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SPECTRAL DEGRADATION OF FREQUENCY SYNTHESIZERS

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GODDARD SPACE FLIGHT CENTER

GREENBELT, MD.

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INTRODUCTION

The derivation of a desired frequency by the use of direct synthesis techniques is becoming more and more common in modern electronic systems. The increasing use of these devices in local oscillator, transmitter, exciter, and phaselock loop applications typifies this trend. However, there are certain restrictions imposed on the use of these devices due to the signal degradation that occurs during the synthesis process. The amount of degradation which can be expected varies considerably with the synthesis technique employed and the frequency coverage provided. In order to get a quantitative value for the degradation which can be expected, an evaluation of three commercially available synthesizers has been made. The units involved were the Hewlett Packard 5100/5110, the General Radio 1162, and the Fluke 303A. Data was obtained and recorded of the RF Spectrum and the phase fluctuation spectral densities of each of these synthesizers. In addition, each synthesizer was compared with a hydrogen maser to determine the aging rate of the crystal standard in the synthesizer. For the purpose of the measurement, the output frequency of each synthesizer was set to 1 megahertz. This choice of output frequency was chosen since it is the only output frequency common to the three synthesizers. In addition, one megahertz is a convenient input for the measurement system employed.

INSTRUMENTATION FOR RF SPECTRUM MEASUREMENT

The measurement scheme used to determine the RF spectrum is shown in Figure 1. It consists of two separate multiplier chains which provide nominal 390 MHz output signals. The 10 kHz difference between the two multiplier outputs is analyzed using a narrow band spectrum analyzer with an 80 db dynamic range. The GR 1910A set to a 3 Hz bandwidth was used for this purpose. In order to determine the RF spectrum of the 1 MHz input, a conversion is required from the measured value. The conversion is required due to the modulation index increase which resulted during the multiplication by 390. Therefore a measured carrier-to-noise ratio in a 3 Hz bandwidth at 390 MHz must be increased by a factor of 52 db to obtain the 1 MHz spectrum.

This conversion makes the assumption that an increment of the frequency disturbance is sinusoidal modulation. In addition, the assumption is made that $\Delta f / f_m$ (modulation index) $\ll 1$ (a reasonable assumption for any synthesizer of practical importance).

Since $\Delta f / f_m$ is increased by the multiplication factor,

$$\left(\begin{matrix} V_{\text{sideband}} \\ \text{at 1 MHz} \end{matrix} \right) = \left(\frac{\begin{matrix} V_{\text{sideband}} \\ \text{at 390 MHz} \end{matrix}}{390} \right)$$

or

$$\left(\frac{V_{\text{carrier}}}{V_{\text{sideband}}} \right)_{1\ \text{MHz}} = \left(\frac{V_{\text{carrier}}}{V_{\text{sideband}}} \right)_{390\ \text{MHz}} + 52\ \text{db}$$

In the process of making the actual measurements the output of a single 1 MHz crystal standard was fed into each of the multiplier inputs (Fig. 2).

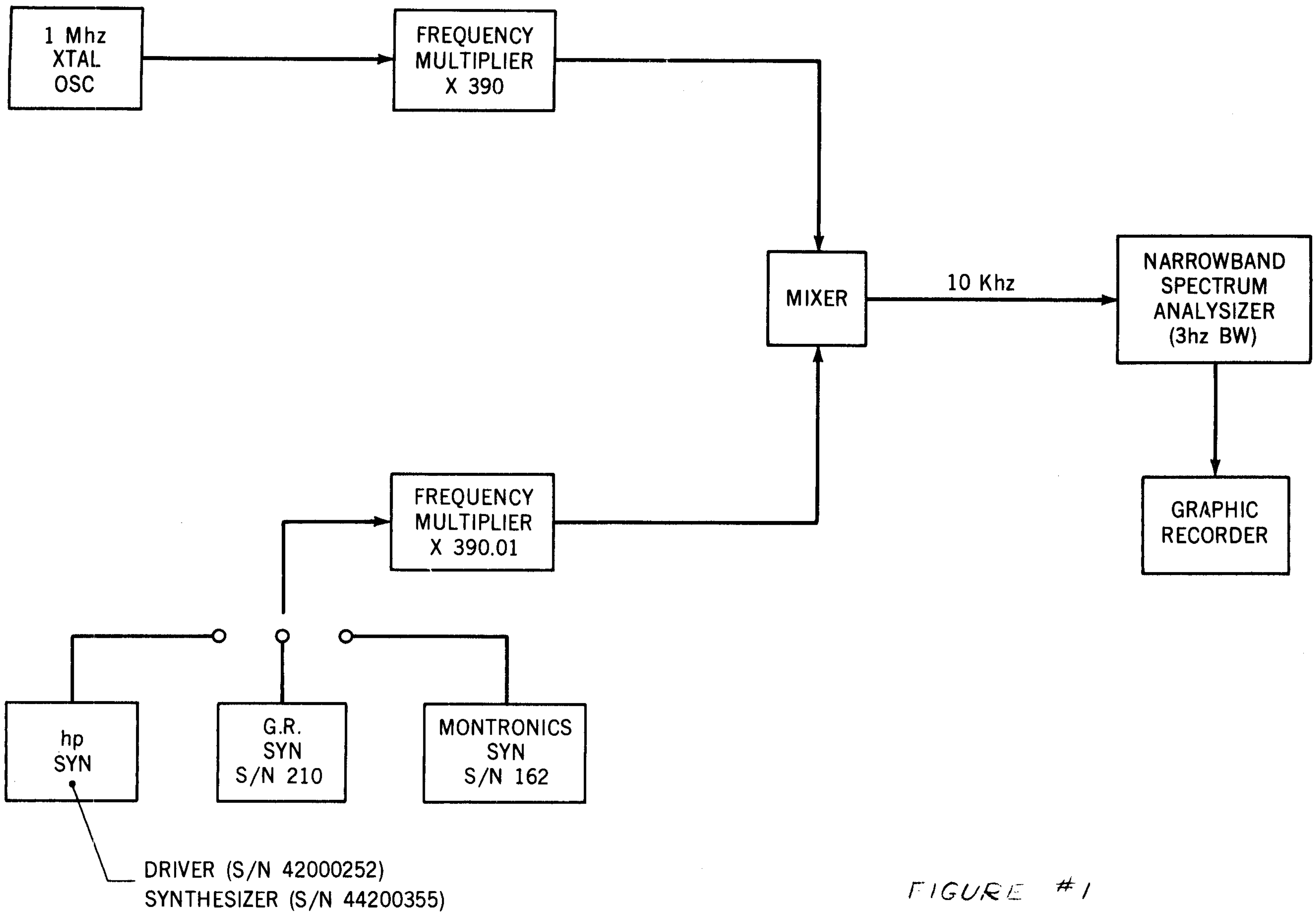
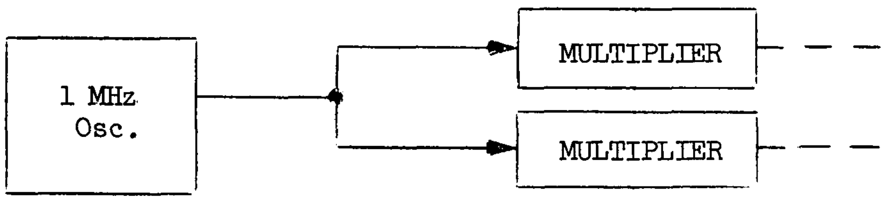

1 Mhz XTAL OSC
FREQUENCY MULTIPLIER X 390
MIXER
10 Khz
NARROWBAND SPECTRUM ANALYSIZER (3hz BW)
GRAPHIC RECORDER
FREQUENCY MULTIPLIER X 390.01
hp SYN
G.R. SYN S/N 210
MONTRONICS SYN S/N 162
DRIVER (S/N 42000252)
SYNTHESIZER (S/N 44200355)

FIGURE #1

The resulting spectral plot (Figure 3) is then the system noise of the measurement scheme. After determination of system noise, two different 1 MHz crystal standards were compared (Figure 4).

FIGURE 2



Each of the 1 MHz synthesizers was then compared with the 1 MHz crystal standard. The resulting spectrums are shown in Figures 5, 6, and 7.

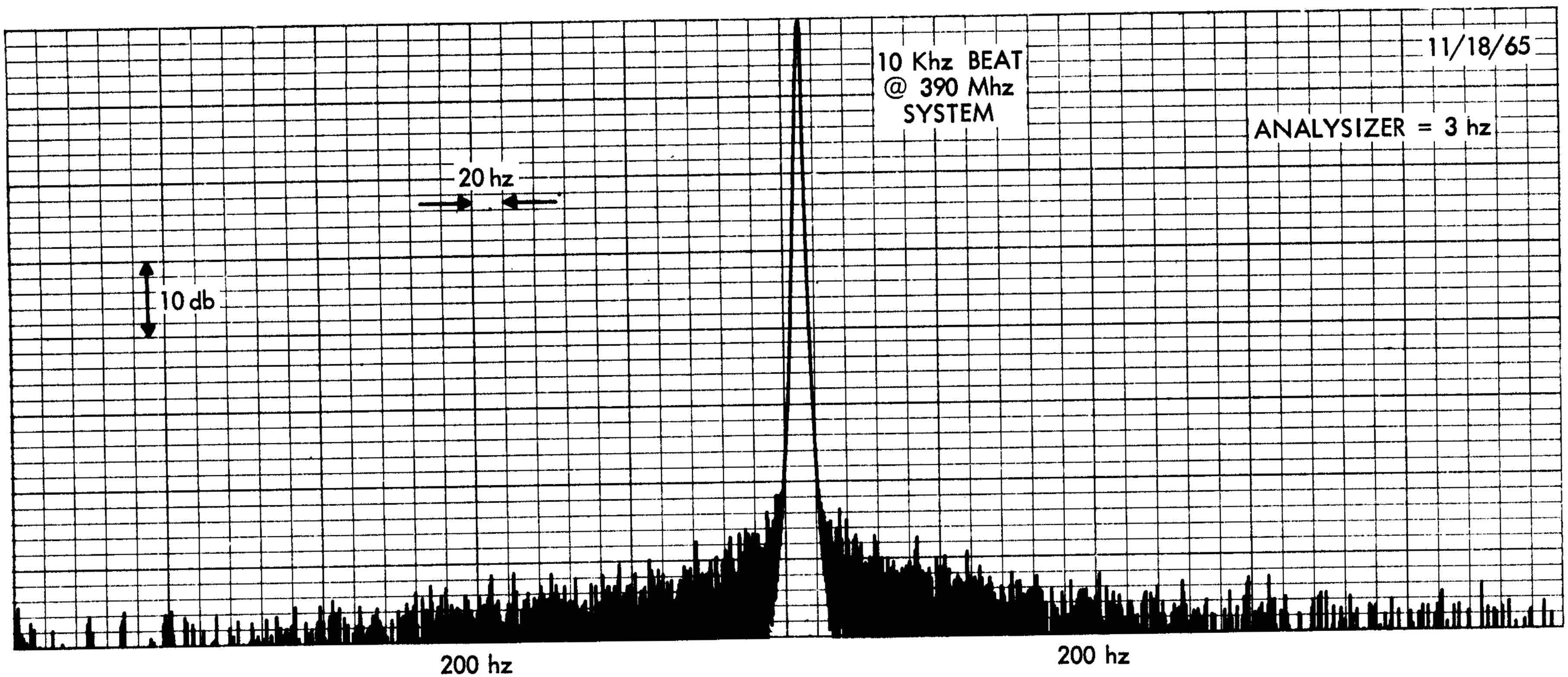

11/18/65
10 Khz BEAT
@ 390 Mhz
SYSTEM
ANALYSIZER = 3 hz
20 hz
10 db
200 hz
200 hz

FIGURE #3

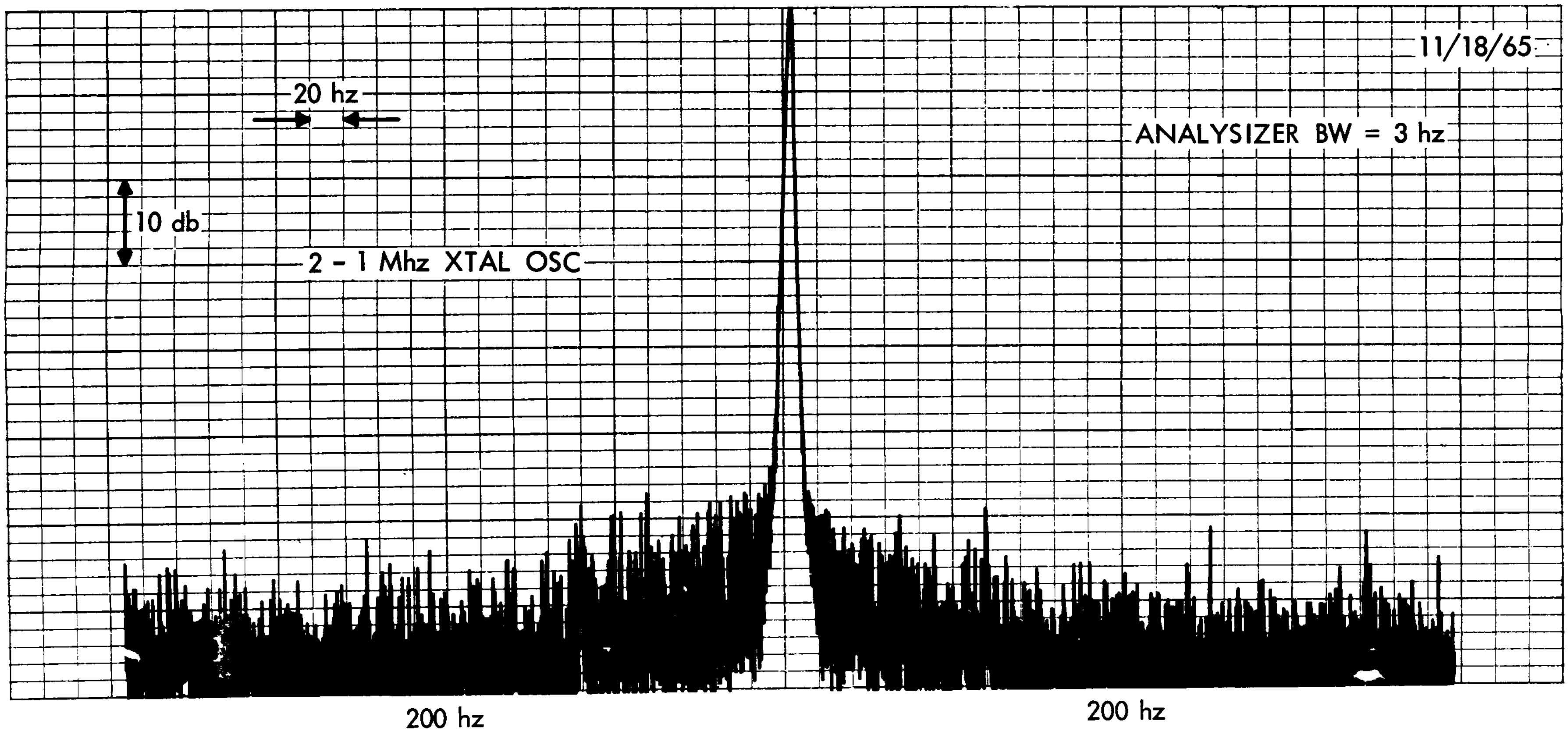

11/18/65
20 hz
ANALYSIZER BW = 3 hz
10 db
2 - 1 Mhz XTAL OSC
200 hz
200 hz

FIGURE # 4

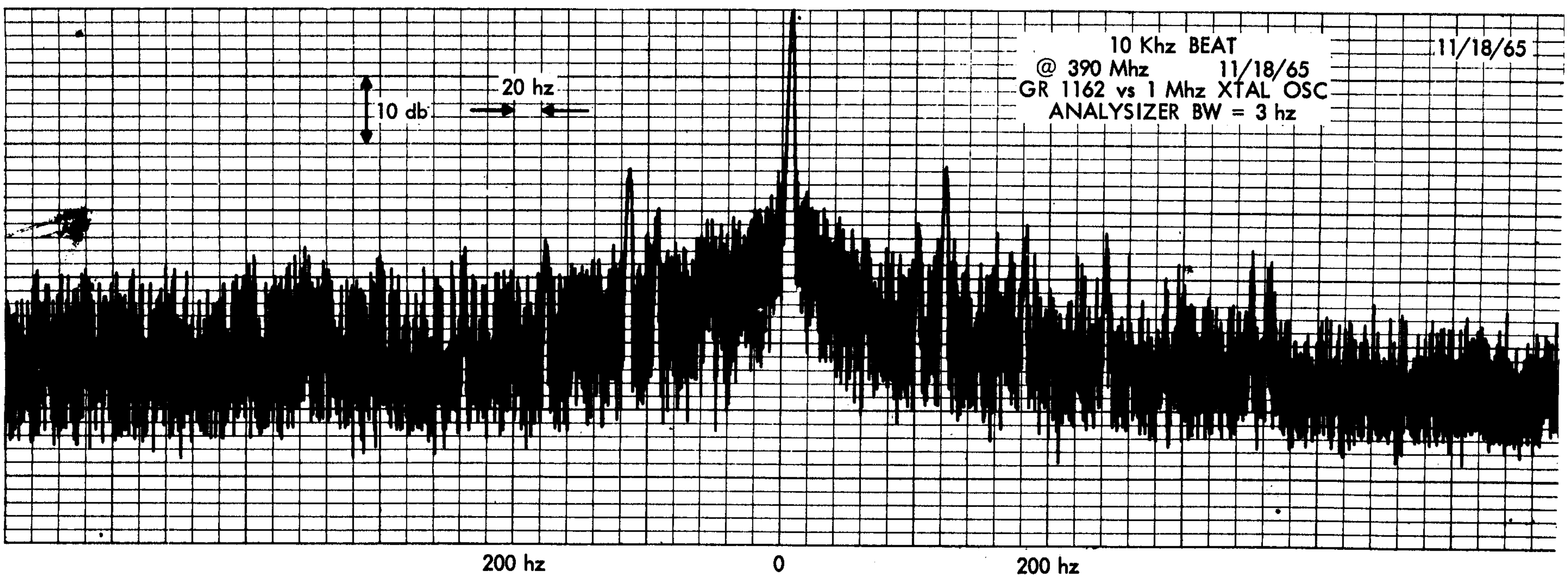

10 Khz BEAT
@ 390 Mhz 11/18/65
GR 1162 vs 1 Mhz XTAL OSC
ANALYSIZER BW = 3 hz
11/18/65
10 db
20 hz
200 hz
0
200 hz

FIGURE # 5

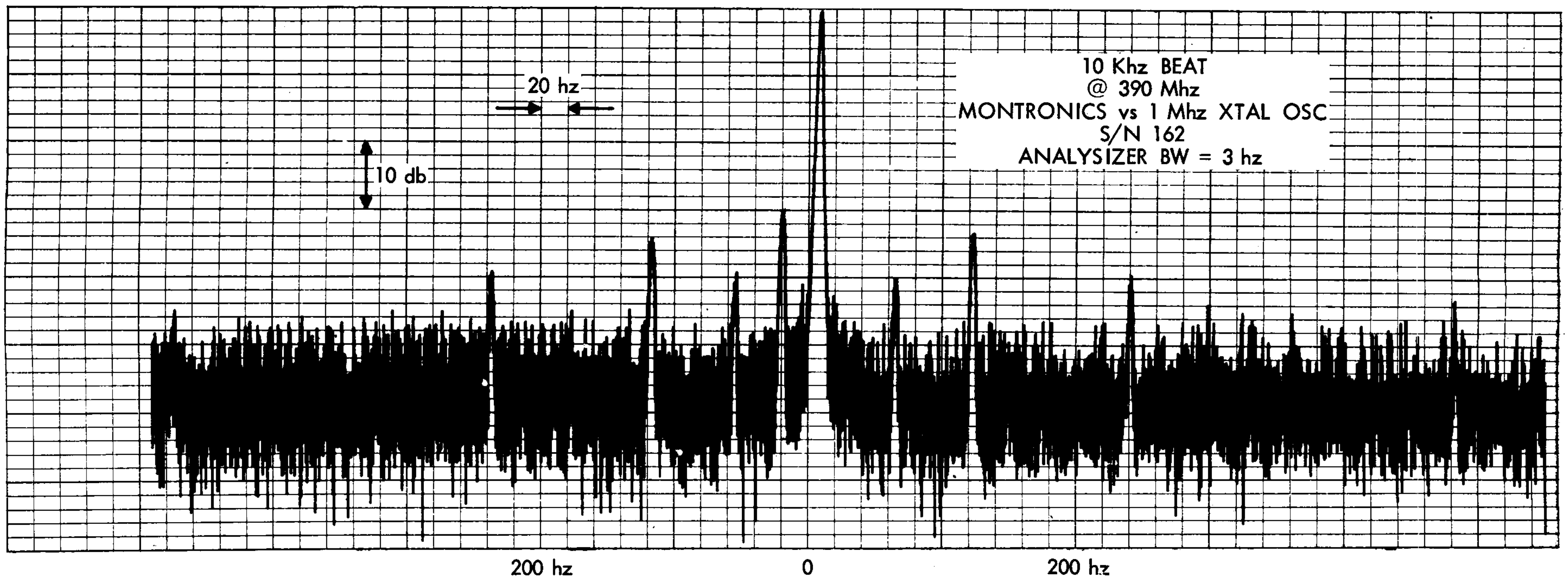

10 Khz BEAT
@ 390 Mhz
MONTRONICS vs 1 Mhz XTAL OSC
S/N 162
ANALYSIZER BW = 3 hz
20 hz
10 db
200 hz
0
200 hz

FIGURE # 6

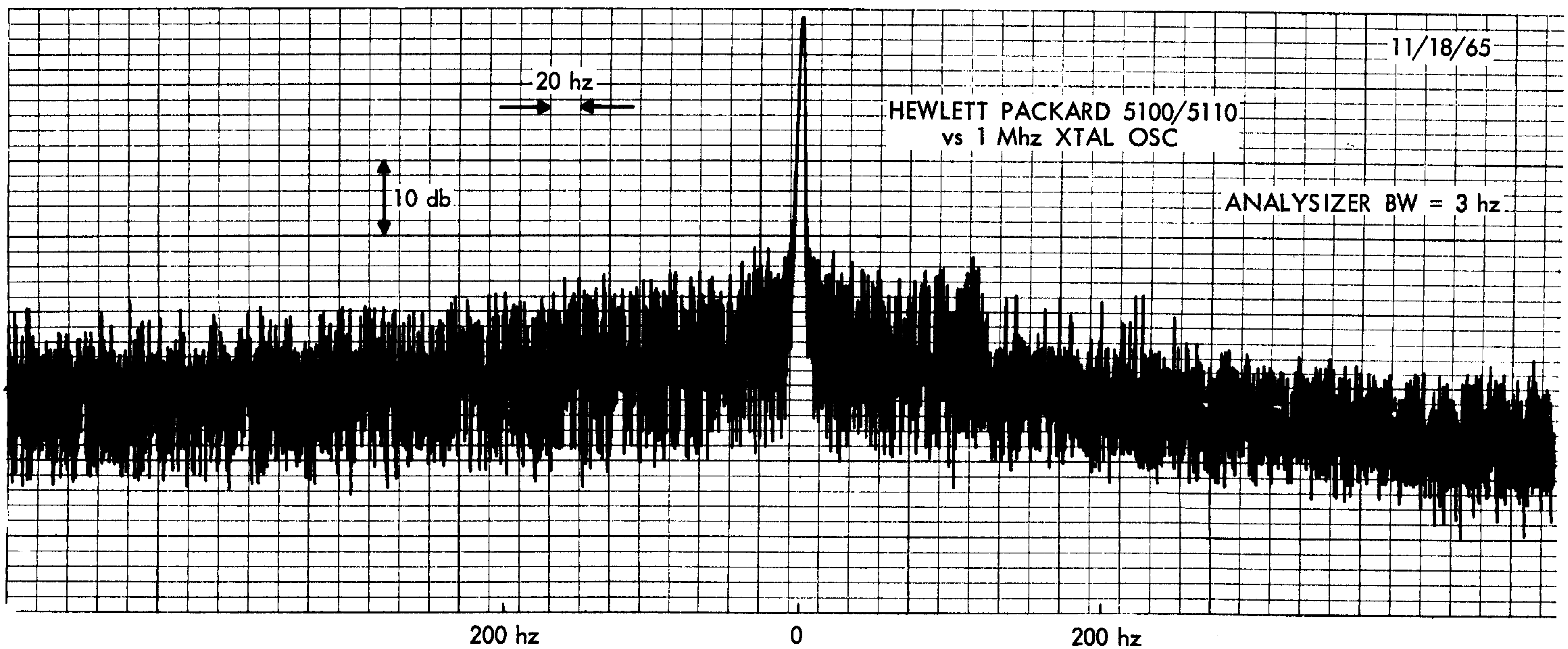

11/18/65
20 hz
HEWLETT PACKARD 5100/5110
vs 1 Mhz XTAL OSC
10 db
ANALYSIZER BW = 3 hz
200 hz
0
200 hz

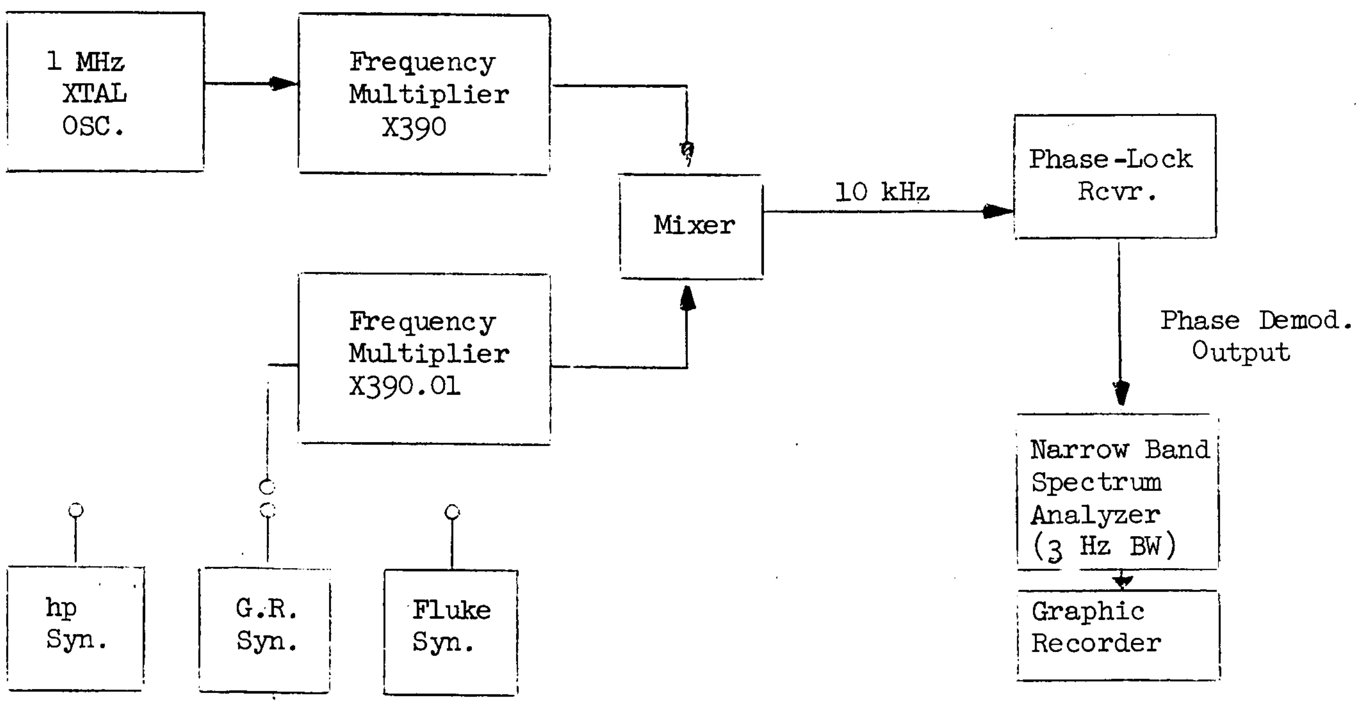
FIGURE # 7

INSTRUMENTATION FOR MEASUREMENT

PHASE FLUCTUATION SPECTRAL DENSITY

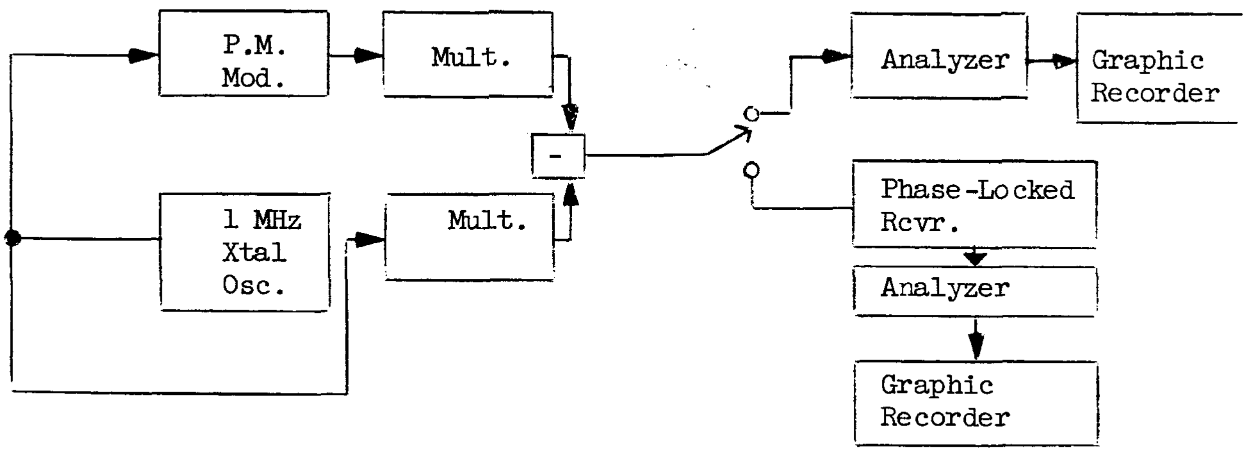
The measurement technique used to determine the phase fluctuation spectral density is shown in Figure 8. The multiplier chain and mixer assembly position of the system is identical to that used to determine the RF spectrum. The 10 kHz output of the mixer is fed to a phase lock loop receiver. The receiver used for the measurement was the Electrac Model 215 with a 3 Hz tracking bandwidth. The loop phase detector output is analyzed with a spectrum analyzer and graphically recorded.

FIGURE 8



In order to calibrate the system (i.e., the phase lock receiver), the following system configuration (Figure 9) and procedure was employed:

FIGURE 9



The signal input to one multiplier was PM modulated at a 100 Hz rate and the modulation index was increased until the spectrum of Figure 10 resulted. (Switch in Position 1)

The J_1 (λ) sidebands in Figure 10 are 22 db below the carrier, i.e. $J_1(\lambda)/J_o(\lambda) = .079$. This corresponds to a phase deviation of .16 radians. The equivalent deviation at 1 Mhz is less by the multiplication factor (390) i.e., 0.41 milliradians. The switch is then placed in position B. The mixer output is fed to the tracking receiver and the receiver phase demod output is analyzed with the spectrum analyzer. The analyzer gain is adjusted so that the J_1 (λ) sideband is full scale (Figure 11).

The measurement system is now calibrated so that a full scale deflection on the phase fluctuation spectral density plot is 0.41×10^{-3} radians. The vertical scale of the graphic recorder is in db (80 db full scale).

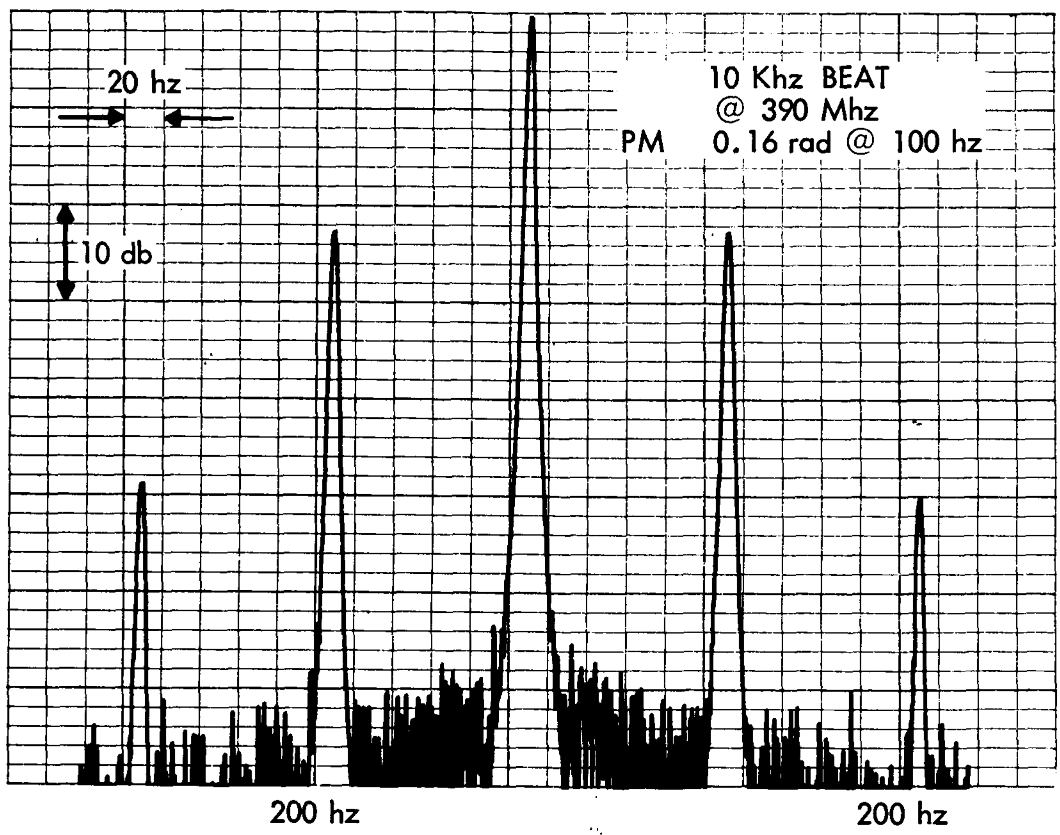
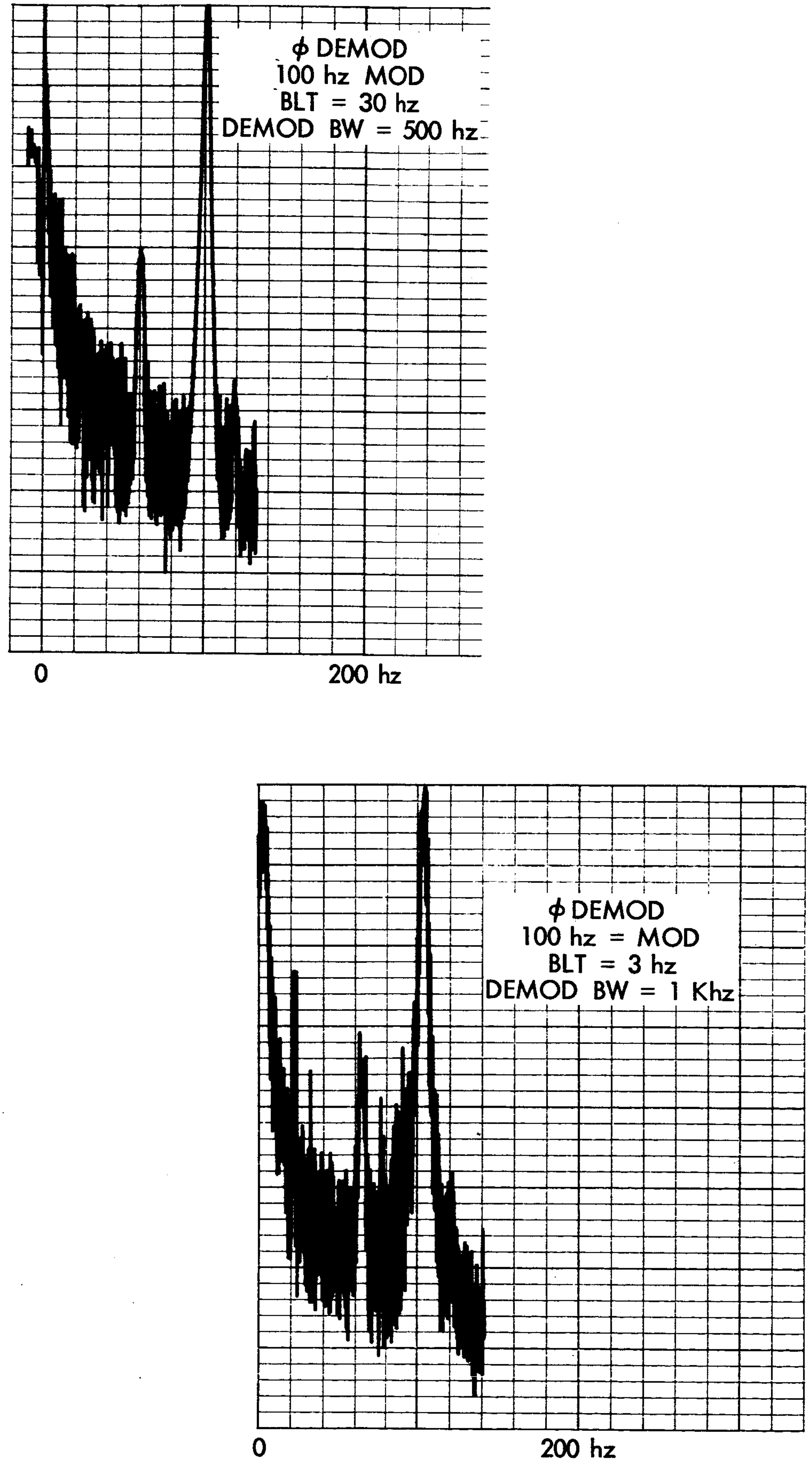


FIGURE #10



φ DEMOD
100 hz MOD
BLT = 30 hz
DEMOD BW = 500 hz
0
200 hz
φ DEMOD
100 hz = MOD
BLT = 3 hz
DEMOD BW = 1 Khz
0
200 hz

FIGURE #11

The total system noise is obtained by driving both multiplier chains from the same 1 MHz crystal oscillator. The result is shown in Figure 12.

The receiver contribution to the total system noise is obtained by locking the receiver to its internal frequency standard and removing the 10 kHz input to the receiver. Figure 13 is the resulting phase fluctuation spectral density.

Prior to the synthesizer comparisons against a 1 MHz crystal oscillator, two 1 MHz crystal oscillators were compared. Figure 14 is the resulting plot. The comparison of the synthesizers with a 1 MHz crystal oscillator are shown in Figures 15, 16, and 17.

In addition to the spectral information, a comparison of each of the three units with a hydrogen maser was made in order to establish aging characteristics. The Fluke exhibited an aging rate of approximately 1.7×10^{-9} per day. In addition to the aging, a 3.2×10^{-9} frequency change was observed when the 1 MHz internal standard auxiliary output was terminated with 50 ohms.

Aging of the GR 1162 was unobtainable due to temperature dependent frequency excursions. These excursions were typically 3 to 4 parts in 10^7 and were due to the non-controlled environment in which the internal crystal standard is placed.

The Hewlett Packard unit aged at a rate of 2×10^{-9} per day.

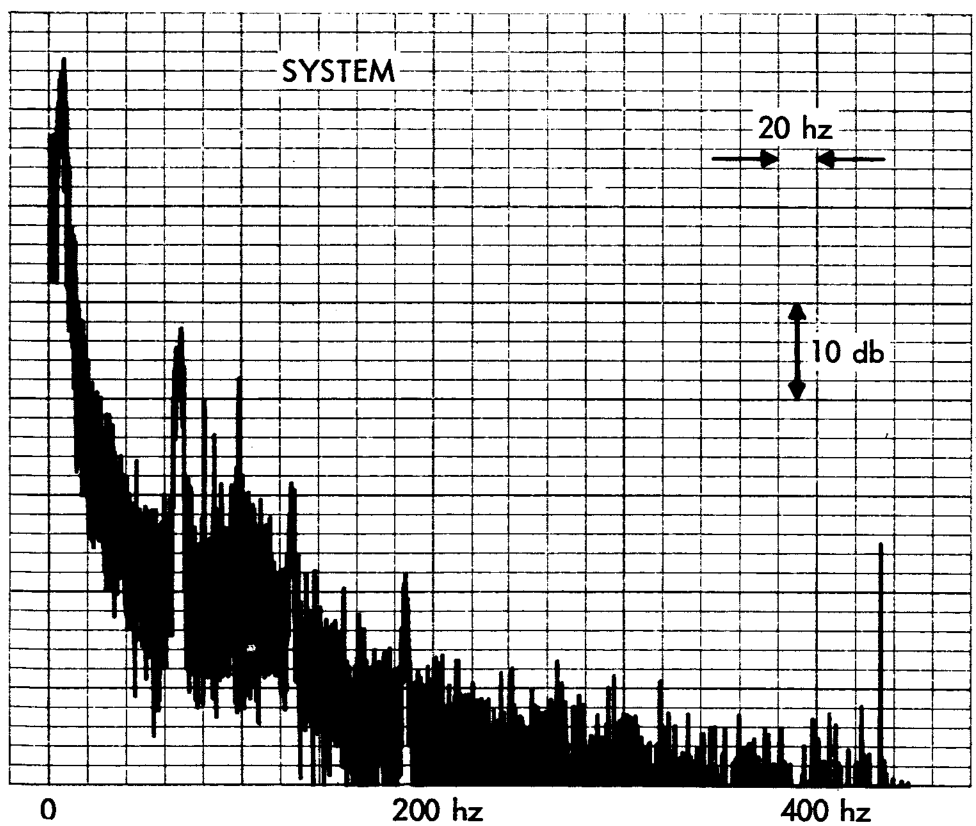


FIGURE #12

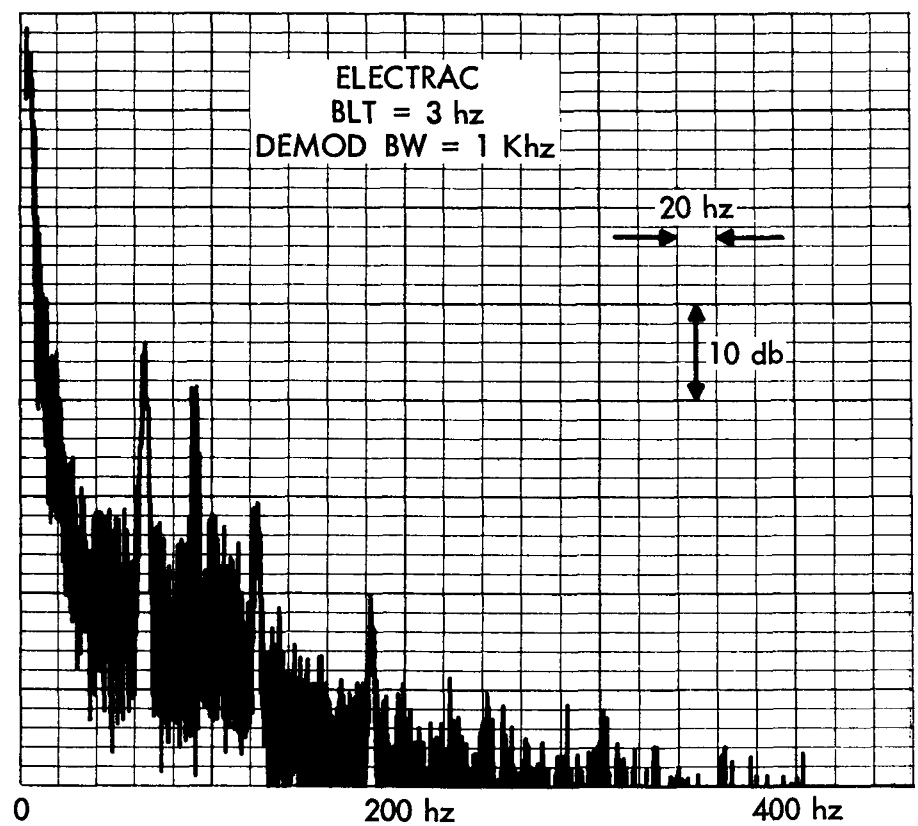


FIGURE #13

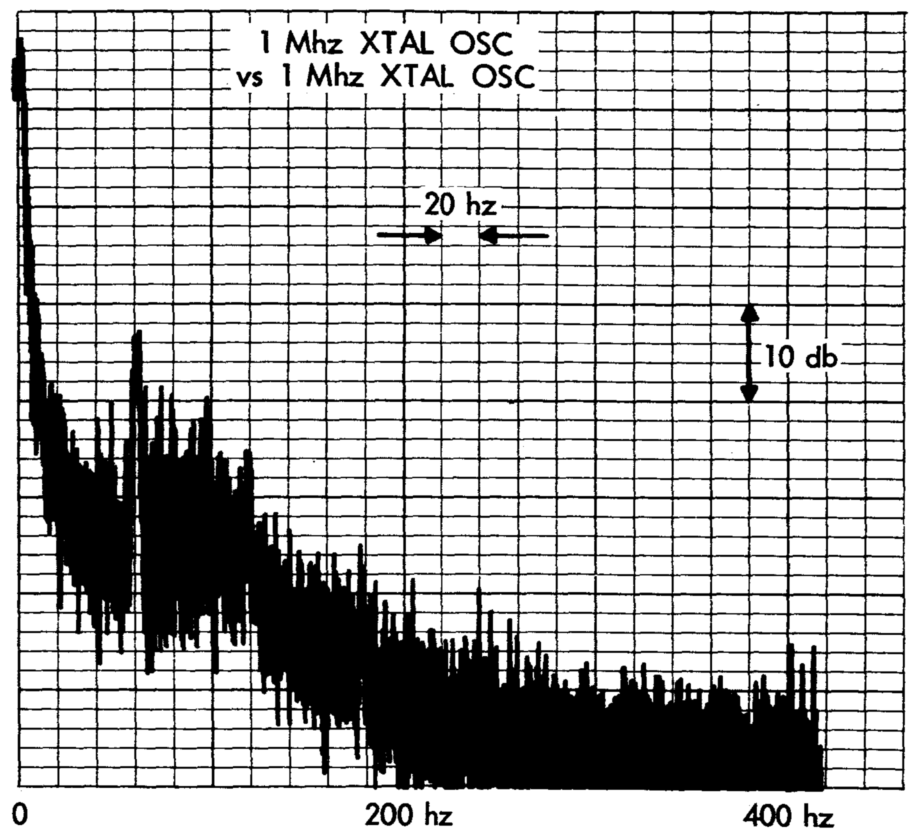


FIGURE #14

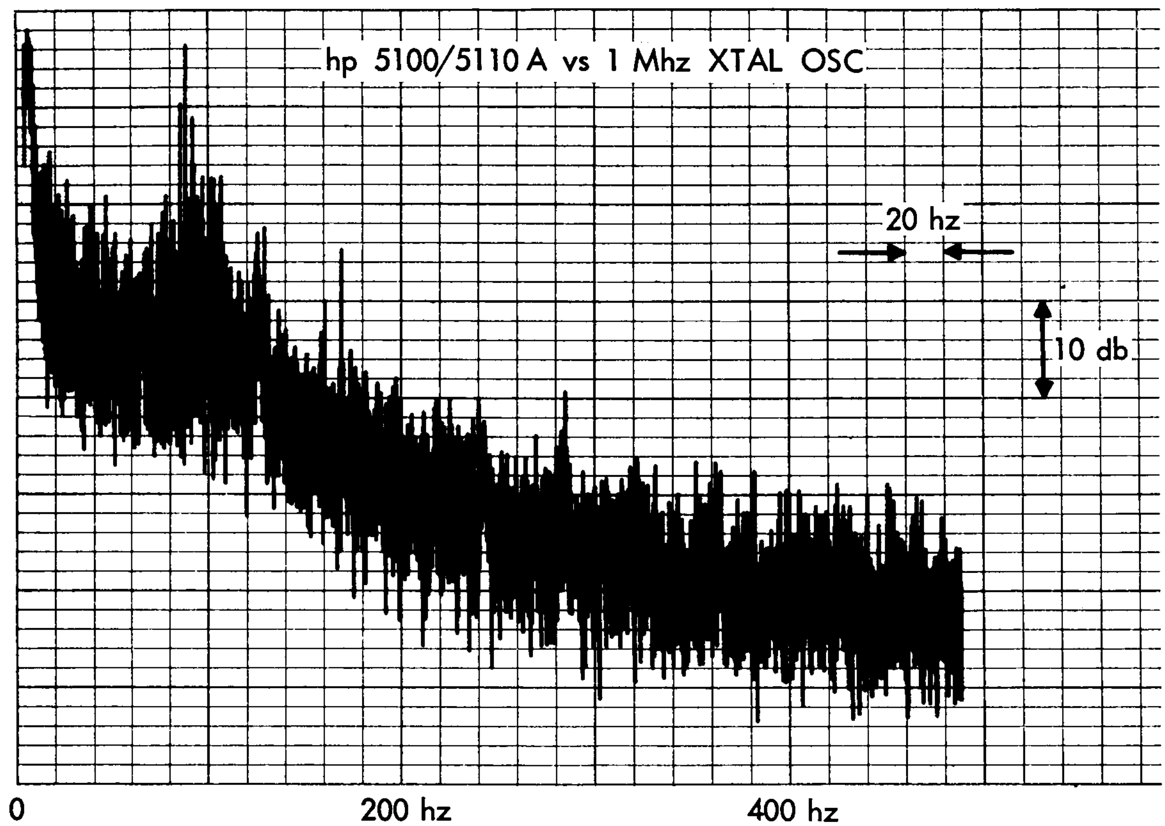


FIGURE #15

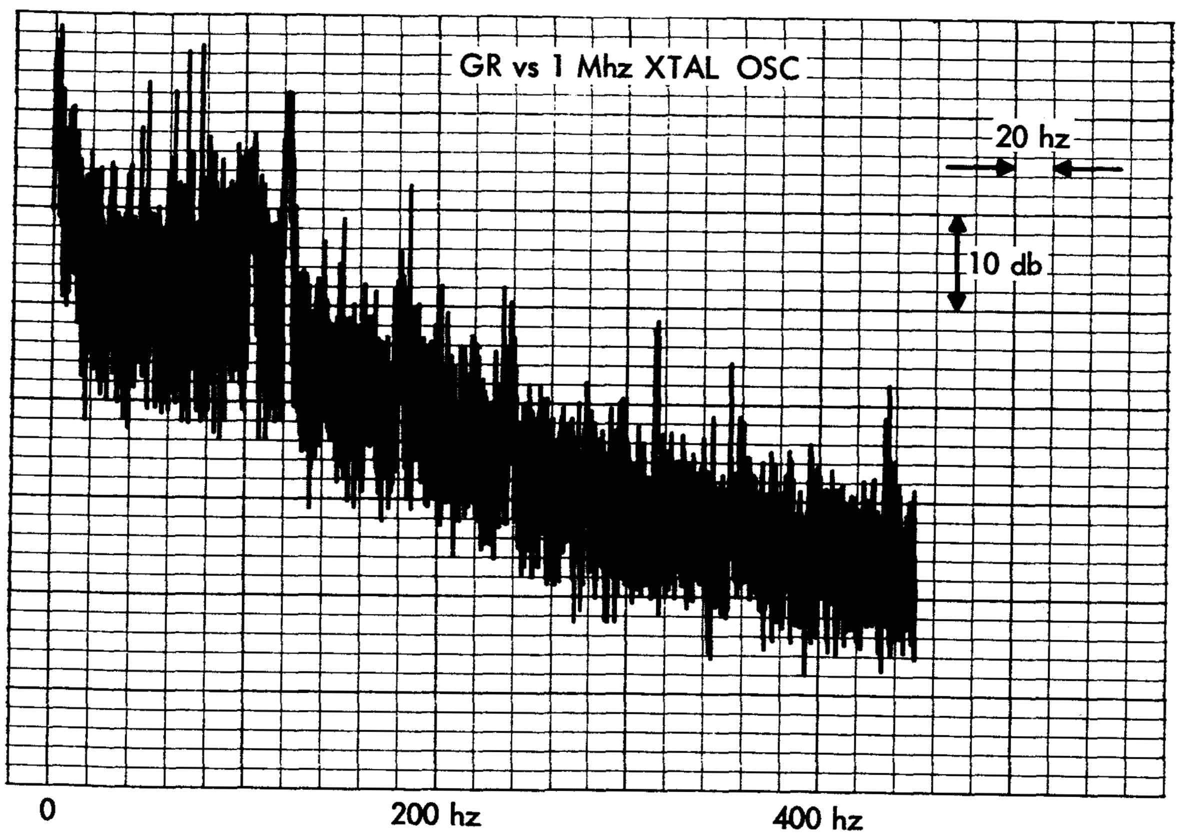


FIGURE #16

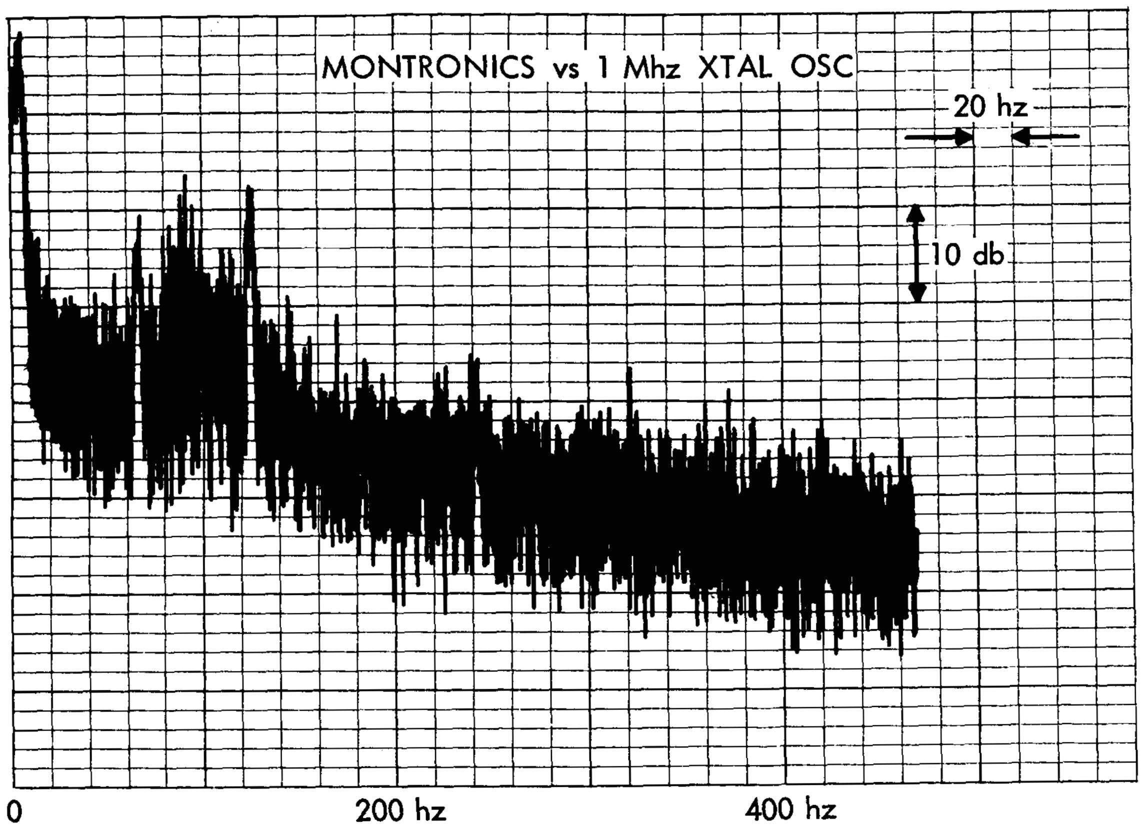


FIGURE #17

CONCLUSIONS

The plots of the RF spectrums indicate that there are areas in the frequency domain where one of the synthesizers was better than the other two. Spurious signals appeared in spectrums of both the General Radio and the Fluke. No spurious was detectable in the Hewlett Packard unit. Additive noise at frequencies greater than 500 Hz was approximately the same for all units. At frequencies nearer the carrier, the Fluke shown approximately 10 db improvement over the other two units. The plots of the phase fluctuation spectral density lead to the same conclusions which were drawn from examining the RF spectrum.

It should also be noted that the synthesizer which provides the best spectral characteristics at 1 MHz may not be the best for a given application. It is interesting to note that the output frequency of a synthesizer is seldom sythesized directly, but is the result of various sum and difference frequency combinations. This technique is used to avoid undesired spurious in the output over the desired range of frequency coverage. Associated with the sum-difference technique are frequency bands which exhibit the same spectral characteristics as the final output signal. For example, the spectrum which Hewlett Packard 5100 exhibits at 1 MHz also exists from 0 to 50 MHz, 30 to 31 MHz, 360 to 361 MHz and 390 to 400 MHz. Similarly, the GR synthesizer spectrum exists at 50 to 51 MHz and the Montronics spectrum exists from 10 to 11 MHz. If, for example, frequency coverage from 3.9 to 4.0 Ghz is desired a spectrum degradation by a factor of ten would result if the Hewlett Packard 390 to 400 MHz output was multiplied by ten. Frequency coverage around 4 Ghz, through the use of the GR synthesizer or the Montronics synthesizer, would result in a spectrum degraded by a factor greatly in excess of ten due to the higher multiplication factor required. Because of the availability of these spectrums at different frequency intervals, the choice of one synthesizer over the other is dependent on the intended application.

In any event, the spectrums included in this report, along with some knowledge of the frequency intervals at which the spectrums are available in a given synthesizer, will permit the user to determine which of the three is best suited for a given application and the spectral characteristics which may be expected.