DOUBLE SIDEBAND SUPPRESSED CARRIER TELEMETRY SYSTEM[1]

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Summary Vibration, shock, and acoustic data constitute one of the principal requirements for wideband telemetry. In order to permit a quantitative comparison of DSB/FM with the experimental results on constant bandwidth FM/FM for telemetry wideband noise-like data, a laboratory investigation has been conducted at WSMR. This paper reports experimental data on RF spectrum occupancy, intermodulation, performance against thermal noise, and some preliminary data on the effects of tape recording.

Introduction Based on a survey of the requirements of principal users, desired telemetry systems characteristics for shock, vibration, and acoustic measurements have been compiled by an SAE subcommittee and reported by H. Himelblau (1). Vibration and acoustic data are noise-like and display large crest factors. Analysis of the data link optimumization for this type of data have been published by several writers (2, 3). The EMR FM/FM baseband structures study (4) provides data for FM/FM proportional and constant bandwidth formats. The accompanying paper by M. H. Nichols includes an interpretation of the data presented herein and insofar as possible compares the DSB/FM data with the FM/FM data of reference 4. Many of the results are also applicable to SSB/FM subject to certain restrictions relative to pilot tone, etc.

DSB Test Hardware The DSB test equipment consists of ten channels spaced 8 kc apart, running from 16 kc to 88 kc.[2] Each channel is modulated by a 3 kc pilot tone which provides power for subcarrier recovery when no data are present and also provides a reference level for individual channel AGC. The latter provides “closed loop” channel gain standardization. The 3 kc pilot tone is also modulated directly on the carrier to serve as the reference for a “fast acting” AGC loop. A detailed description of this equipment is given in references 5 and 6.

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[1] This work was supported by White Sands Missile Range under Contract No. DA-29-040-AMC-1293(R).

[2] This equipment was purchased from Dynatronics, an Operation of the Electronics Division of General Dynamics.

Spectrum Occupancy Tests For the spectrum occupancy tests and all other tests unless otherwise stated, each channel was modulated by white thermal noise de-emphasized by a two stage RC filter with the 3 db point at approximately 1 kc. Four independent General Radio model 1390 noise generators were used with generator No. 1 modulating the 16 kc and 80 kc DSB channels, No. 2 modulating the 24, 56, and 88 kc channels, No. 3 modulating the 32, 48, and 72 kc channels, and No. 4 modulating the 40 kc and 64 kc channels. The 3 kc individual channel pilot tones were set 26 db down from the noise modulation level which was 1.6 vrms. The 3 kc pilot tone directly modulated on the carrier was 6 db down from the modulated data channels. Two subcarrier tapers were used. One was flat and the other was 6 db per octave pre-emphasized with breakpoint at 23 kc. This breakpoint gives constant S/N in the ten DSB channel outputs at an IF signal-to-noise ratio of 12 db in a 500 kc IF bandwidth. The spectral power in a 3 kc bandwidth was measured with a Hewlett Packard model 310A wave analyzer. Figure 1 is a block diagram of the set up.

An EMR model 121D FM transmitter at 256 Mc carrier frequency was used. Figure 2 shows the modulation characteristics of the transmitter obtained by the carrier disappearance method. The deviation sensitivity in the linear range is 89.5 kc per volt. Out to ± 200 kc peak deviation, the modulation frequency response is flat within -1 db for modulations of 3 kc to 90 kc. Figure 3 shows the RF spectra corresponding to 110 kc rms and 78 kc rms deviations with all data channels fully loaded with random noise input and using a flat subcarrier taper. Note that the IRIG 40 db down requirement at ±320 kc is satisfied and the 55 + 10 log P_t requirement at ±500 kc is satisfied for a 3 watt transmitter. Thus, a principal result of the WSMR experiment is that with 10 channels of 2 kc data bandwidth, the link can be modulated 110 kc rms with a flat taper and satisfy the IRIG 106-66 spectrum occupancy standards. Figure 3 shows, superimposed in dashed lines, the spectra with all data channel inputs removed so that only the individual channel pilot tones and the fast AGC pilot tone at 3 kc in the baseband remain. Note that the airborne AGC maintains the transmitter input essentially constant on an rms basis because the two rms values of the deviations remain essentially constant. Since the level of the 3 kc baseband tone is 20 db higher than the individual channel pilot tones, the modulation for the dashed spectra of Figure 3 is mostly due to the 3 kc baseband tone. The modulation index for the tone is therefore very high accounting for the two “rabbit ears.” The dashed spectra of Figure 3 are well within the IRIG 106-66 spectrum occupancy standards.[3] In order to allow for frequency drift, etc., the other tests in this paper were all run at 78 kc rms.

Figure 4 shows the spectra for the 6 db/octave subcarrier pre-emphasis taper with breakpoint at 23 kc. The solid lines again are for all channels fully modulated with 1.6

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[3] It might be noted that had the fast AGC pilot tone been placed at, say, 100 kc, the spectrum would be much wider.

vrms noise. The rms carrier deviations are noted on the graph. Dashed lines depict the corresponding spectra with all data channel inputs removed so that only the individual channel pilot tones and the 3 kc baseband tone remain giving rms carrier deviations of 63 and 45 kc rms. These spectra also satisfy the IRIG 106-66 spectrum occupancy standards.

Intermodulation and Noise Effects Initially, an attempt was made to locate a telemetry receiver with intermodulation characteristics similar to the one used for the EMR FM/FM baseband structure study, reference 4. This proved to be impractical and a DEI model TR-711 receiver was finally selected for the evaluation. Several 500 kc IF plug-in strips were tested, and the one showing the least intermodulation effects was chosen. Figure 5 is a plot of the measured 500 kc IF attenuation and time delay variation characteristics. As discussed in the following, the notch noise test method for intermodulation measurement is extensively used in our measurements; however, in order to compare with the results of reference 4, total harmonic distortion and two tone intermodulation distortion data were taken using the EMR model 121D transmitter and the DEI receiver. Figures 6 and 7 give the results for total harmonic distortion and two tone intermodulation caused by even harmonic distortion. These may be compared with the corresponding EMR results in reference 4.

The notch noise test method was used extensively for results reported in this paper. This method has been in use for a long time in frequency division multiplexed commercial communications systems, and excellent test equipment for a wide variety of frequency bands is commercially available. The Marconi model OA-2090 white noise test set was used for the results reported herein. Four notch filter pairs at 14 kc, 34 kc, 70kc and 105 kc were used. Figure 8 provides a graphic representation of the test method, and reference 7 gives a more detailed explanation of the technique. The notch noise input spectrum was limited to the band between 12 kc and 108 kc. Figure 9 gives the results of the notch noise test with a flat taper using the EMR transmitter and the DEI receiver. The abscissa is the baseband frequency and the ordinate is the ratio of the output of the notch noise tester with notch out to with notch in. The parameter for the different curves is $(S/N)_c$, the signal-to-noise ratio in the 500 kc IF. This ratio was measured with the receiver AGC clamped at -4 volts. The method of measurement consisted of measuring the output with noise alone and then adding enough signal to increase the output by 3 db. This establishes the zero db signal level. Figure 9 shows the receiver is above threshold across the baseband at 12 db $(S/N)_c$ because an increase of 3 db in $(S/N)_c$ to 15 db everywhere increases the output S/N by 3 db. Note also that for the very large $(S/N)_c$ of 39 db, the output S/N is limited by intermodulation. Comparison with Figure 75 of reference 8, which was taken with a "super" linear transmitter, indicates that the intermodulation at the high frequency end is caused by delay variation in the IF and the intermodulation at the low end by static non-linearity in the radio transmitter. Figure 10 is a corresponding plot for a 6 db/oct. pre-emphasis with breakpoint at 23 kc.

Figure 11 gives a comparison of the DSB channels of approximately the same frequency as the three lowest notch frequencies. The ten DSB channels were fully modulated with the four noise generators each at 1.6 vrms. All data were taken with 78 kc rms carrier deviation, and data with and without the pre-emphasized taper are shown. The dashed linear characteristic shown represents above threshold performance in the absence of intermodulation. The DSB characteristic lies above the notch noise characteristic in the linear range because with the data input noise spectrum, which has a 12 db/octave de-emphasis with breakpoint at approximately 1 kc, the DSB modulated spectrum occupies only about 1/6 of the 96 kc notch noise tester baseband. For this reason, the DSB characteristic without carrier modulation pre-emphasis should lie about 8 db above the notch noise characteristic which is in approximate agreement with the data. In the carrier modulation pre-emphasis case, the fact that the notch noise test baseband spectrum runs out to 108 kc results in relatively more suppression of the lower frequencies, so the DSB data should lie several db more than 8 db above the notch noise data since the rms value of the transmitter deviation is held constant.

Because of the fact that the baseband spectrum of the DSB is centered in approximately 2 kc bands around each center frequency and because each center frequency is a multiple of 8 kc, the effects of intermodulation on DSB will be some different than in the notch noise test. For example, with third harmonic distortion, the 24 kc channel, the pairs of channels 48 and 24, 56 and 40, 64 and 56, and the triplet 16, 24, and 32 all contribute interference to the 72 kc channel. Also, with second harmonic distortion, the pair 32 and 40 contribute intermodulation to 72kc. As can be seen from references 3 and 8, intermodulation power resulting from delay distortion is proportional to the square of the frequency of the intermodulation products, so that it is to be expected that the high frequency subcarriers such as 72 kc will display more intermodulation than the low, as is borne out in Figure 11. From Figure 11c, the two characteristics almost coincide at $(S/N)_c$ = 39 db, whereas in Figure 11a, there is about 6 db difference.

The manner in which the (S+N)/N ratio in the output of the DSB subcarrier channels was measured needs discussion. All the DSB channels were loaded with 1.6 vrms noise, representing the data signal, as previously discussed. Power output of the channel in question is then S + N. With removal of the data signal from the test channel input, the power output becomes N. The DSB channel output power density spectra for S + N and N were recorded in a 200 Hz bandwidth using a Honeywell model 9050 automatic wave analyzer.

Examination of the individual DSB channel output power spectrum recordings for large $(S/N)_c$ revealed that for the higher frequency channels, the power density near zero output frequency (i.e., in the fold over region of the analyzer bandpass filter) was 5 to 10 db higher than at 200 Hz to 300 Hz. By removing harmonically related DSB channels, this effect was removed. The effect is tentatively attributed to “leak-thru” in the airborne package of the subcarrier clocks, which are generated at four times subcarrier frequency and divided down. This is possibly caused by the wiring layout; i.e., it is not a fundamental DSB property. Figure 1 2 shows the power spectrum for the 72 kc channel output with pre-emphasis and with $(S/N)_c$ = 39 db and $(S/N)_c$ = 12 db in the 500 kc IF.[4] Note that for $(S/N)_c$ 39 db, there is 25 db attenuation in the signal plot which is removed for the noise plot, and for $(S/N)_c$ = 12 db, the corresponding attenuation is 15 db. In order to avoid this low frequency effect, the power measurements for the (S+N)/N ratios were made to the left of the rise in the spectrum near zero frequency.

It can also be noted from Figure 11 that for a $(S/N)_c$ = 12 db, the preemphasis used results in fairly constant (S+N)/N of 30 db in the output of the three DSB channels measured (all ten channels fully modulated).

Tape Effects Direct recorded DSB suffers degradation when recorded on tape due to four principal causes, namely additive noise, drop out, intermodulation and time base error.[5] As discussed in reference 3, if the phase lock loop used for subcarrier recovery is sufficiently wide to track the time base error, then this effect is eliminated. However, if $\epsilon(t)$ is the tracking error, then a multiplier of $\cos \epsilon(t)$ appears on the data. To the extent that $\cos \epsilon(t)$ departs from unity, a multiplicative error appears. Tape drop out is really an amplitude modulation of the output of varying depth and of relatively low frequency. The high speed AGC using the 3 kc baseband tone as reference is intended to remove this effect. There is no way with amplitude modulated subcarriers to suppress additive noise or intermodulation effects, other than to eliminate or reduce their causes.

With predetection recording, tape drop out effects are nearly eliminated by the limiter. Principal effects are additive noise, intermodulation, and flutter time base error. The additive noise and flutter are suppressed by the FM improvement, which depends on the carrier modulation index.

The test procedure used for evaluating the combined effects of the tape consists of putting a dc voltage into the DSB test channel, all other channels being modulated by 1.6 vrms noise as previously discussed, and measuring the rms value of the fluctuating component of the channel output. The part of this component due to time base error, which is multiplicative, is proportional to the dc input voltage. Table I gives the results using an Ampex FR-600 at 60 ips. For these results, the record/reproduce levels were set

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[4] Although the manufacturer specified the low pass output filter to be 3db down at 2 kc, it is actually 6 db down at 2 kc.

[5] Time base error is a result of speed variation in the tape as it passes over the record/playback heads. See reference 9.

at optimum values relative to intermodulation and additive noise. In all cases, the $(S/N)_c$ in the 500 kc receiver IF was 39 db.

TABLE I

TAPE RECORDER EFFECTS

40 kc Channel Modulation (vdc)	40 kc Channel Output AC Component (Noise): Receiver Input to DSB	Pre-Detect Playback	Post-Detect Playback
0. 5 vdc	. 03 vrms	. 035 vrms	. 05 vrms
1. 0 vdc	. 03 vrms	. 045 vrms	. 06 vrms
1. 5 vdc	. 03 vrms	. 075 vrms	. 07 vrms
2. 0 vdc	. 03 vrms	. 10 vrms	. 08 vrms
2. 5 vdc	. 03 vrms	. 145 vrms	. 10 vrms

Further tests with tape recording are planned in order to determine the time base error power spectrum and its effect relative to the bandwidth of the subcarrier recovery phase-lock loops.

Miscellaneous Tests were also run to determine static modulation linearity, frequency response, phase delay, and distortion of individual channels of the DSB test hardware. For these tests, all channels except the test channel were fully modulated with 1.6 vrms noise, and the $(S/N)_c$ in the 500 kc receiver IF was 39 db. Briefly, the departure of static modulation from the best straight line was 1.2% for the best channel to 3.2% for the worst channel. In all channels, the frequency response was down approximately 6 db at 2 kc with the 3 db point at approximately 1.4 kc. Tests showed that all but about 1 db of this attenuation was due to the low-pass output filter. The total harmonic distortion with an input frequency of 640 cps varied between 0. 9% for the best channel tb 1. 8 for the worst.

It should be pointed out that these particular results are characteristic of the DSB test equipment utilized and at this time, cannot be said to be fundamental limitations of the DSB method.

Acknowledgments The author is indebted to many people for assistance in planning and performing these tests. He is particularly indebted to Dr. M. H. Nichols, J. D. Cates, and J. K. Baird for their contributions and extends his thanks to 0. L. Berge and G. R. Ford for their outstanding job in taking the data contained herein.

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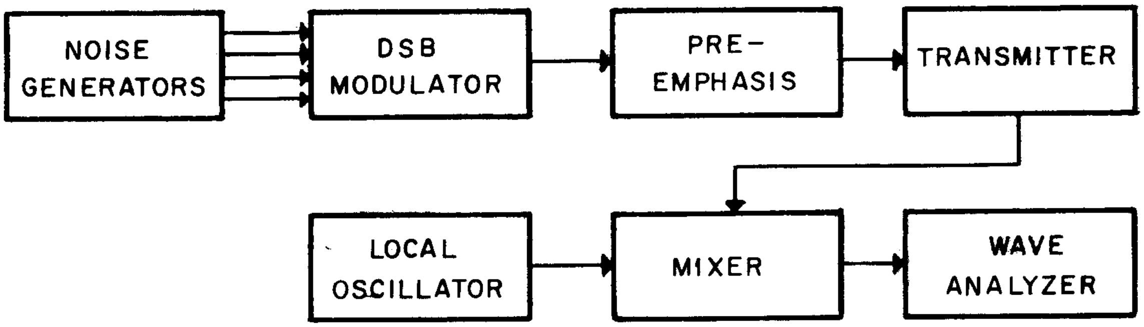


Fig. 1 - Block Diagram for Spectrum Occupancy Measurement

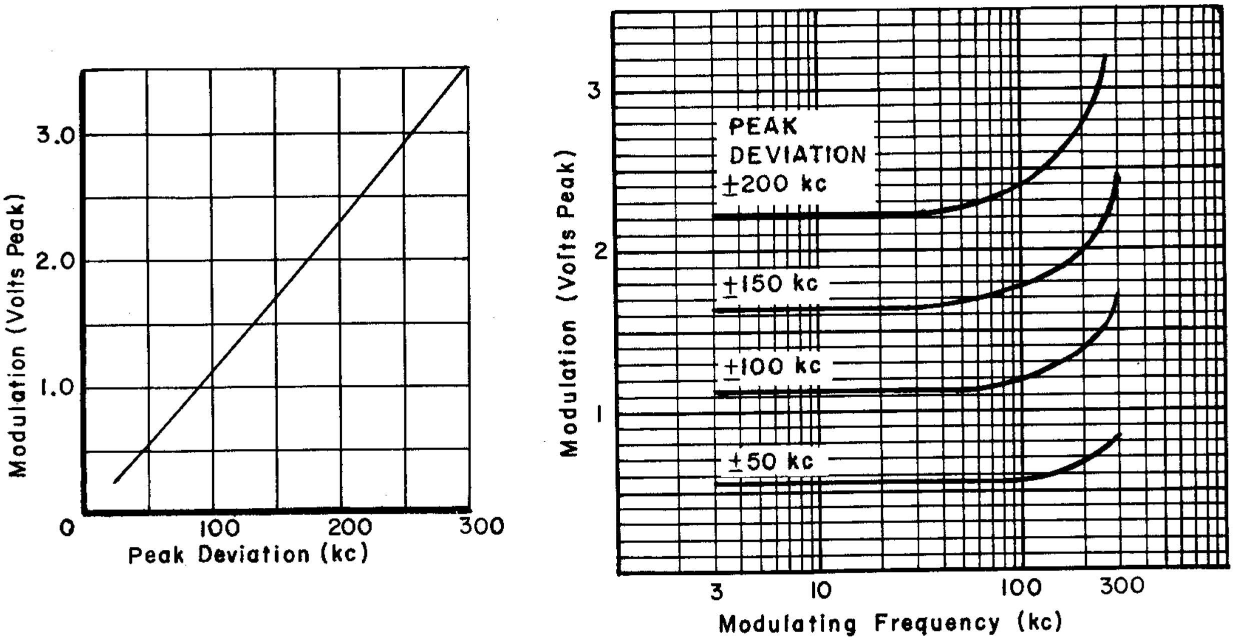


Fig. 2 - Transmitter Modulation Characteristics

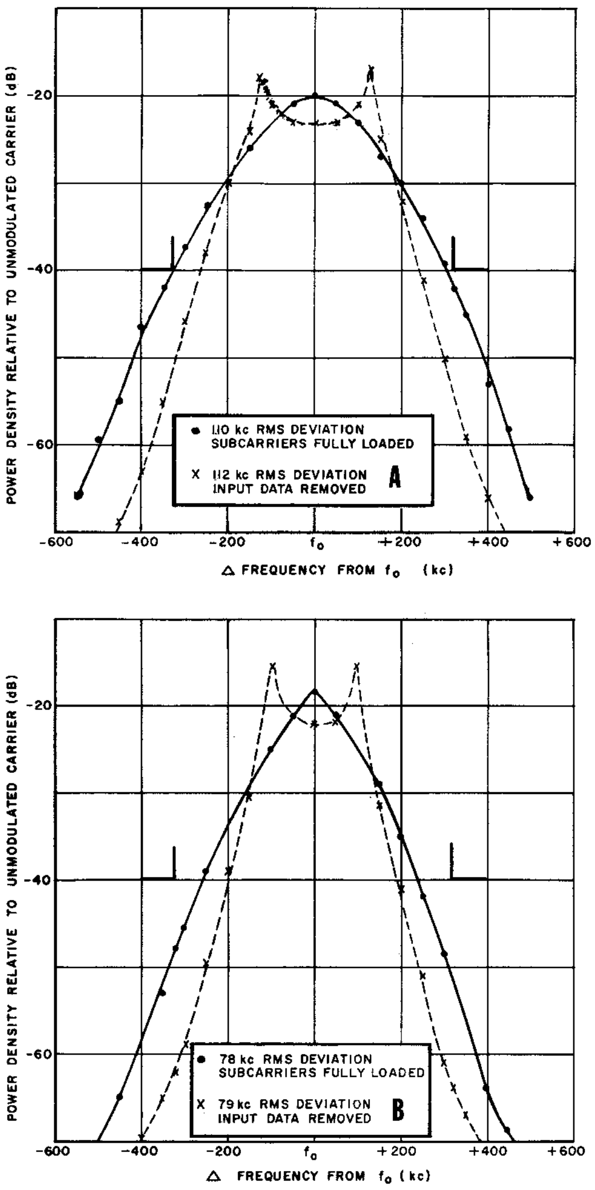


Fig. 3 - Radiated Spectrum - Flat Subcarrier Taper

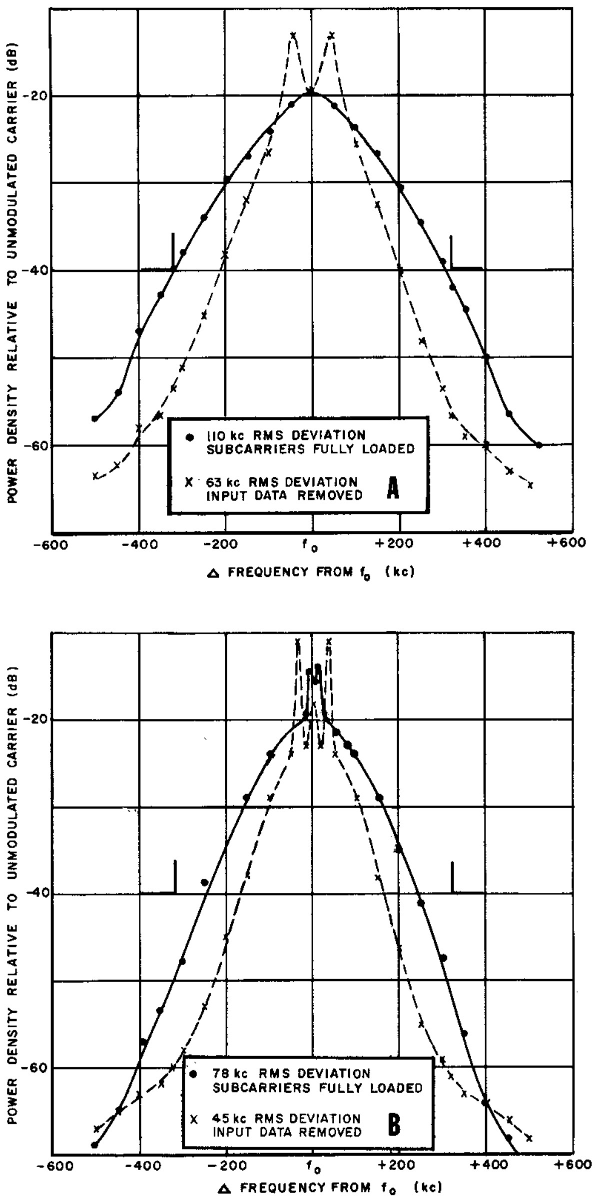


Fig. 4 - Radiated Spectrum - 6 db/Octave Pre-emphasis

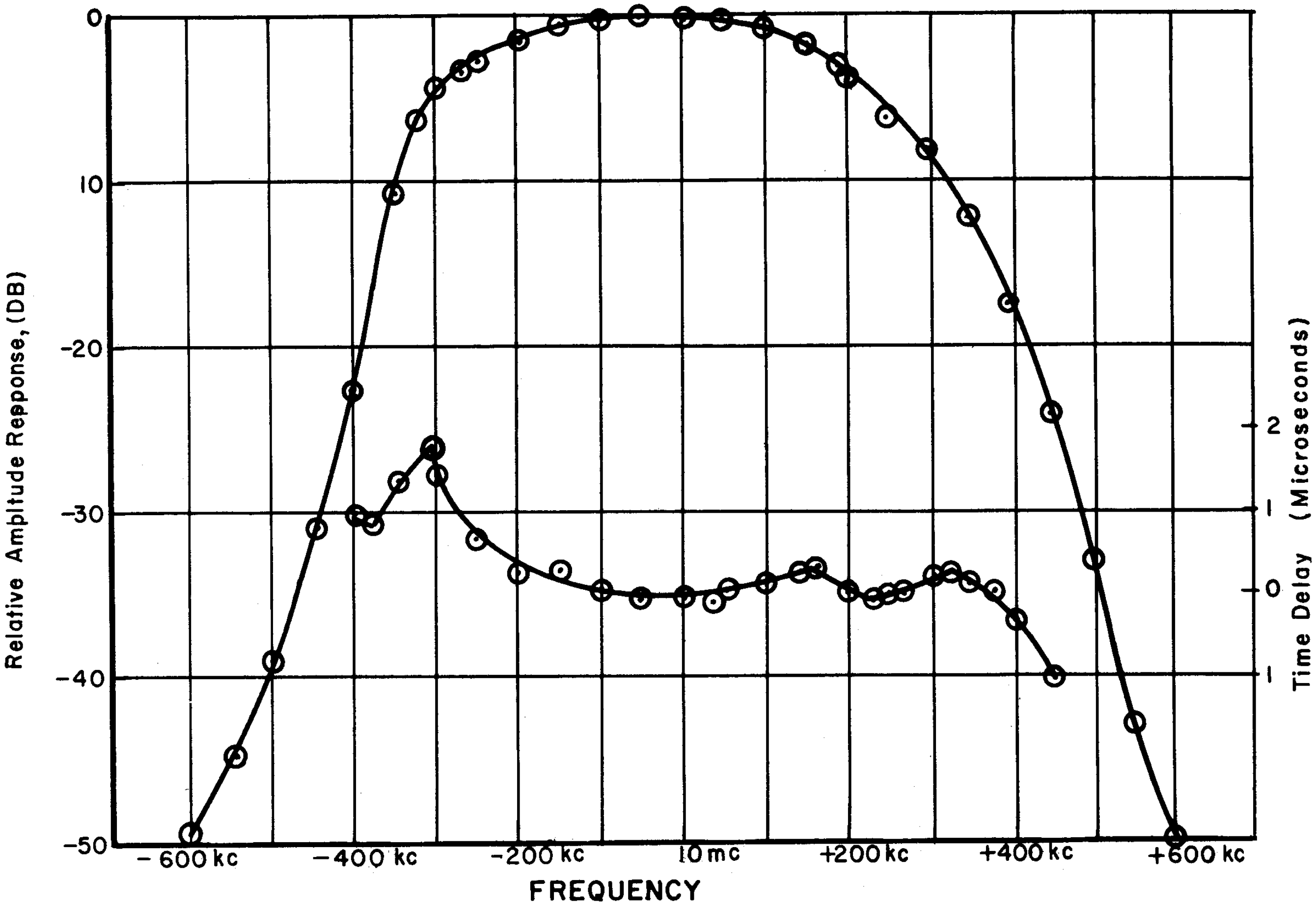


Fig. 5 - Receiver IF Attenuation and Time Delay Characteristics

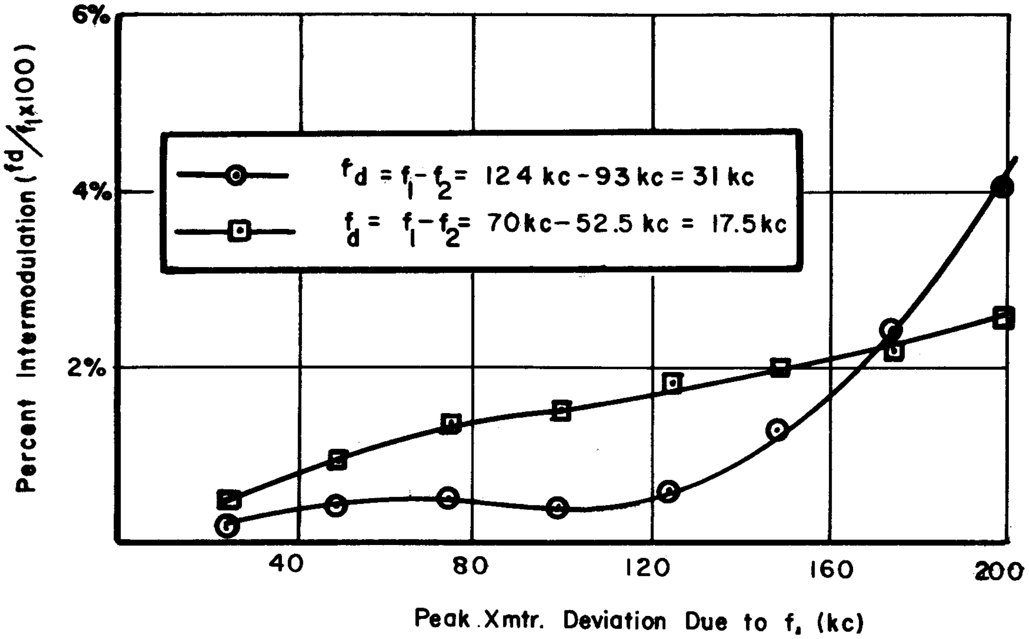


Fig. 6 - RF Link Difference Frequency Intermodulation

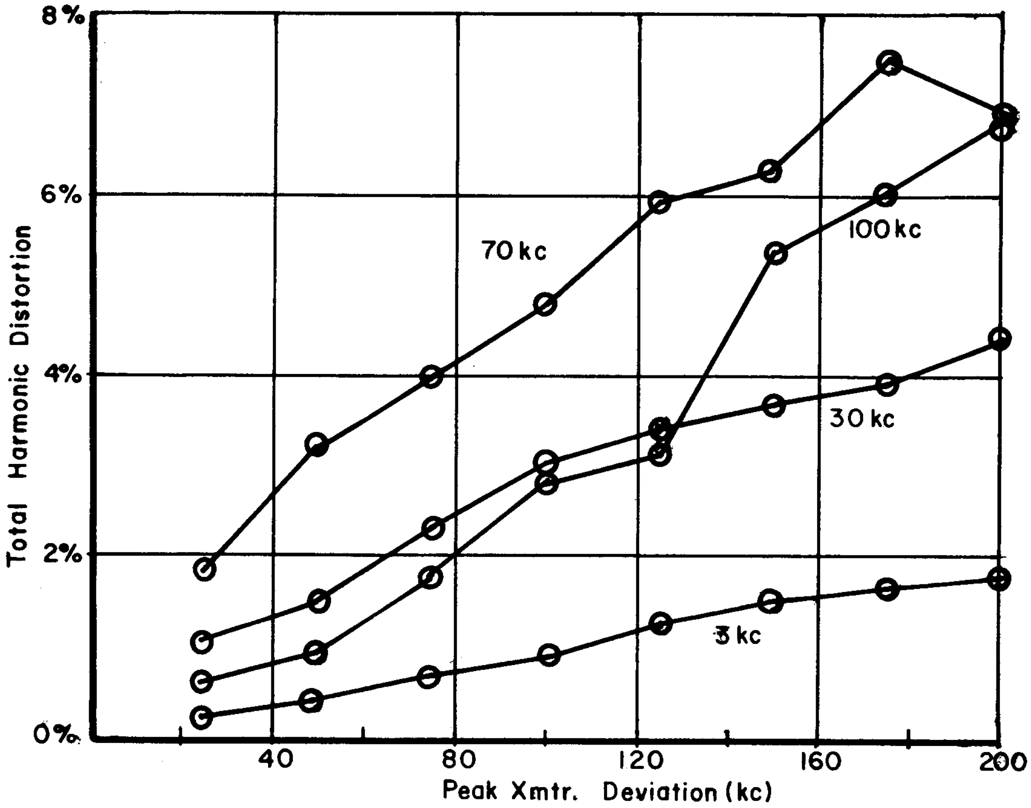


Fig. 7 - RF Link Total Harmonic Distortion

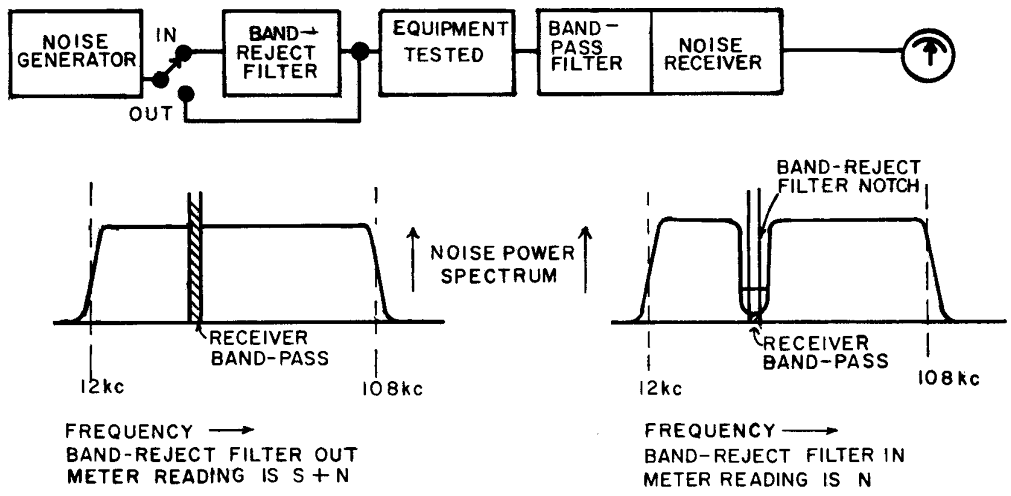


Fig. 8 - Notch Noise Test Illustration

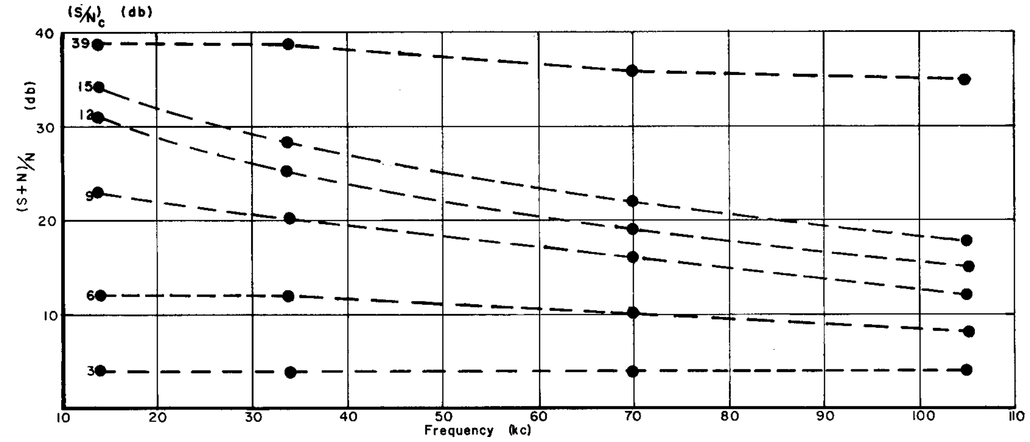


Fig. 9 - Notch Noise Test - Flat Taper

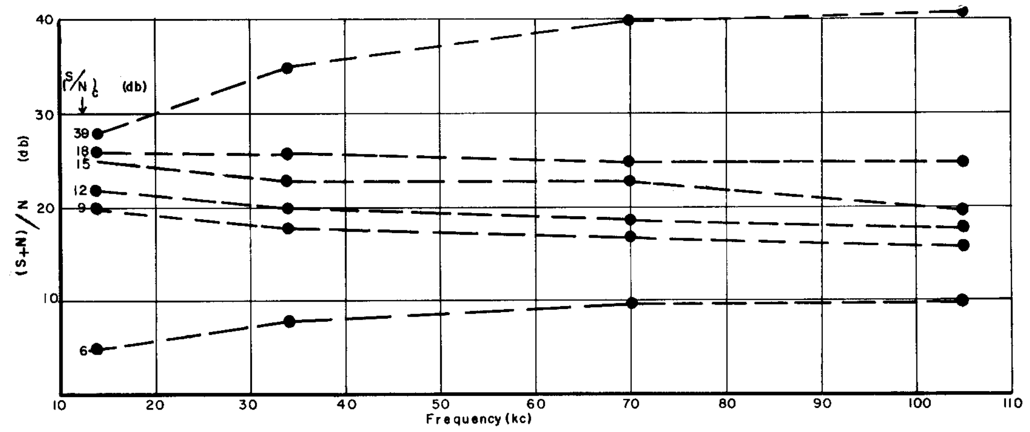
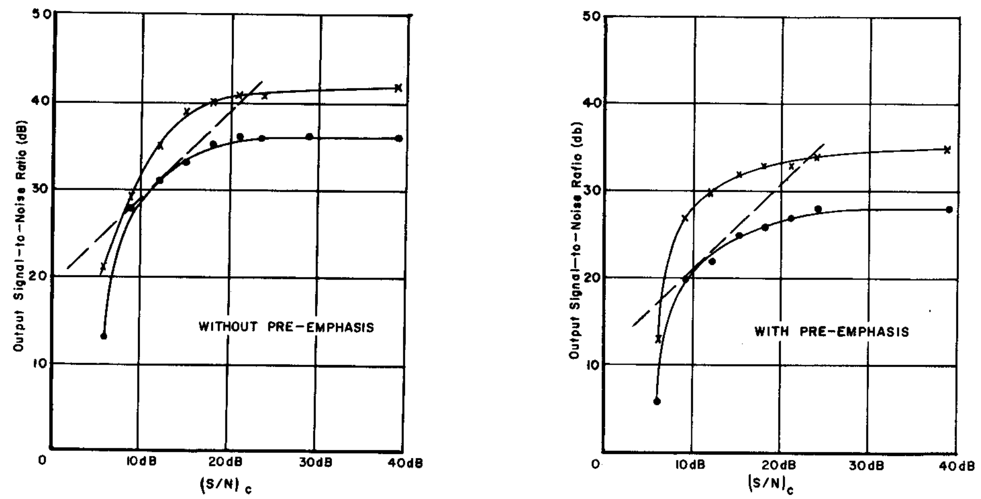
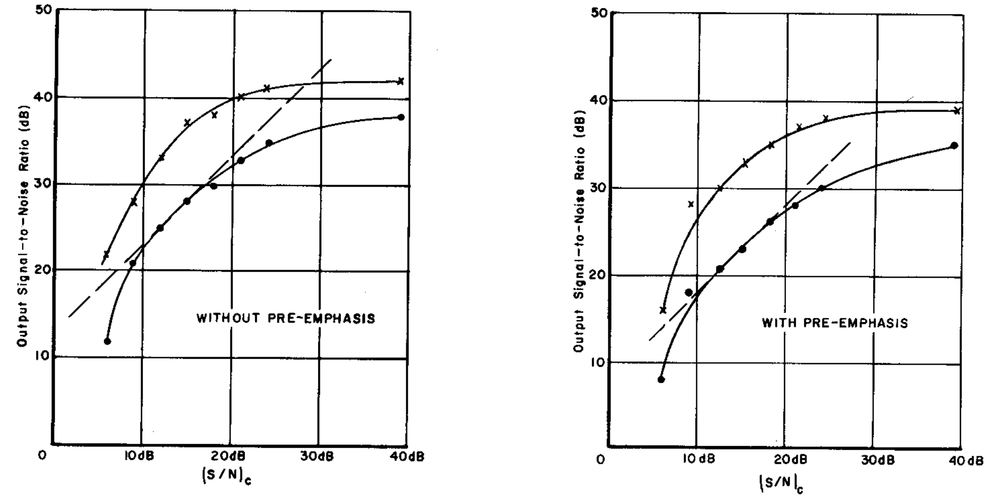


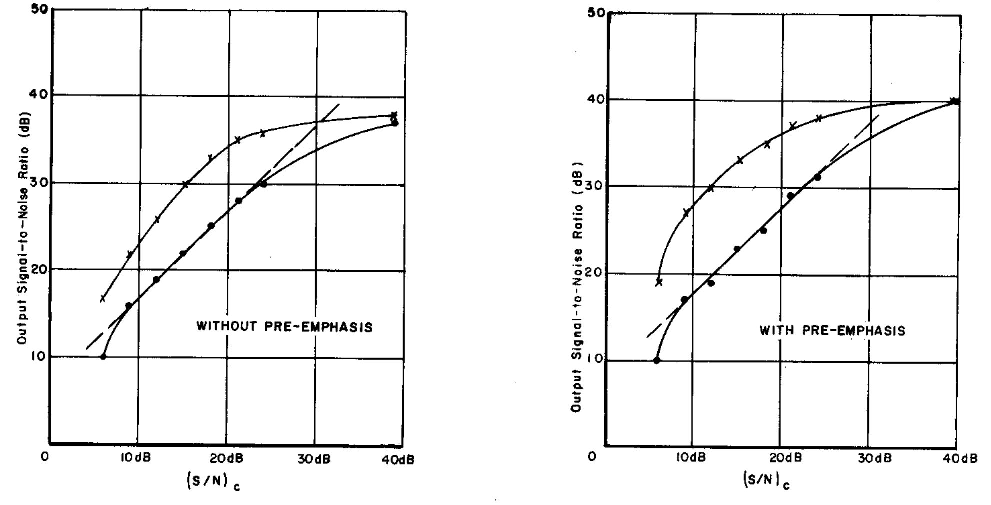
Fig. 10 - Notch Noise Test - 6 db/Octave Pre-emphasis



A • NOTCH NOISE 14kc
× DSB 16kc



B • NOTCH NOISE 34kc
× DSB 32kc



C • NOTCH NOISE 70kc
× DSB 72kc

Fig. 11 - Comparison of Notch Noise and DSB Signal-to-Noise Performance

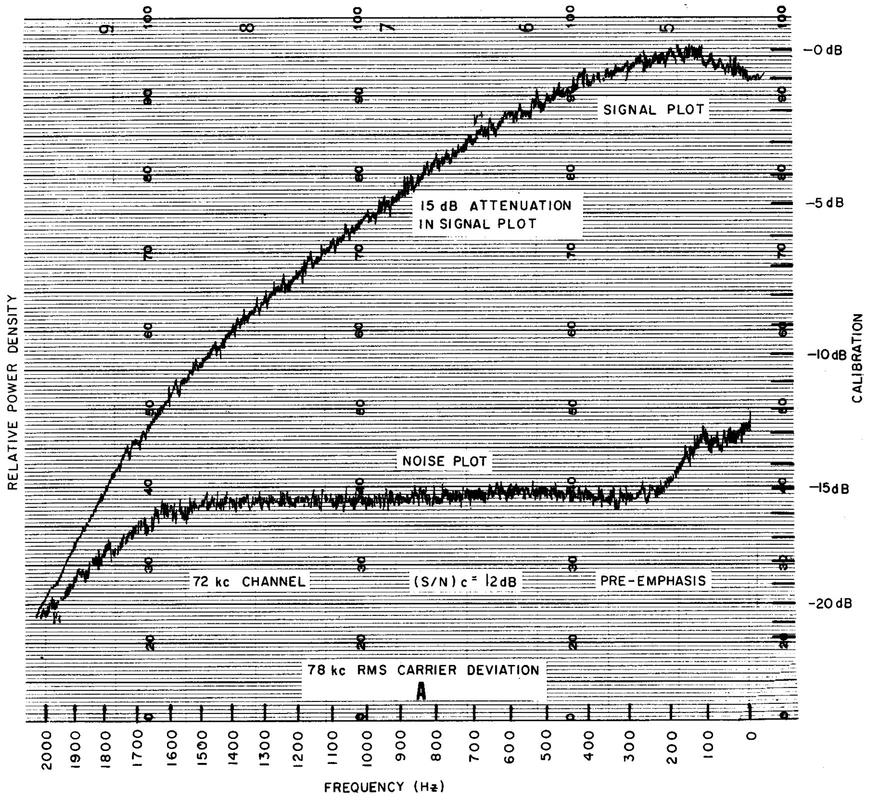


Fig. 12 - DSB 72 kc Channel Output Power Spectrum

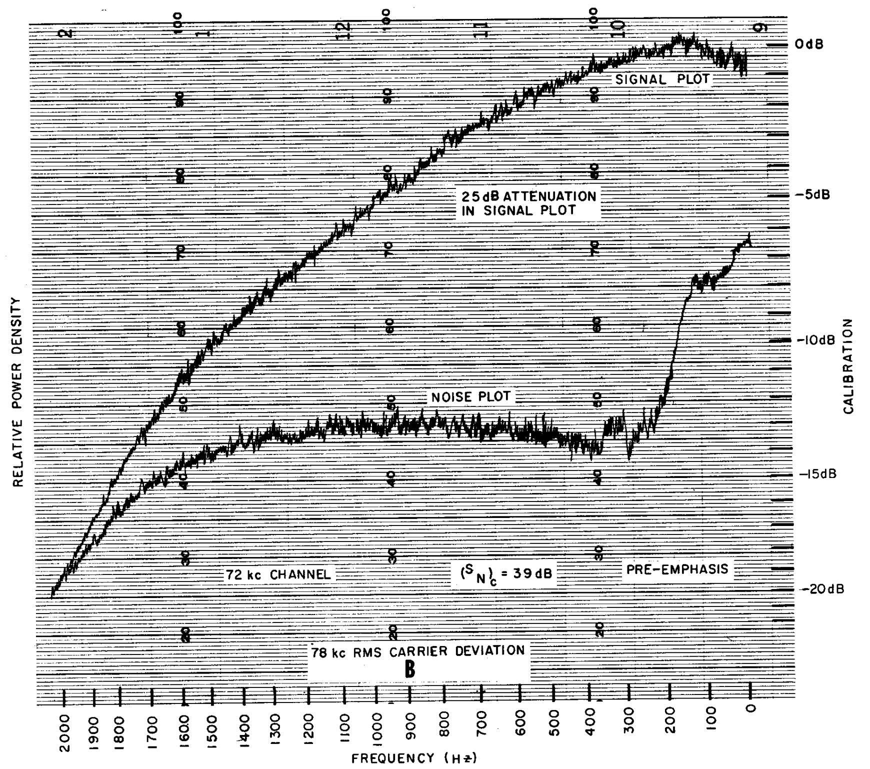


Fig. 12 - DSB 72 kc Channel Output Power Spectrum