EFFECTS OF INSTRUMENTATION RECORDER TIME BASE ERROR ON SPECTRAL PURITY

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Summary Experimental data is presented to show how carrier amplitude of a recorded signal is affected by Time Base Error. Time Base Error effects on the sideband structure of a recorded signal are also shown for different amounts of Time Base Error and at several frequencies. The effect of capstan servo adjustment on spectral purity demonstrates the need for new methods of performance evaluation to achieve optimum performance when recording spectrum information. The data presented shows that skew (ITDE) has little effect on spectral purity for analysis bandwidths of 50 Hz or greater.

Introduction Experience has shown that the Time Base Error characteristics of an instrumentation tape recorder can have a significant effect on the ability to accurately reproduce information when the analysis is being carried out in the frequency domain. It is quite easy to determine and apply the known characteristics of Time Base Error to data signals in the time domain, since the figures given for the equipment can be related dir6ctly to the errors they would cause in the information processed. However, the effects that Time Base Errors have in the frequency domain are less clearly recognizable and more difficult to predict.

Previous information published on the effect of Time Base Error on spectral purity (Bradford and Jaffe)[1] dealt with the problem of predicting the reduction in amplitude of the center frequency being measured as a function of increasing Time Base Error or as a function of increasing frequency with a fixed Time Base Error. The derivations presented were based on a theoretical prediction of the reduction in carrier amplitude as Time Base Error increased from zero to a maximum of one radian of the frequency being measured. A primary purpose of my work in preparing for this paper was to verify that the predicted performance could be supported by experimental data. I have also attempted to provide data on two other characteristics. These are the effect of skew on spectral dispersion and the effect of capstan servo adjustment on the carrier frequency sideband spectrum. These

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[1] Bradford, R. S. and Jaffe, R. M. , “The Output Signal-to-Noise Ratio, Achieved When a Sinusoid is Recorded and Played Back on a Tape Recorder Having a Specified, Mean-Square TDE”; Mincom Division of 3M Company

latter tests were undertaken to show that although one can predict within a limited range the effect of Time Base Error on carrier amplitude reduction, it is very difficult to predict the makeup or shape of the sideband structures without specific information about the machine being used. I must point out that the data presented in this paper uses a different bandwidth analysis filter than that described by Bradford and Jaffe. I have used a 50 Hz analysis bandwidth which will integrate out the errors that could be seen with a narrower filter. This will be particularly true when we analyze the effects of skew on spectral purity since most skew rates are well within a 50 cycle band limit. The overall purpose of this paper is to present experimental evidence showing how increasing Time Base Error affects frequencies in different portions of the passband of a wideband instrumentation recorder and how capstan servo adjustment can have a strong effect on the shape of the sideband structure on data signals.

The data shown in Figure 1 does not have a strong correlation with the predicted results described in the referenced paper. I would like to point out that this should not be interpreted as being a refutation of their derivations, but should be viewed as possible errors caused by the limitations of the measuring system (i.e. , analysis bandwidth) and the necessary assumptions made during the mathematical derivation. The two limiting cases presented by Bradford and Jaffe are for peak-to-peak Time Base Errors which are less than one radian of the signal being measured and for Time Base Errors much larger than one radian of the measured signal. In the data presented, the measured Time Base Errors transcend from the one limiting case to the other and, therefore, lie in that “never, never land” between the two limiting cases described by Bradford and Jaffe. The wider analysis bandwidth which I have used can mask some of the effects that would otherwise be shown and, in particular, will affect the correlation of the carrier amplitude reduction. A narrower analysis filter would be much more desirable, but limitations of equipment did not permit use of such a setup. The 50 Hz filter bandwidth used will mask some of the detailed characteristics of the sideband structure very near the carrier and will also show errors as the baseline noise level adds into the filter and causes the curves to deviate from their expected path when the signal level begins to fall off.

Figure 2 is a block diagram of the experimental apparatus used to gather the information presented. The recorder was a Mincom® TICOR III, 14 track recorder using one inch wide magnetic tape. The analyzer used to measure the spectral distribution of the various carrier frequencies was a Hewlett-Packard Model 8553B/8552A connected to a Hewlett-Packard 7035 X-Y plotter for printout. I F bandwidth in the analyzer was 50 Hz. Slew rate of the analyzer was set at 200 Hz per second. This slow rate was used to make sure that the rate of analysis did not exceed the writing rate of the X-Y plotter. The recorder capstan servo was connected to an external breadboard phase modulator to allow artificial generation of specific levels of peak-to-peak Time Base Error to monitor the effects on spectral purity. The phase modulator was driven from a noise generator band limited to 10 kHz. This technique gave a random distribution for induced large Time Base Errors.

Figure 3 shows the spectral purity of the oscillator used for the experiments. A very clean oscillator was needed to eliminate any possible masking of recorder effects due to poor oscillator performance.

Figure 4A shows the spectral distribution of a 200 kHz carrier frequency recorded at 120 ips and played back with a peak-to-peak Time Base Error of 400 nanoseconds. The spectrum clearly shows several significant characteristics of the recorder. The high first order of sidebands reaching to -30 db represent the servo corner frequency at approximately 900 Hz. The deep trough immediately adjacent to the center carrier, which extends to -50 db, is at approximately 300 Hz and represents the zero db flutter rejection frequency of the servo. The residual sidebands above and below 300 Hz represent uncorrected power in the flutter spectrum. Figure 4B shows the same recorder under identical conditions of operation with the exception that a defect was purposely introduced into the reproduce heads to show the effect of mechanical resonances on spectral dispersion. You will note the significant sidebands at a frequency of approximately 450 Hz. These sidebands are caused by head mechanical resonance. The significance of this demonstration is that the flutter and Time Base Error performance of the recorder showed only a very slight change between these two cases. The Time Base Error was increased approximately 100 nanoseconds and broadband flutter, as measured on a flutter meter, appeared essentially unchanged. The point is, significant changes can be made in the composition-of the sideband structure without these effects being clearly apparent in traditional methods of measurement. Spectral purity analysis is truly a much more sensitive means of measuring the subtle characteristics of a tape transport’s performance.

Figures 5A through 5D show the change in sideband structure as greater amounts of peak-to-peak Time Base Error are applied to the signal. These curves show the spectral dispersion effects for Time Base Errors of 0.5, 1.0, 3.0 and 5.0 microseconds, respectively, on a 200 kHz carrier frequency. Similar effects are shown in Figures 6A through 7D for carrier frequencies of 500 kHz and 1.0 MHz. Please note that, for Time Base Errors of I microsecond or greater, the sideband structure takes on the appearance of random noise and the coherency of the sidebands that was evident at lower Time Base Errors disappears. This is true because the forcing function used to create these higher Time Base Errors was random noise. The effect for large Time Base Errors (see Figure 7D) is similar to that predicted by Bradford and Jaffe for Time Base Error greater than one radian. Had these been created by a poorly functioning tape transport or one with less sophisticated servo performance, the sideband structures would take on characteristics similar to those for low Time Base Error performance, but with higher residual sideband levels.

Figures 8A through 8C show the effect of skew on the sideband spectrum for a 200 kHz frequency. Skew (ITDE) would show a significant impact on the sideband spectrum if a narrower analysis filter had been used. However, since the bandwidth of 50 Hz encompasses a large percentage of skew rates, the effect is not clearly shown.

Figures 9A through 10C show a comparison of different capstan servo adjustments on the spectral purity of a 200 kHz carrier frequency. Figure 9A shows the performance of the system with the capstan servo adjusted for minimum peak-to-peak Time Base Error (300 nanoseconds). Figure 9B is the same condition of operation with the servo gain increased approximately 2 db, with a peak-to-peak Time Base Error of 600 nanoseconds Figure 9C shows the results with an increase in capstan servo gain of 3 db and a peak-to-peak Time Base Error of 1.0 microsecond. The increase in Time Base Error is caused, for the most part, by an increase in the ringing rate at the servo corner frequency which is obvious from the dramatic increase in the sidebands at approximately 900 Hz. In Figure 9C, the gain increase has generated second order sidebands of the servo corner frequency at approximately 1800 Hz. I would like to point out, however, that in all three cases the machine was meeting typical Time Base Error specdfications for this type of equipment - Figures 10A through IOC show the same conditions of operation with reduced capstan servo gain. Figure IOA is identical to the previous Figure 9A. Figure IOB shows the results with the capstan servo gain reduced by 2 db which gives a resultant peak-to-peak Time Base Error of 380 nanoseconds. Figure 10C is for a reduction in capstan servo gain of 7 db and a resultant peak-to-peak Time Base Error of 550 nanoseconds. You will note that the significant change is a reduction in amplitude of the higher frequency sidebands and an increase in the level of the sidebands nearest to the carrier. This demonstrates the trade-off between the ability to reduce low frequency flutter and the generation of unwanted high frequency sidebands in a high performance servo. The relative importance of this information depends upon the bandwidth of the analysis instrument and the data of interest. Again, I would like to point out that the Time Base Error changed less than 2 to 1 for these latter cases, but there was a significant shift in the makeup of the sideband structure for the signal being analyzed. The Time Base Error for the conditions described by Figures 10A.- IOB and IOC meets published specifications. In this particular case, it would appear that it would be wise to run the servo at a slightly lower gain setting than that which would provide lowest Time Base Error. These data are another demonstration that traditional methods for performance measurement may not be adequate for the user who is concerned about spectral purity. The overall objective of the user is to minimize the errors introduced by the recorder so that his results reflect data from the signal of interest and not anomalies introduced by the data storage process.

FIGURE 1

CARRIER AMPLITUDE SUPPRESSION VERSUS TIME BASE ERROR

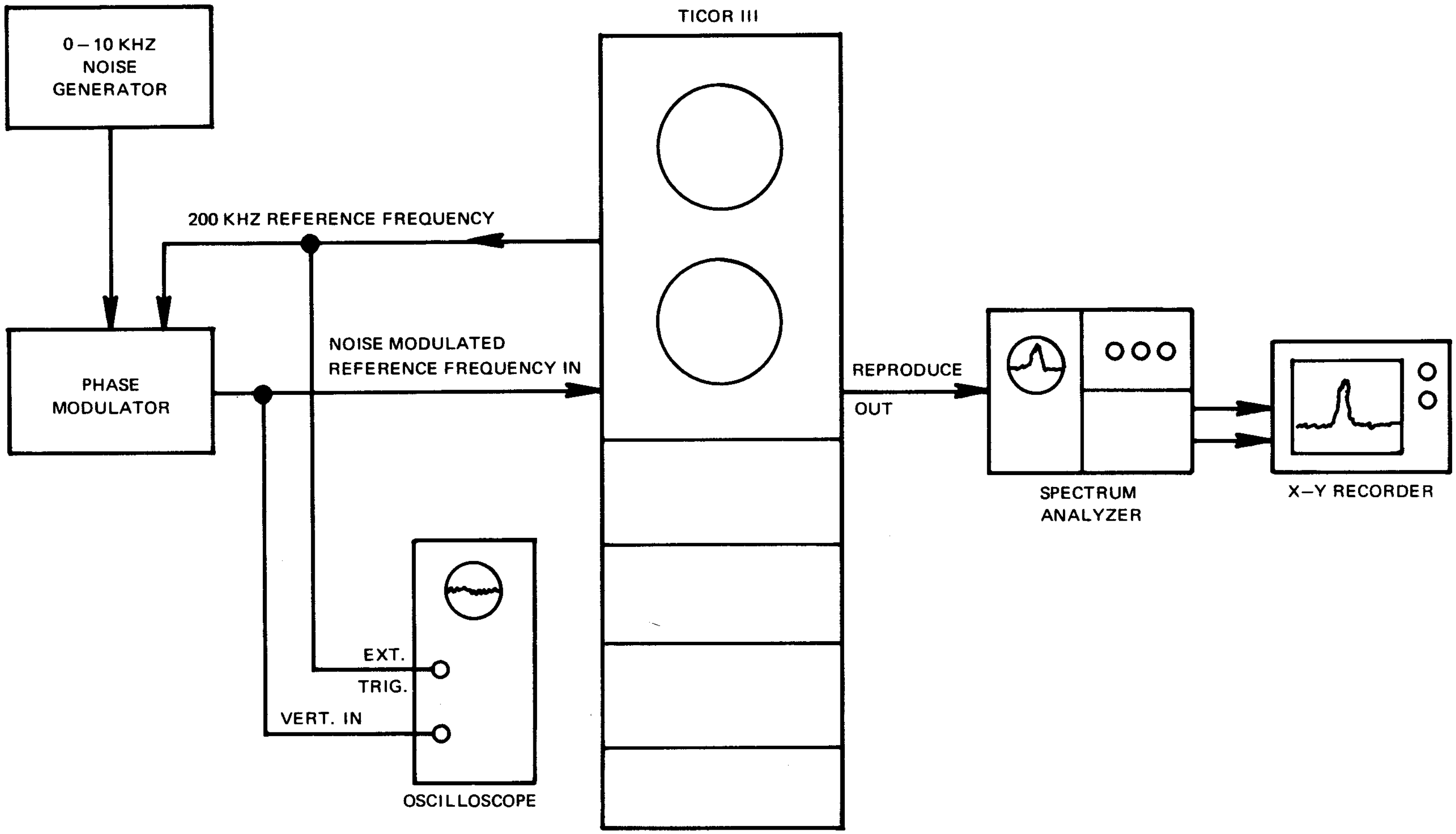

FIGURE 2

TEST EQUIPMENT BLOCK DIAGRAM

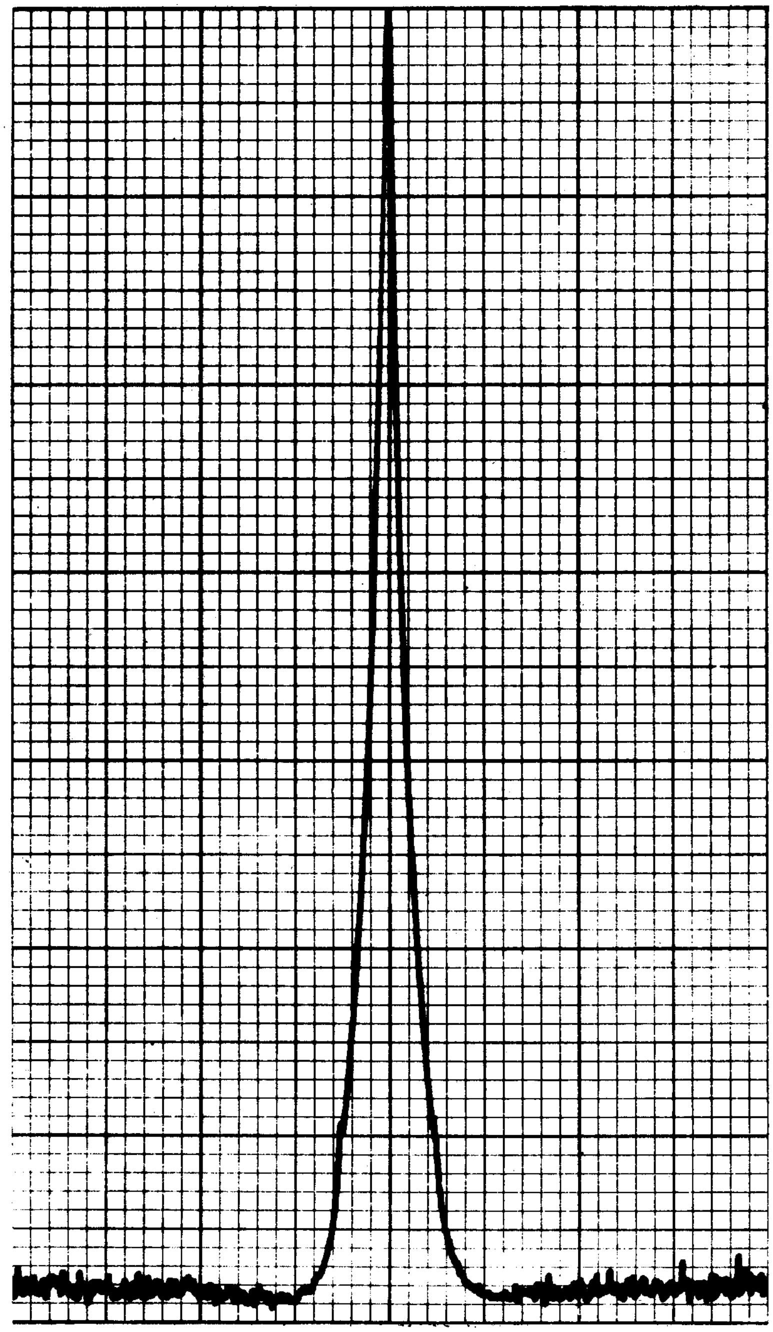

FIGURE 3

SPECTRAL PURITY - REFERENCE OSCILLATOR.
ANALYSIS BANDWIDTH, 50 Hz.
SPECTRUM ANALYSIS FROM 190 kHz TO 210 kHz.
HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.

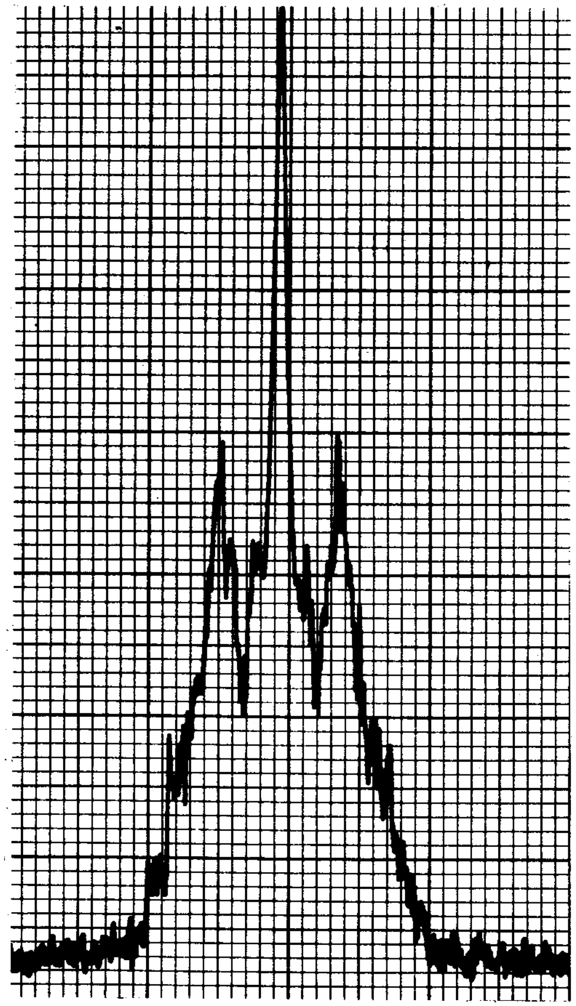

FIGURE 4A
STANDARD UNMODIFIED HEADS

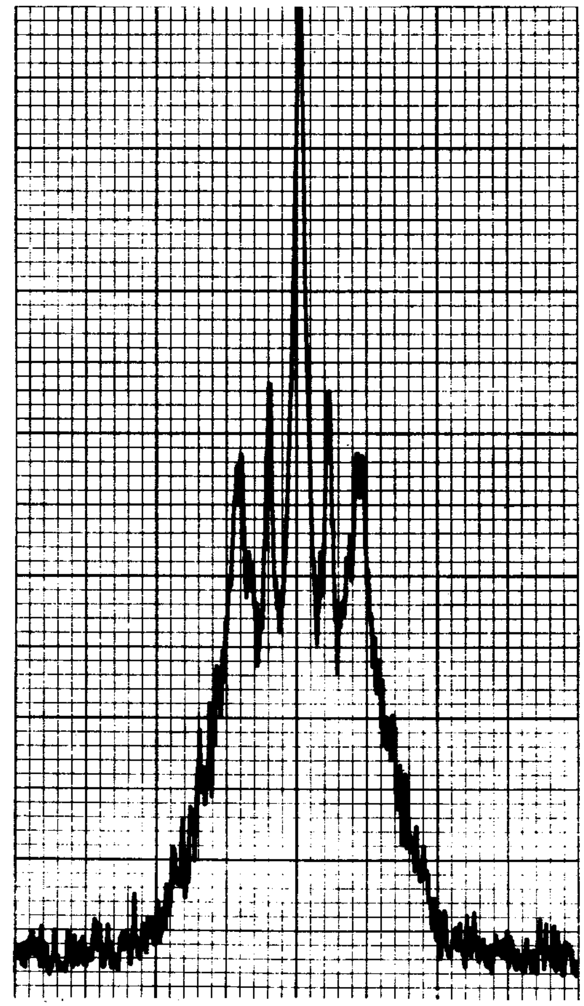

FIGURE 4B
HEADS MODIFIED TO INDUCE MECHANICAL RESONANCE

SPECTRAL PURITY OF A 200 kHz CARRIER FREQUENCY RECORDED AND REPRODUCED ON A MINCOM TICOR III WIDEBAND RECORDER.

ANALYSIS BANDWIDTH, 50 Hz.

HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.

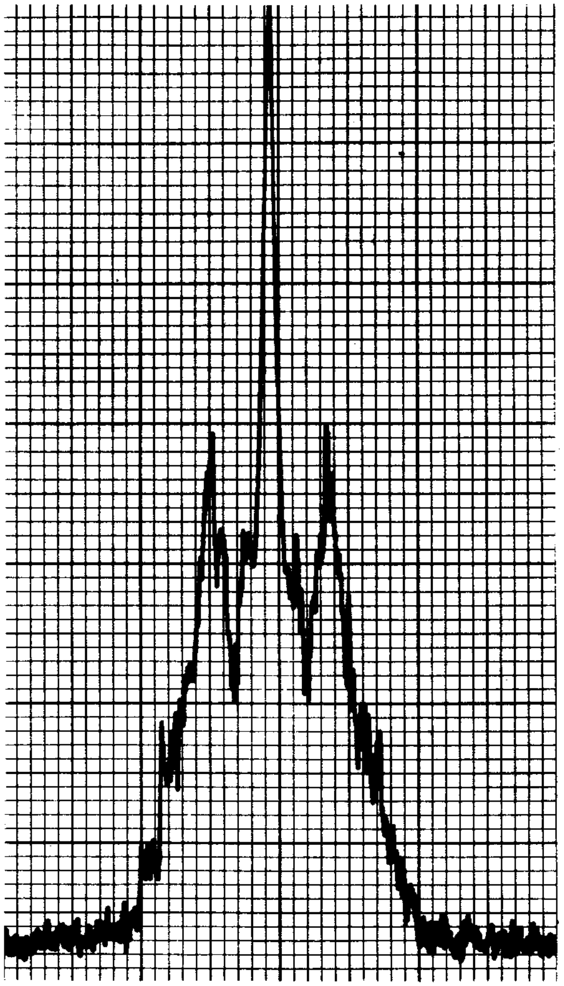

FIGURE 5A

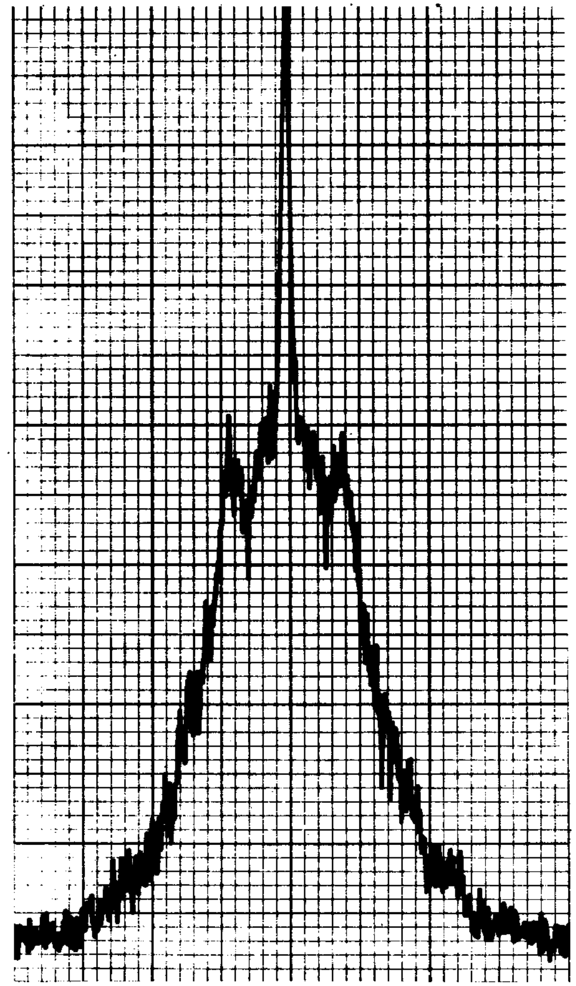

FIGURE 5B

TIME BASE ERROR EFFECTS ON

SPECTRAL PURITY OF A 200 kHz CARRIER FREQUENCY RECORDED AND REPRODUCED ON A MINCOM TICOR III WIDEBAND RECORDER.

ANALYSIS BANDWIDTH, 50 Hz.

HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.

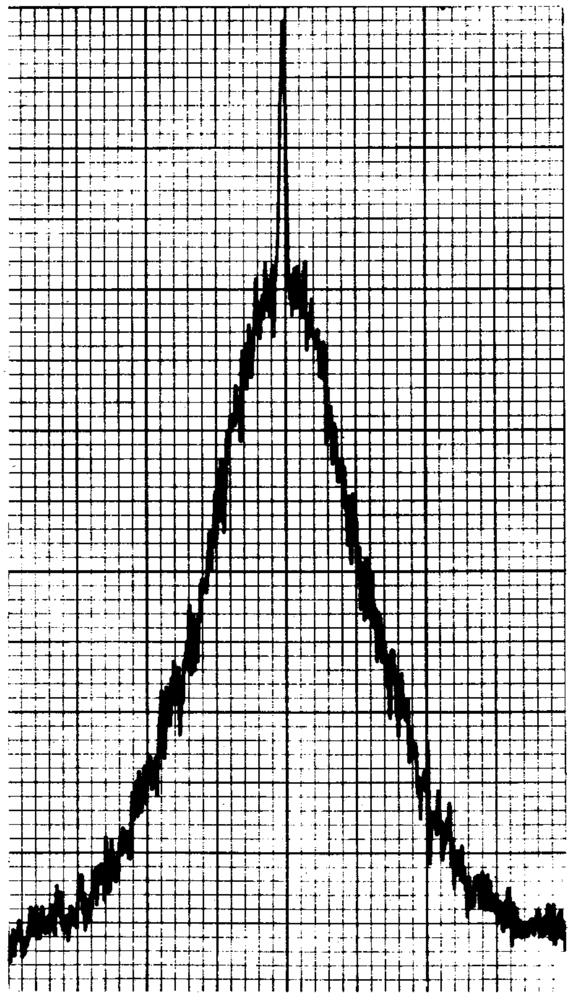

FIGURE 5C

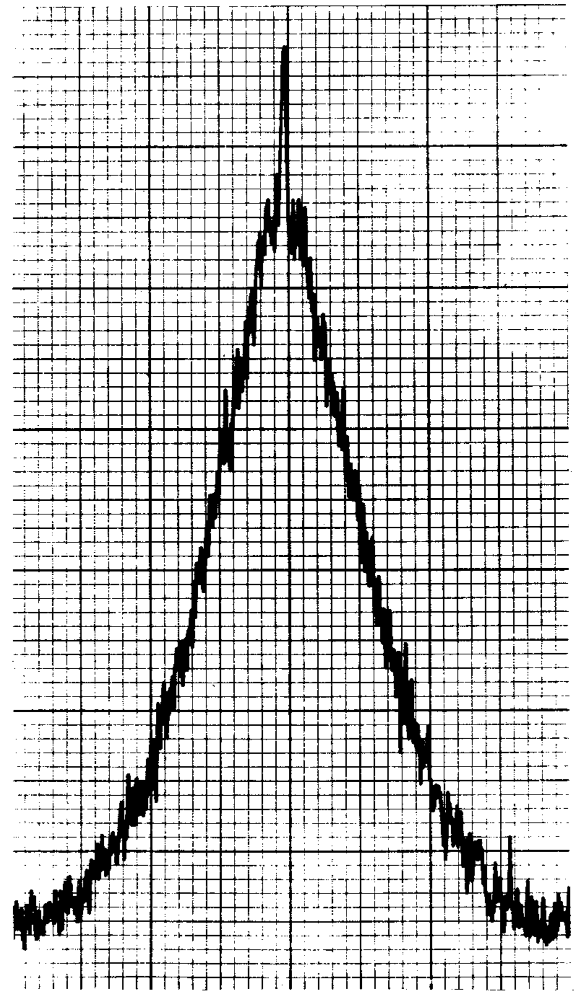

FIGURE 5D

TIME BASE ERROR EFFECTS ON
SPECTRAL PURITY OF A 200 kHz CARRIER FREQUENCY RECORDED AND REPRODUCED ON A MINCOM TICOR III WIDEBAND RECORDER.
ANALYSIS BANDWIDTH, 50 Hz.
HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.

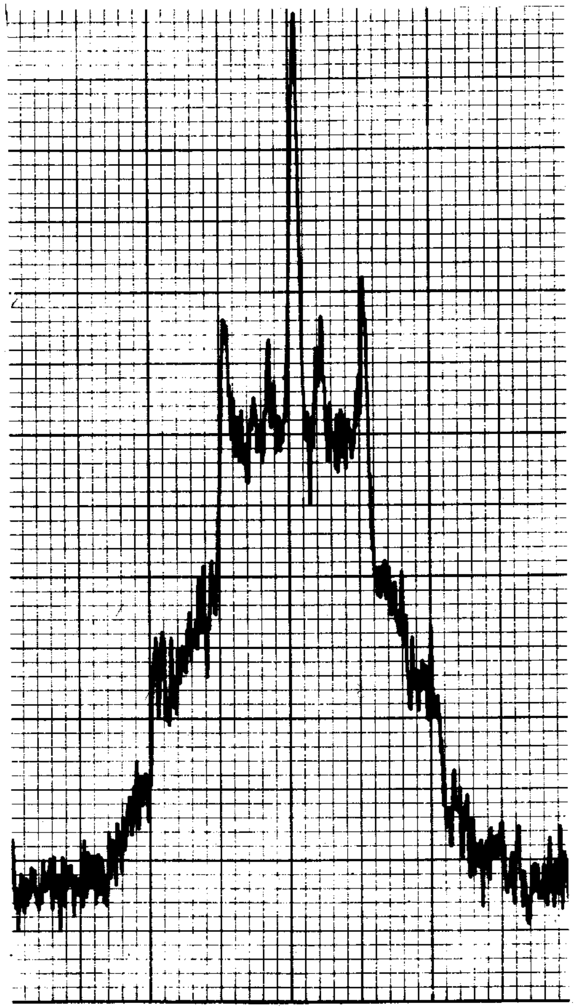

FIGURE 6A

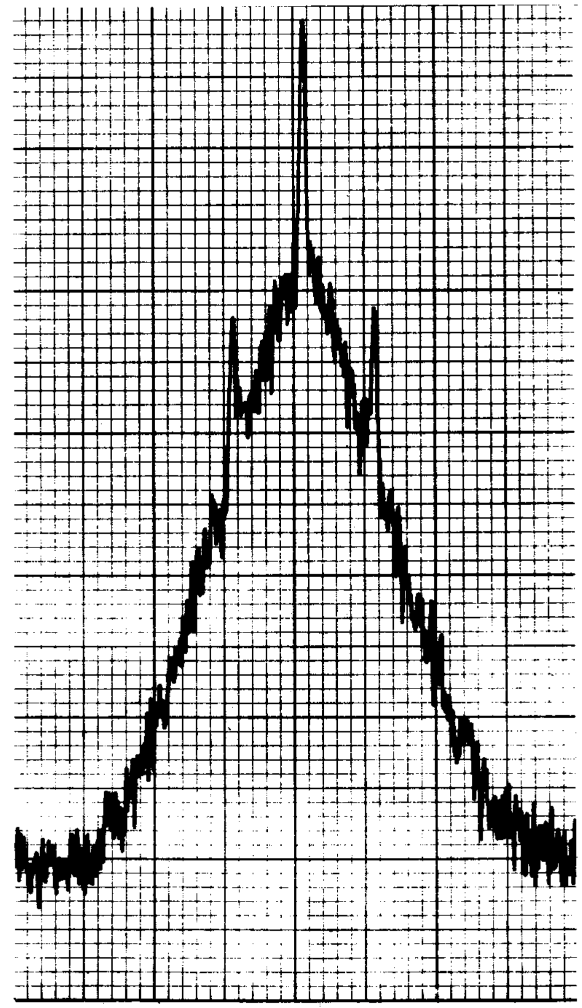

FIGURE 6B

TIME BASE ERROR EFFECTS ON

SPECTRAL PURITY OF A 500 kHz CARRIER FREQUENCY RECORDED AND REPRODUCED ON A MINCOM TICOR III WIDEBAND RECORDER.

ANALYSIS BANDWIDTH, 50 Hz.

HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.

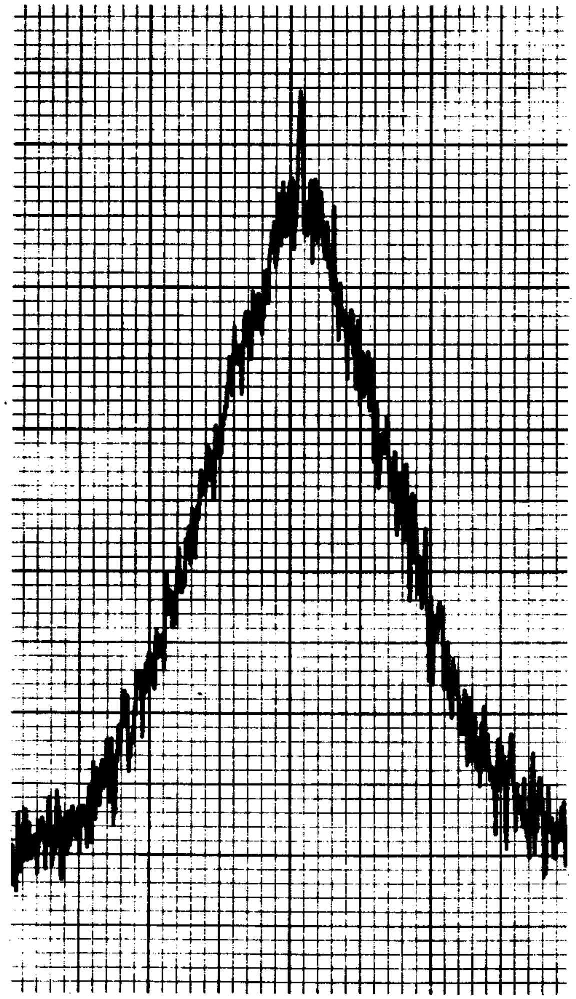

FIGURE 6C

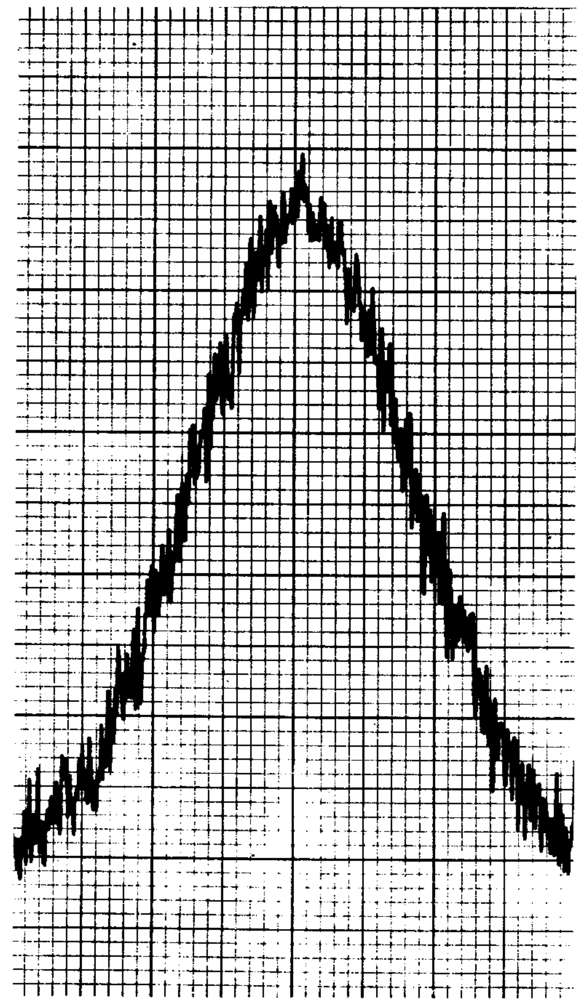

FIGURE 6D

TIME BASE ERROR EFFECTS ON
SPECTRAL PURITY OF A 500 kHz CARRIER FREQUENCY RECORDED AND REPRODUCED ON A MINCOM TICOR III WIDEBAND RECORDER.
ANALYSIS BANDWIDTH, 50 Hz.
HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.

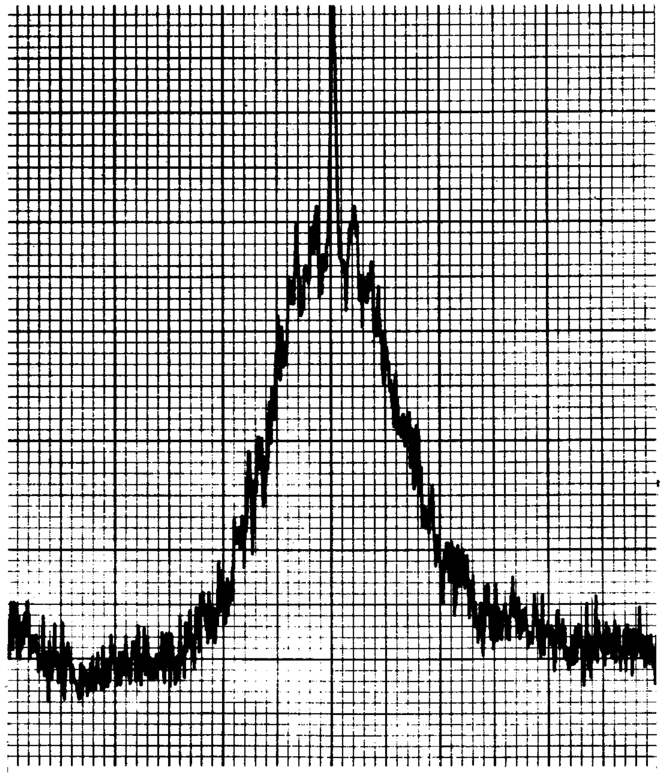

FIGURE 7A

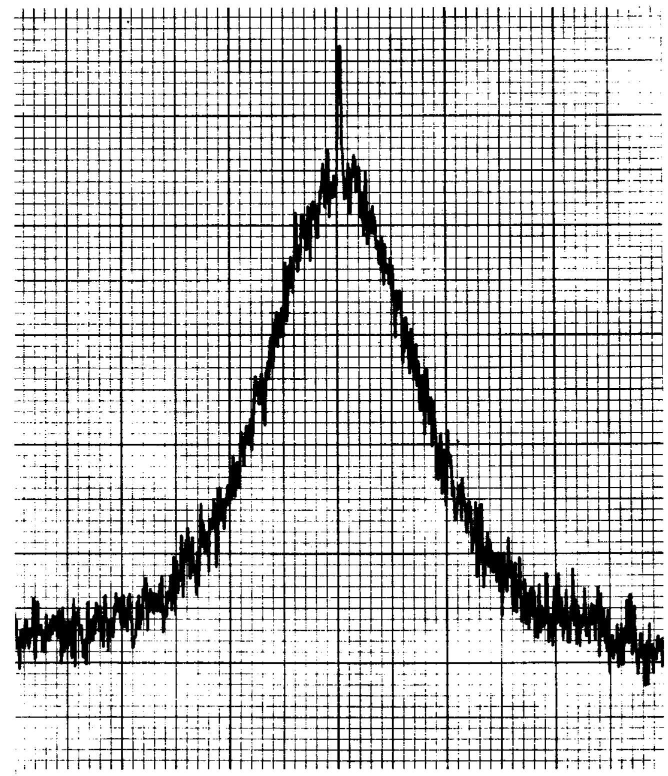

FIGURE 7B

TIME BASE ERROR EFFECTS ON
SPECTRAL PURITY OF A 1.0 MHz CARRIER FREQUENCY RECORDED AND REPRODUCED ON A MINCOM TICOR III WIDEBAND RECORDER.
ANALYSIS BANDWIDTH, 50 Hz.
HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.

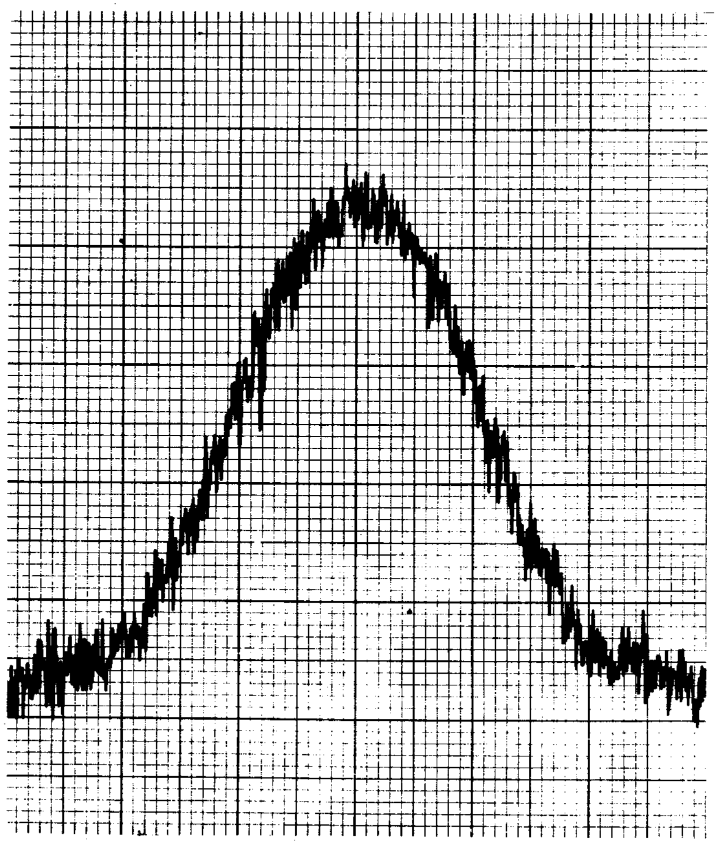

FIGURE 7C

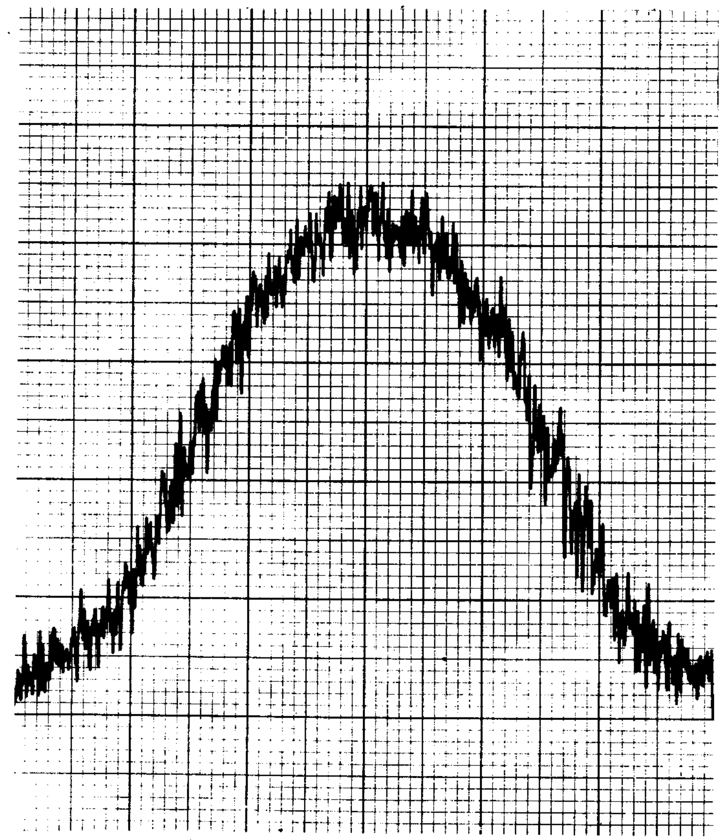

FIGURE 7D

TIME BASE ERROR EFFECTS ON

SPECTRAL PURITY OF A 1.0 MHz CARRIER FREQUENCY RECORDED AND REPRODUCED ON A MINCOM TICOR III WIDEBAND RECORDER.

ANALYSIS BANDWIDTH, 50 Hz.

HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.

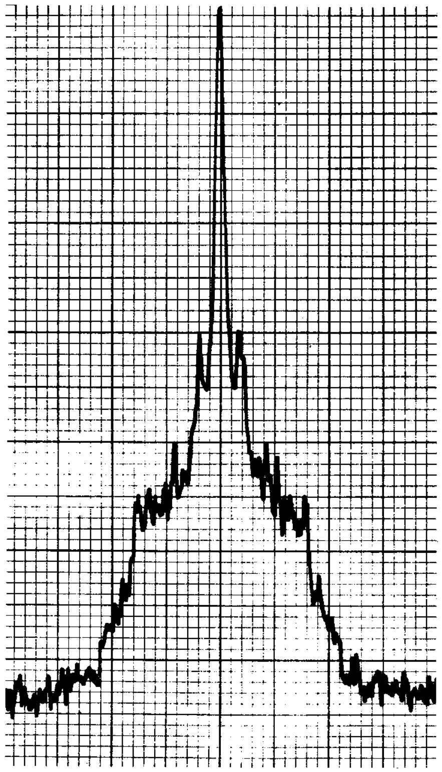

FIGURE 8A
CONTROL TRACK, TRACK #6

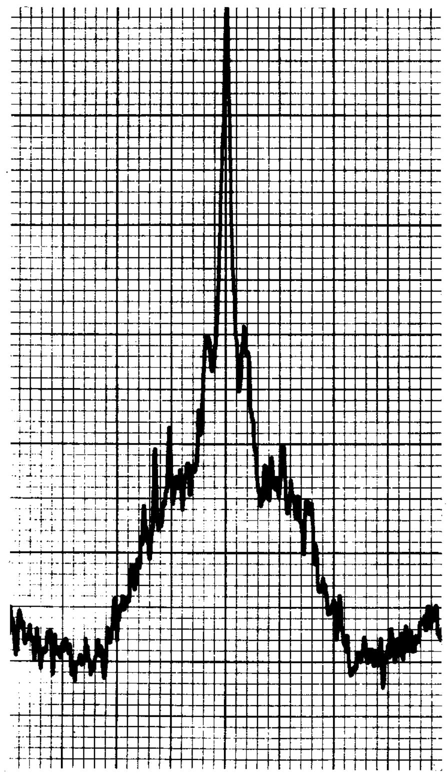

FIGURE 8B
TRACK #10

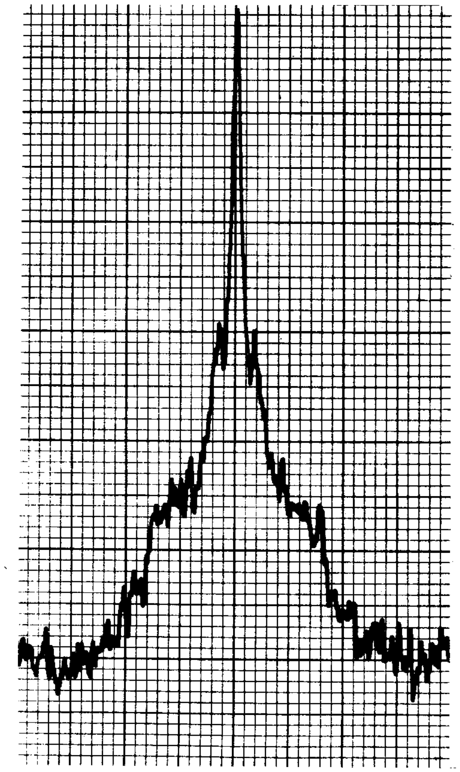

FIGURE 8C
TRACK #14

SKEW EFFECTS ON
SPECTRAL PURITY OF A 200 kHz CARRIER FREQUENCY RECORDED AND REPRODUCED ON A MINCOM TICOR III WIDEBAND RECORDER.
ANALYSIS BANDWIDTH, 50 Hz.
HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.

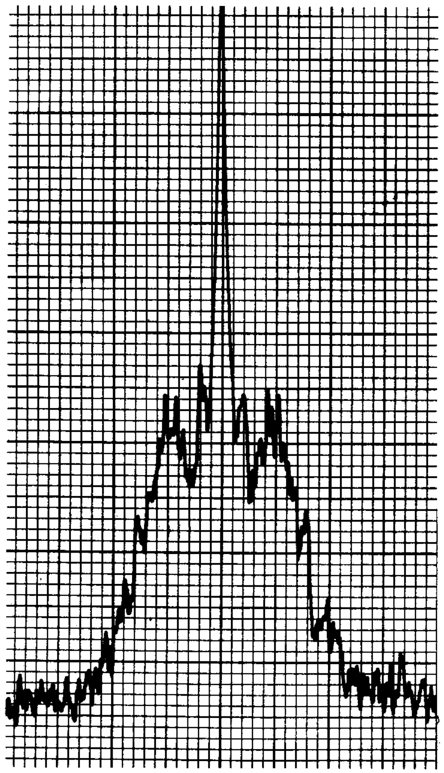

FIGURE 9A
CONTROL TRACK, TRACK #6

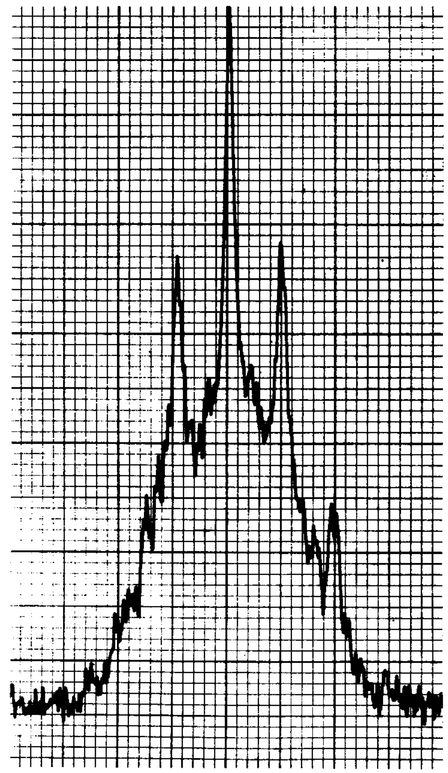

FIGURE 9B
TRACK #10

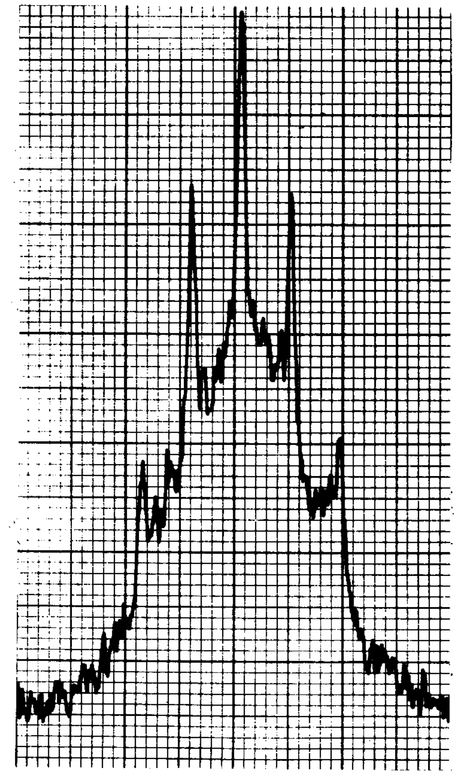

FIGURE 9C
TRACK #14

EFFECT OF CAPSTAN SERVO ADJUSTMENT ON
SPECTRAL PURITY OF A 200 kHz CARRIER FREQUENCY RECORDED AND REPRODUCED ON A MINCOM TICOR III WIDEBAND RECORDER.
ANALYSIS BANDWIDTH, 50 Hz.
HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.

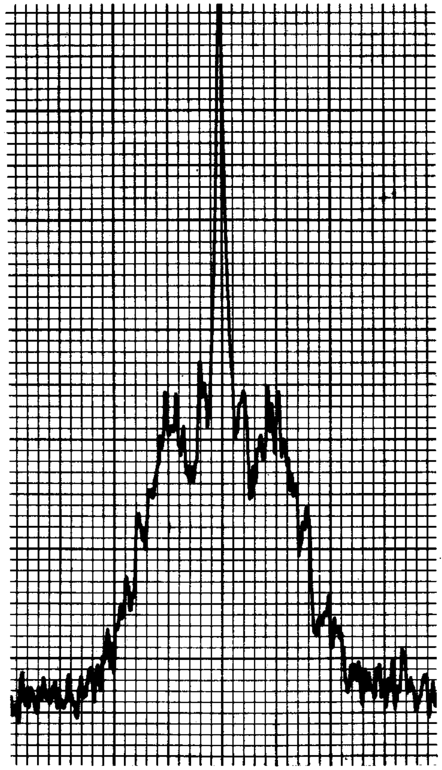

FIGURE 10A
CONTROL TRACK, TRACK #6

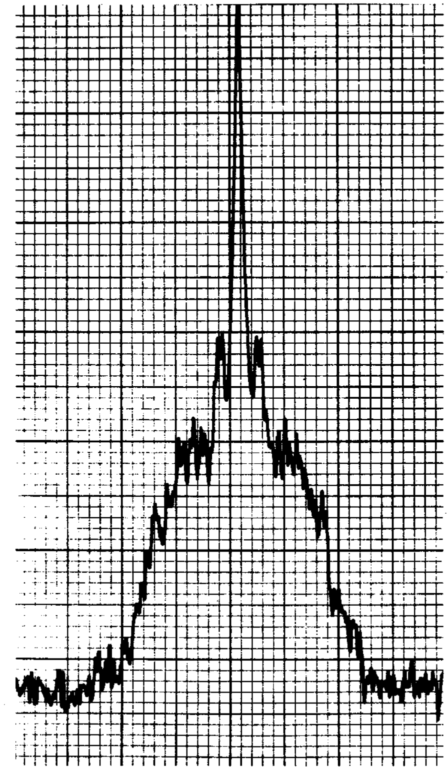

FIGURE 10B
TRACK #10

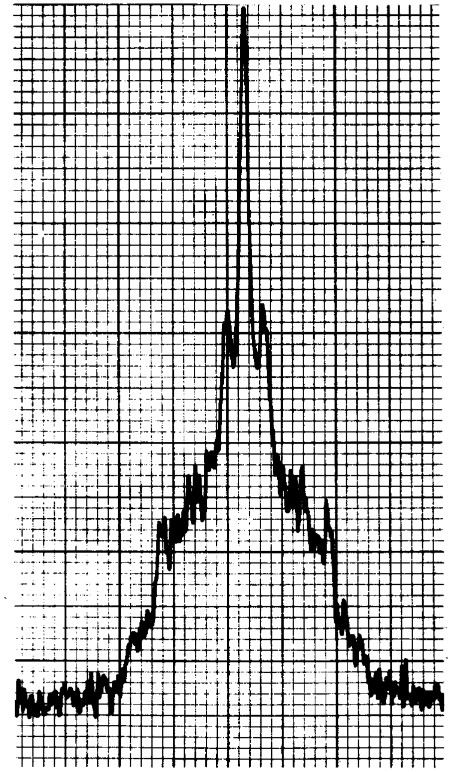

FIGURE 10C
TRACK #14

EFFECT OF CAPSTAN SERVO ADJUSTMENT ON
SPECTRAL PURITY OF A 200 kHz CARRIER FREQUENCY RECORDED AND REPRODUCED ON A MINCOM TICOR III WIDEBAND RECORDER.
ANALYSIS BANDWIDTH, 50 Hz.
HORIZONTAL SCALE, MINOR DIVISION EQUALS 200 Hz.