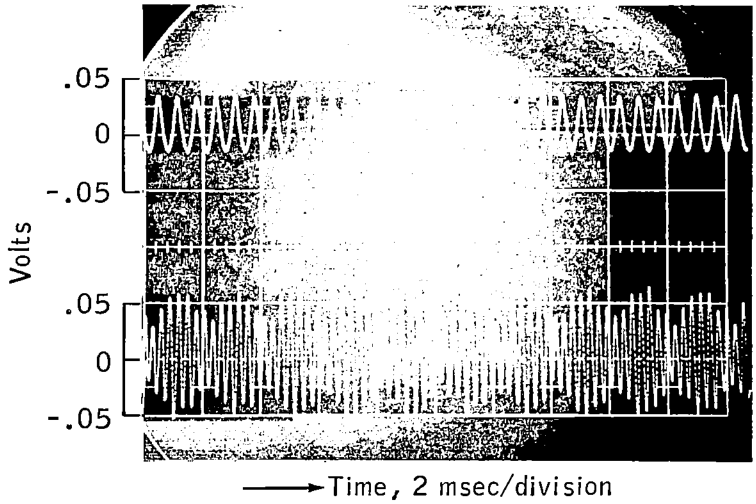

Figure 35. - Upper trace: 1500-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

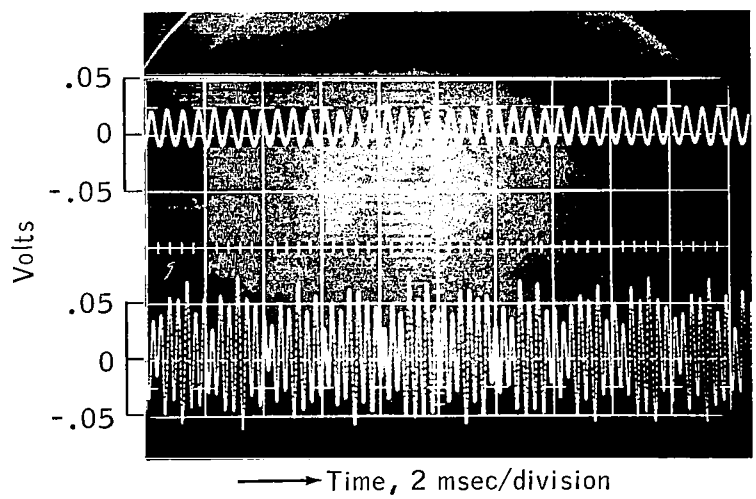

Figure 36. - Upper trace: 1850-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

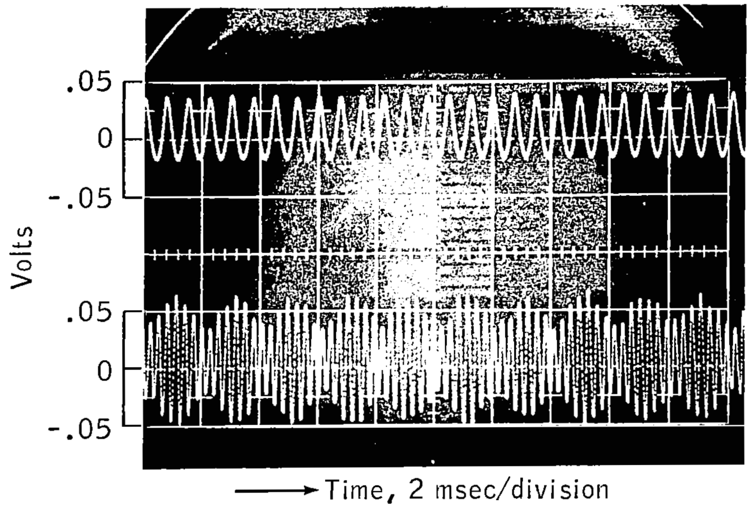

Figure 37. - Upper trace: 1350-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

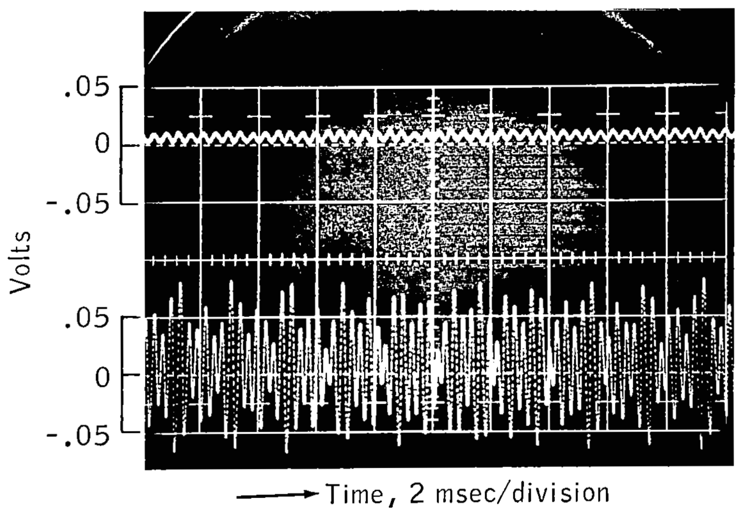

Figure 38. - Upper trace: 2350-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

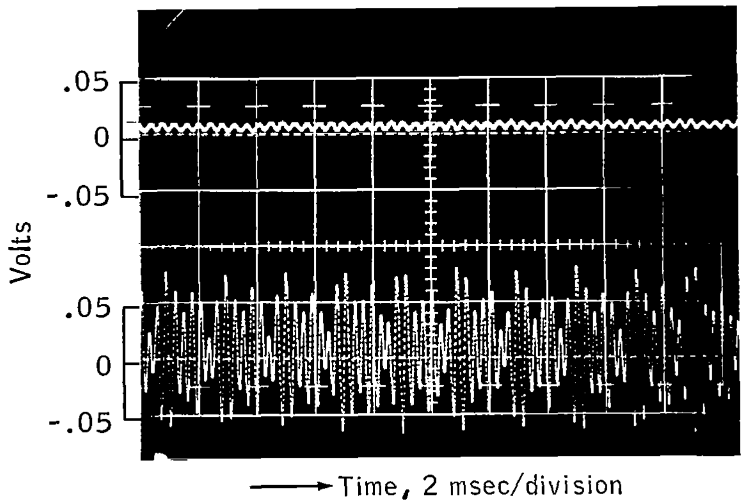

Figure 39. - Upper trace: 2400-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

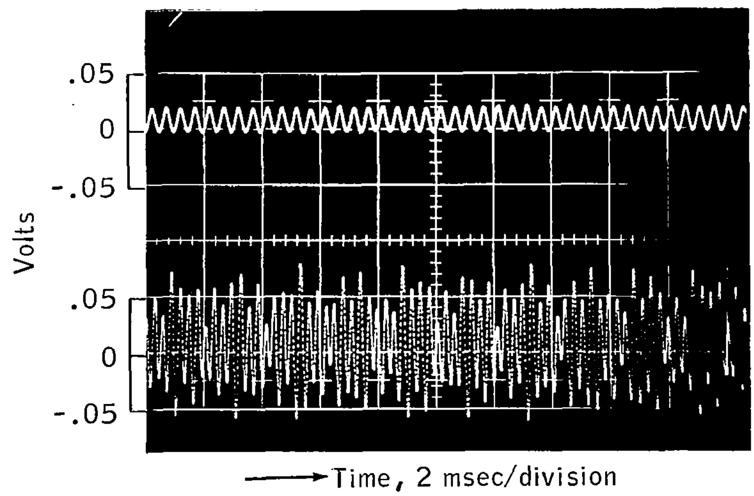

Figure 40. - Upper trace: 2000-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

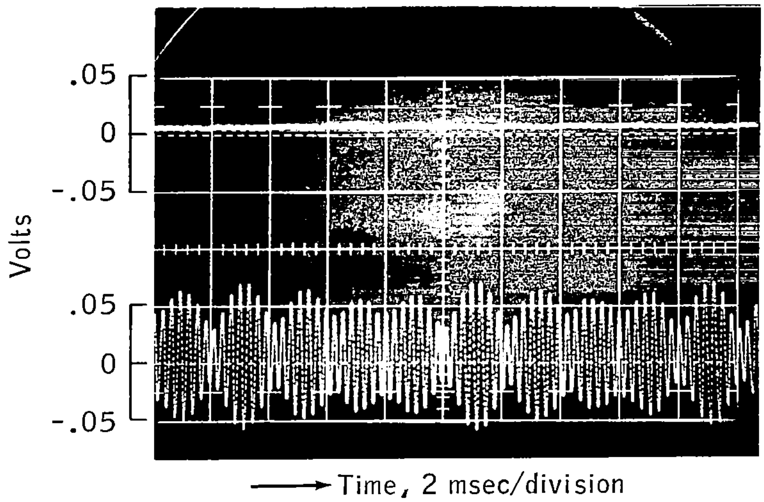

Figure 41. - Upper trace: 3000-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

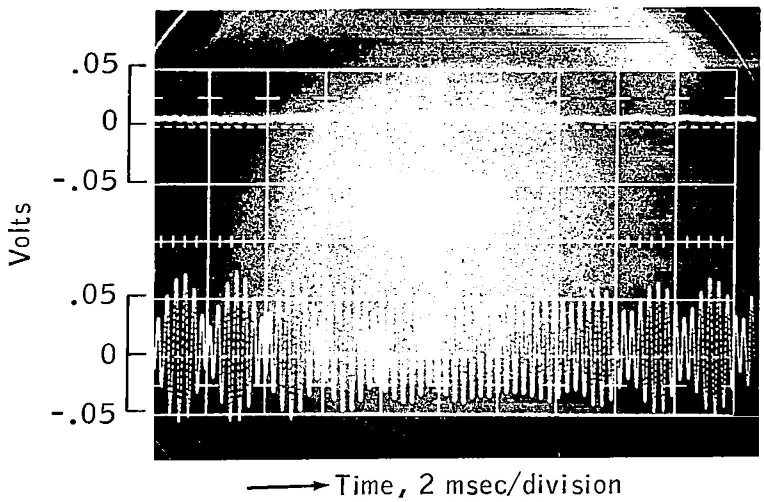

Figure 42. - Upper trace: 2850-hertz audio at audio output (TP-8); lower trace: 1000 bps at data output (TP-7). Carrier frequency of 3350 hertz.

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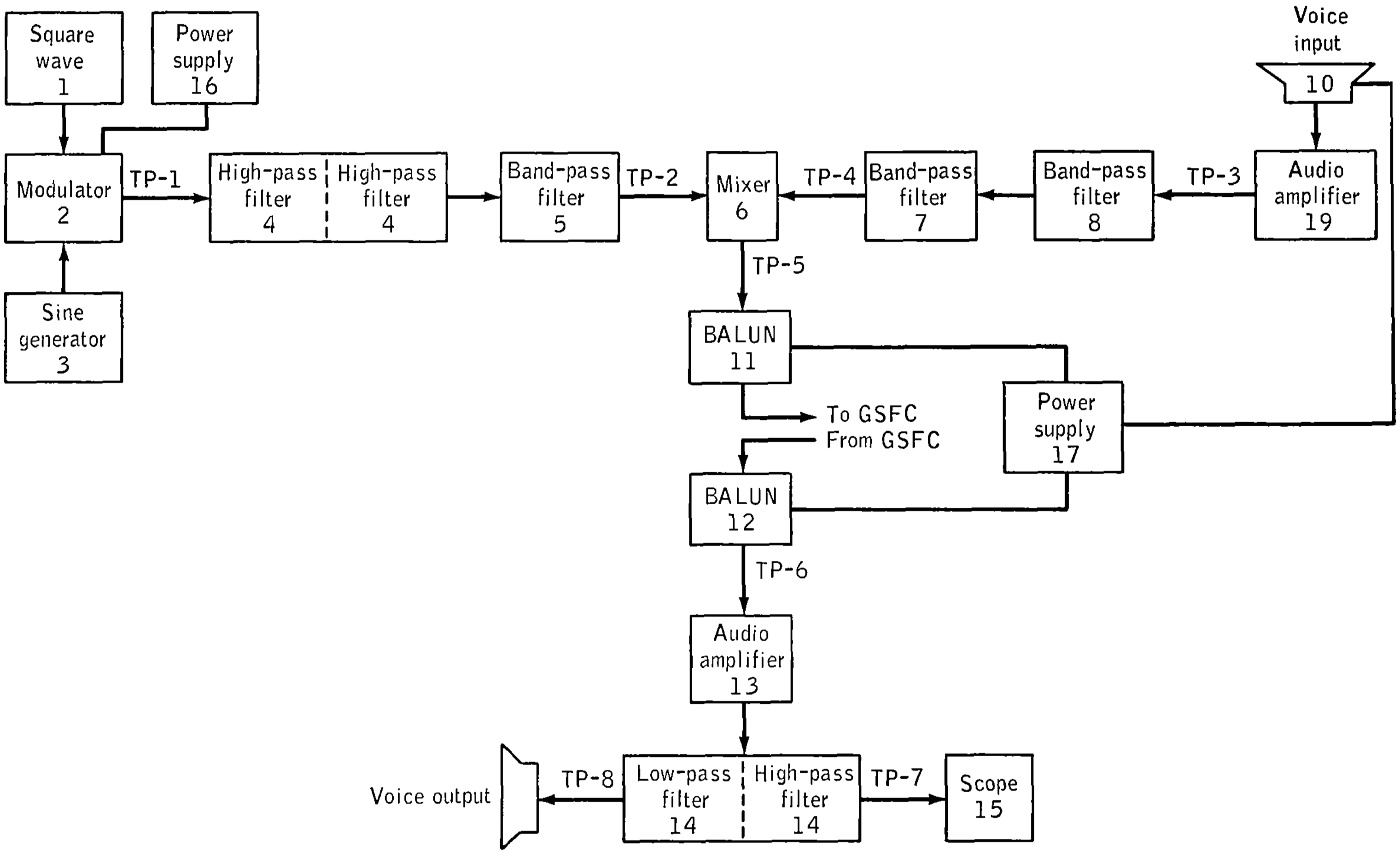

Figure 43. - Equipment layout.

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