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# PHASE LOCKED TRACKING FILTERS FOR INTERFEROMETRY

BY

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# Phase Locked Tracking Filters for Interferometry

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## ABSTRACT

Three phase locked tracking filters that have been built for use with microwave and laser interferometers are described. Block diagrams, circuit diagrams and test data are presented.

# INTRODUCTION

The intermediate frequency signals resulting from plasma density measurements with microwave and laser interferometers have a wide dynamic range and at times suffer from complete drop outs. Phase shifts normally span many complete cycles or fringes so the detector must have some form of memory. One way to build such a detector is with digital logic. It is important to provide a clean signal with single transition edges to the digital device to prevent erroneous fringe counting. A good method for cleaning up a noisy analog signal with widely varying amplitude is to use a phase locked tracking filter. Three such filters built for separate experiments are described in this report.

One Megahertz Phase-Locked Loop

A 1MHz PLL has been constructed for use in each channel of a multichannel 2mm microwave interferometer on the PDX tokamak. The interferometer employs homodyne detection, and a basic block diagram of one channel is shown in Fig. 1.

An Extended Interaction Oscillator tube is used to generate the 2mm signal. It is frequency modulated with 1MHz saw tooth voltage applied to its cathode. Part of the microwave signal is passed through the plasma and mixed with a direct signal from the EIO. The resulting 1MHz mixer output is amplified by a low noise differential preamp. The preamp output signal must be converted to a digital wave form in order to drive the digital phase detector. A level sensitive trigger circuit at this point would severely limit the system dynamic range. This is due to the high signal to noise level required by a trigger circuit to provide a clean single transition waveform. The phase locked loop averages many cycles of the preamp output to preserve the signal phase. The phase locked oscillator output is a clean signal free of multiple transitions having the required digital format.
The output signal is computer processed for diagnostic purposes.

Figure two is a block diagram of the phase locked loop. The input signal from the pre amp is passed through a band pass filter to eliminate wide band noise and other interference. A limiting amplifier follows the filter and drives two phase detectors. Phase detector U4 is associated with the phase locked loop and drives the loop filter. The VCO operates at 4 MHz and is divided to 1MHz with a Johnson counter to provide quadrature outputs. The PLL will lock at 90 degrees so the drive to phase detector U5 is in phase. U5 acts as a synchronous detector and is followed by threshold detector U6. The threshold is adjusted so that low signal levels will be ignored. The PLL stays locked to an even lower signal level so the following digital phase detector never operates on erroneous data.

Phase locked loop bandwidth has been designed so as not to degrade the incoming data even at very high rates of change. With the loop parameters specified in figure 2 a tracking error equal to the digital phase detector resolution ($\frac{1}{16}$ fringe) occurs for a phase slope of $3.3 \times 10^5$ radians per second. This is a factor of 2 or 3 above the maximum rates expected. The Bode plot is shown in Fig. 3.

Threshold characteristics are shown for the 1MHz loop in Fig. 4. This is a measured characteristic and does not include the differential preamplifier. For signals greater than -13dbm the loop pull in range is 0.84 to 1.12MHz. As the signal level is decreased the pull in range decreases and for signals below -97dbm the loop will not pull in at all. The response of the signal detector is also shown for a setting of -42dbm.

The schematic is shown in Fig. 5. Pad layouts are provided on the printed circuit for an input pi attenuator. This attenuator is adjusted for the proper signal level at the following signal detector.

The input transformer, a Minicircuits Lab part number T1-1, provides ground isolation.

The 1MHz bandpass filter is a three pole Butterworth unit manufactured by Lorch Electronics Corporation to our order. Their part number is BP-1-15-P. Other bandwidths are also available in the same case. U1, a Motorola MC1590G, acts as a limiting amplifier and provides 39db gain. The two phase detectors, U4 and U5, are Minicircuits Lab part number SRA-3 double balanced mixers. The loop filter function is provided by U3, an LM318 wideband operational amplifier. U2 is a buffer that allows the output of U3 to be remotely examined. The VCO, U7, is run at 4MHz and dual Flip Flop U8 divides its output to 1MHz. U6 is a differential comparator with adjustable threshold for detecting any input signal.

Figure 6 shows the printed circuit board arrangement. The bandpass filter is designed as a plug in module so that its bandwidth may be easily changed.

## Thirty Megahertz Phase Locked Loop

A basic Heterodyne interferometer is shown in Fig. 7. The heterodyne process may be implemented at much higher intermediate frequencies than the homodyne since there is no need to modulate the microwave source. Also, it offers a potentially greater dynamic range. Two microwave sources are offset by thirty MHz with a synchronizer (PLL) Part of the output power of Klystron #1 is passed through the plasma and heterodyned with Klystron #2. The resulting 30MHz signal is processed by the 30MHz PLL. The 30MHz reference and PLL outputs are heterodyned to 1MHz to be compatable with the existing digital phase detector.

Figure 8 is a block diagram of the 30MHz PLL. It is similar to the 1MHz PLL except that the signal detector is not synchronous. A 31MHz crystal oscillator is used to heterodyne the VCO output and the reference to 1MHz.

Thirty megahertz was chosen because of the available commercial synchronizer for the microwave tubes. The loop output was heterodyned to 1MHz to be compatible with the digital phase processing boards built previously.

The Bode plot for this loop is shown in Fig.9. From this open loop data the closed loop frequency response was calculated and is shown in Fig.10.. Several measured points were also plotted. The major source of error is nonlinearity in the frequency vs voltage characteristic of the VCO.

Other loop measurements are shown in the following table.

| | |
|---|---|
| Pull in range | 29.32MHz to 30.66MHz |
| Hold in range | 28.40MHz to 30.68MHz |
| Pull in time | 25ms for 100KHz offset. |
| Loop threshold | Vin = 1.8mV rms. |
| Signal Detector threshold | Vin = 10mV rms. |
| Full Limiting | Vin = 70mV rms. |

Figures 11 and 11A show the schematic diagram. Two top coupled tuned circuits act as a bandpass filter for the input 30MHz signal. An MC1590G limiting amplifier follows the filter. A Mini-Circuit SRA-3 mixer is used as the phase detector. An LM318 operational amplifier is used as the loop filter. The MC1648 VCO uses an LC tuned circuit with a varactor diode for tuning. The 2N3904 prevents the error voltage from forward biasing the varactor and stopping the oscillator.
The VCO output is buffered and distributed to three circuits with an MC10114. One output drives the SRA-3, one is a monitor and the third drives an MC12002 (Fig. 11A) mixer through a tuned matching network. A Vectron crystal oscillator operating at 31MHz drives the other mixer port. The resulting 1MHz lower sideband is separated by a 1MHz bandpass filter.

The 30MHz reference signal is heterodyned in the same manner to 1MHz. The two outputs are compared by the digital phase detector.

## One Hundred Kilohertz Phase Locked Loop.

The 100KHz PLL was constructed for use with an HCN Laser Heterodyne Interferometer. This loop is very similar to the 1MHZ PLL and will not be described in detail. The schematic is shown in Fig. 12. The input stage is a bandpass limiter rather than separate units. The closed loop band width is 10KHz.

## Summary

Several versions of phase locked tracking filters have been implemented for use in millimeter and sub-millimeter interferometers for plasma electron density measurements. These filters have improved system performance both by removing noise that might disturb subsequent digital processing and by providing a detector for loss of signal.

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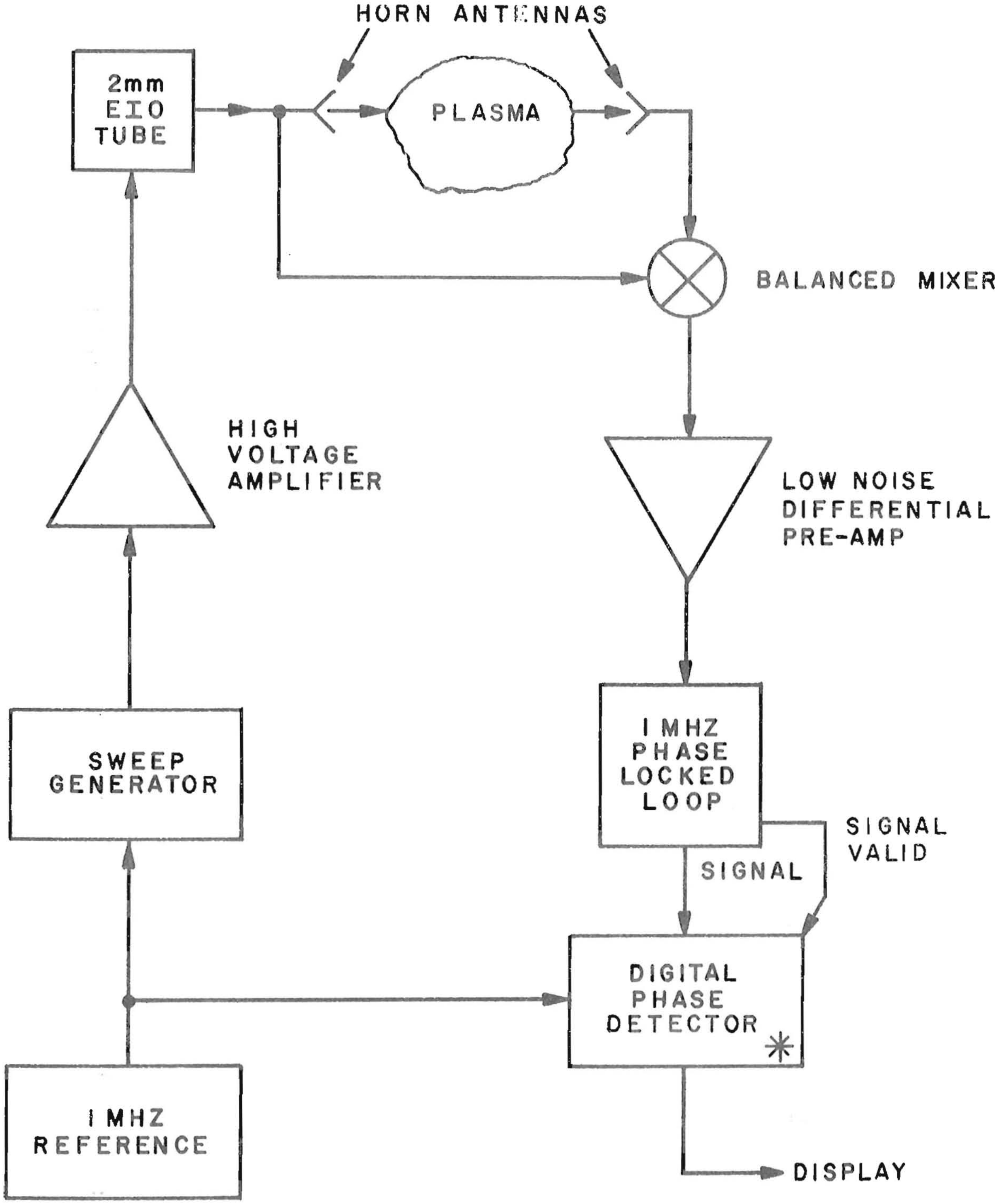
# REFERENCES

1. PPPL-1466 "Digital Multiradian Phase Display Circuit" A. Greenberger 1978.

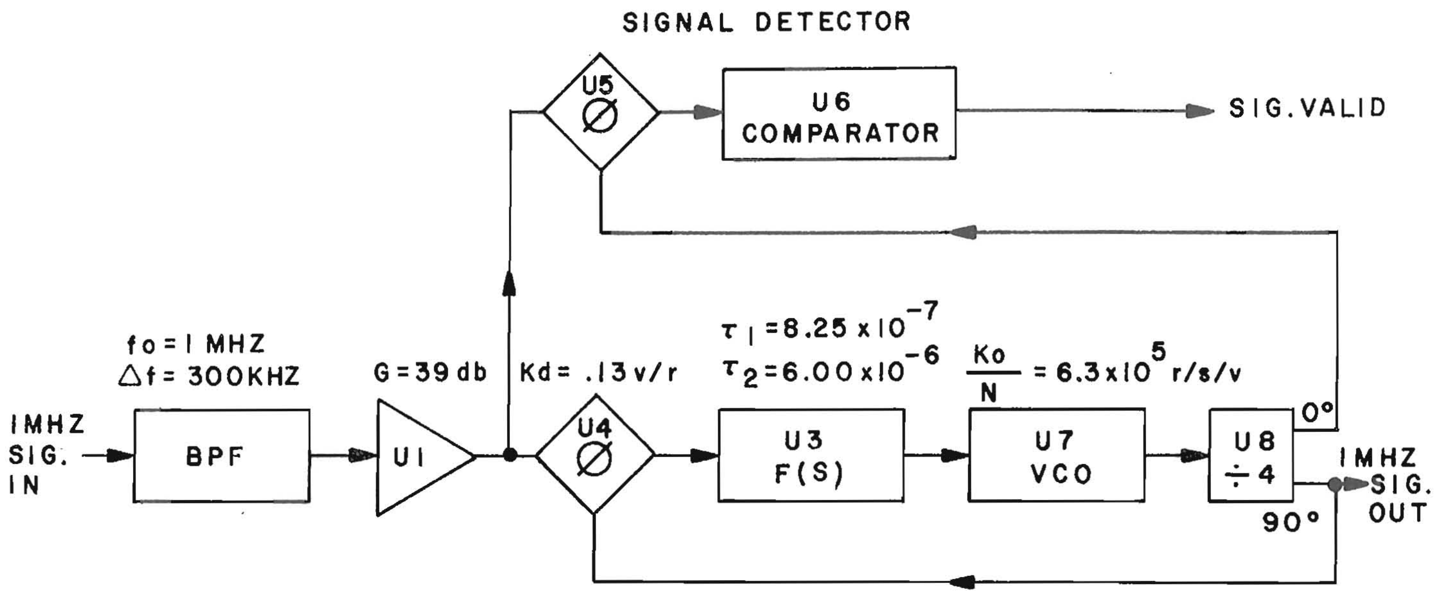
2. Phaselock Techniques Floyd M. Gardner, John Wiley & Sons, Inc. 1966.




BASIC HOMODYNE MICROWAVE INTERFEROMETER

* SEE REFERENCE I

FIGURE I




$$\omega_n = \sqrt{\frac{K_o K_d}{\tau_1}} = 315\,Kr/s = 50.1\,KHZ$$

$$\zeta = \frac{\tau_2}{2}\omega_n = 0.95$$

1MHZ PHASE LOCKED LOOP

FIGURE 2

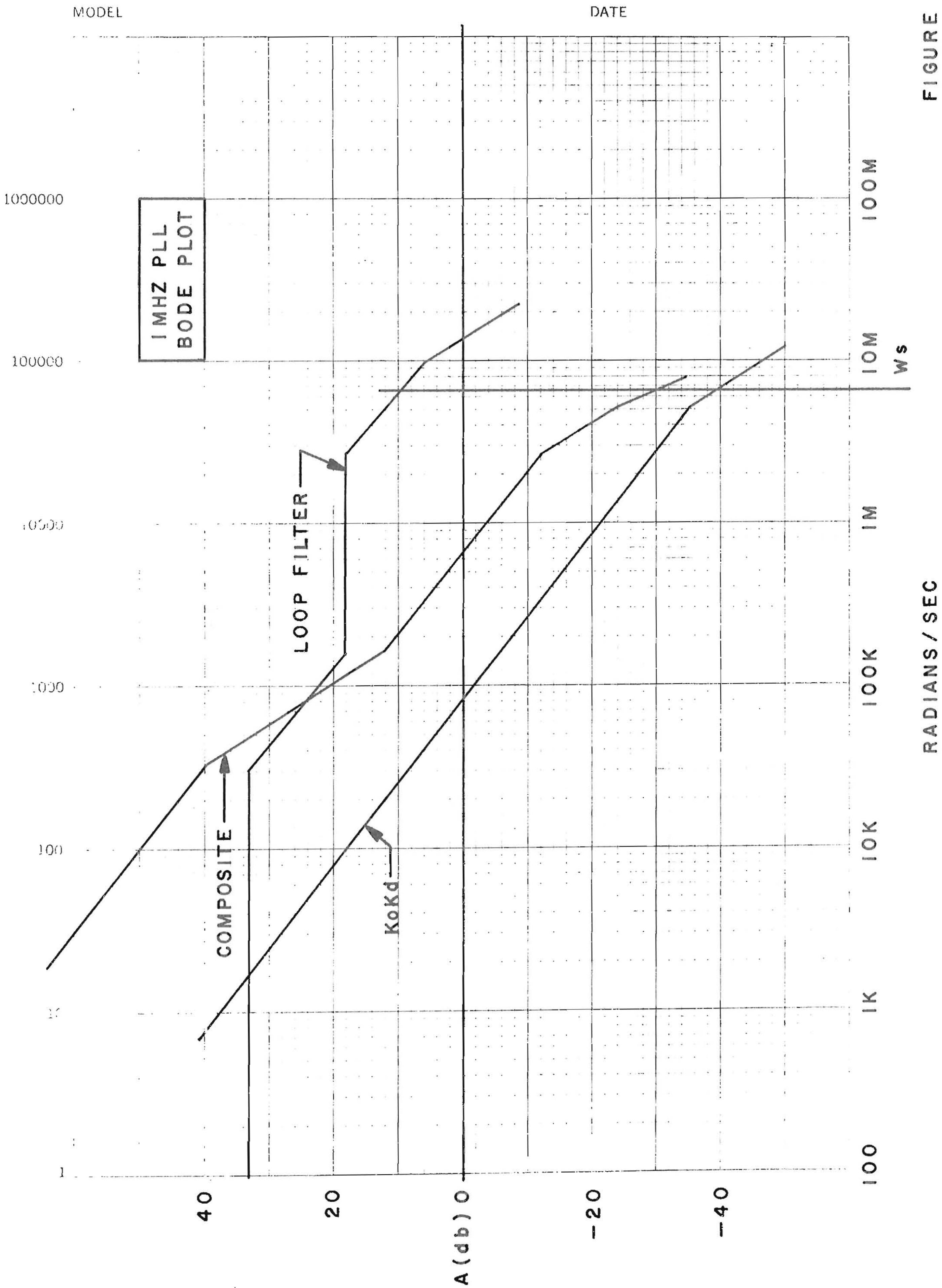

MODEL
DATE
1 MHZ PLL
BODE PLOT
LOOP FILTER
COMPOSITE
KoKd
Ws
A(db) 0
40
20
-20
-40
100
1K
10K
100K
1M
10M
100M
RADIANS/SEC
1000000
100000
1000
100
1

FIGURE 3

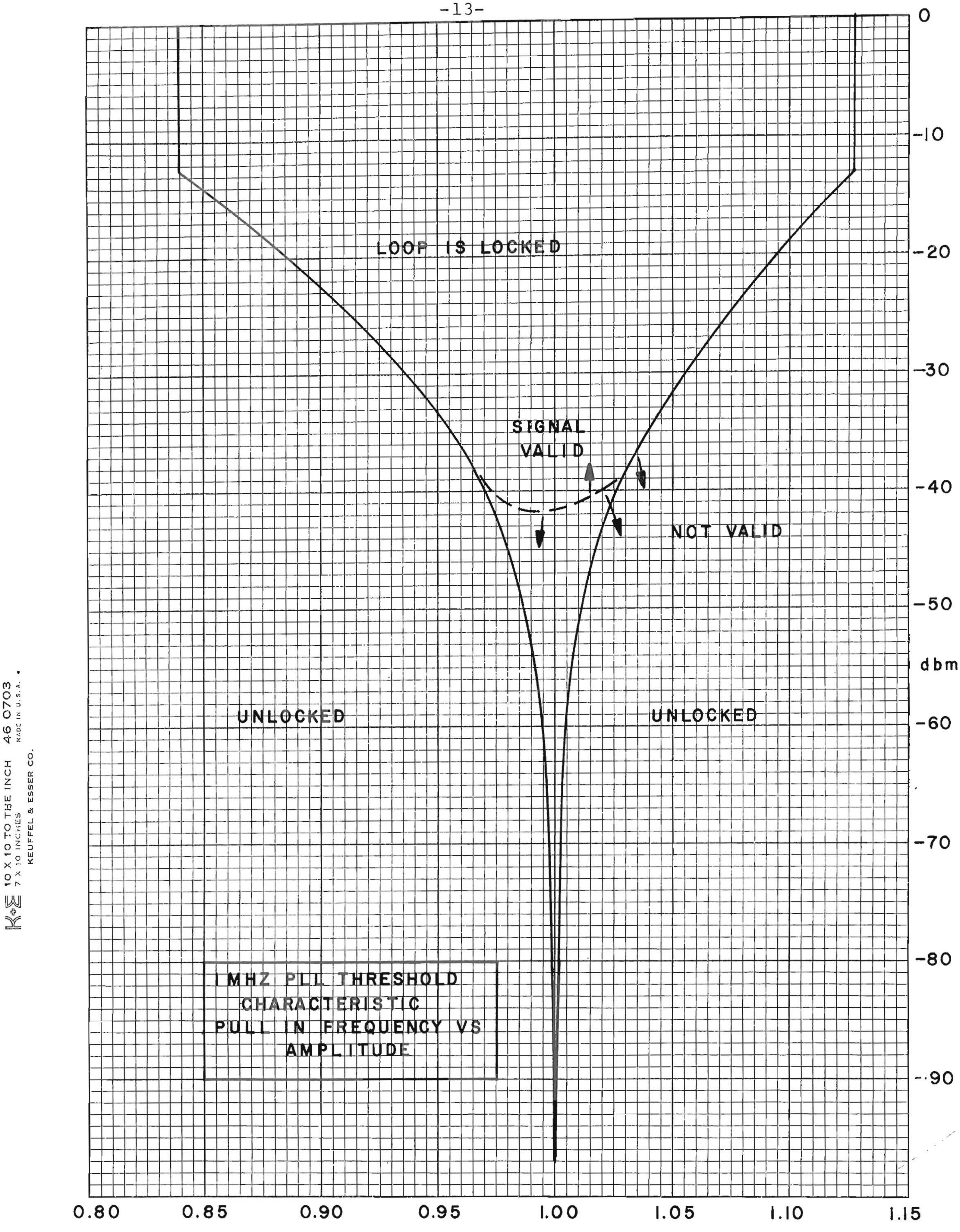

0
-10
-20
-30
-40
-50
dbm
-60
-70
-80
-90
LOOP IS LOCKED
SIGNAL
VALID
NOT VALID
UNLOCKED
UNLOCKED
1MHZ PLL THRESHOLD
CHARACTERISTIC
PULL IN FREQUENCY VS
AMPLITUDE
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
MHZ
K&E 10 X 10 TO THE INCH 7 X 10 INCHES
KEUFFEL & ESSER CO.
46 0703
MADE IN U.S.A.

FIGURE 4

HOMODYNE PHASE LOCKED LOOP BOARD

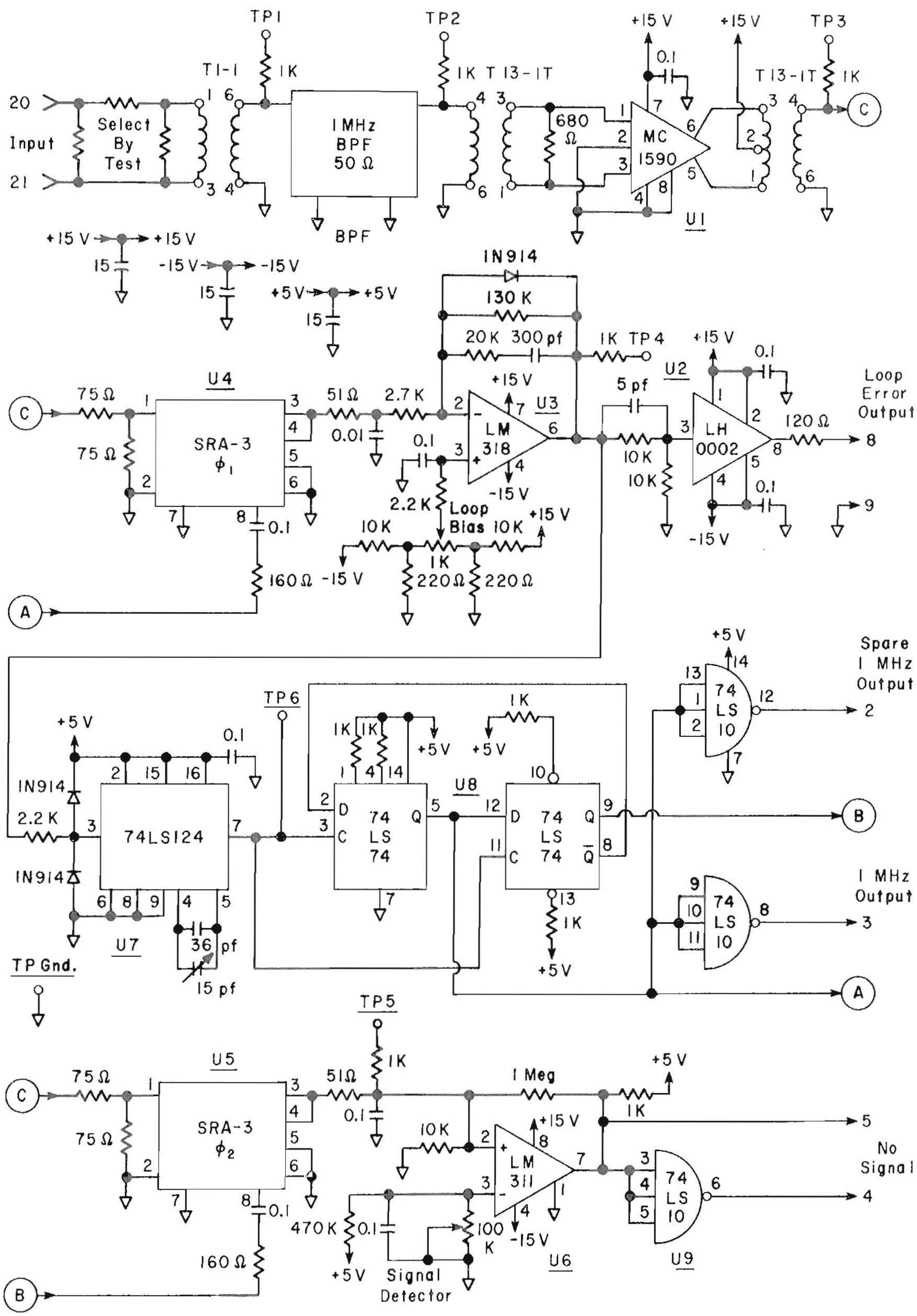



FIGURE 5    794288

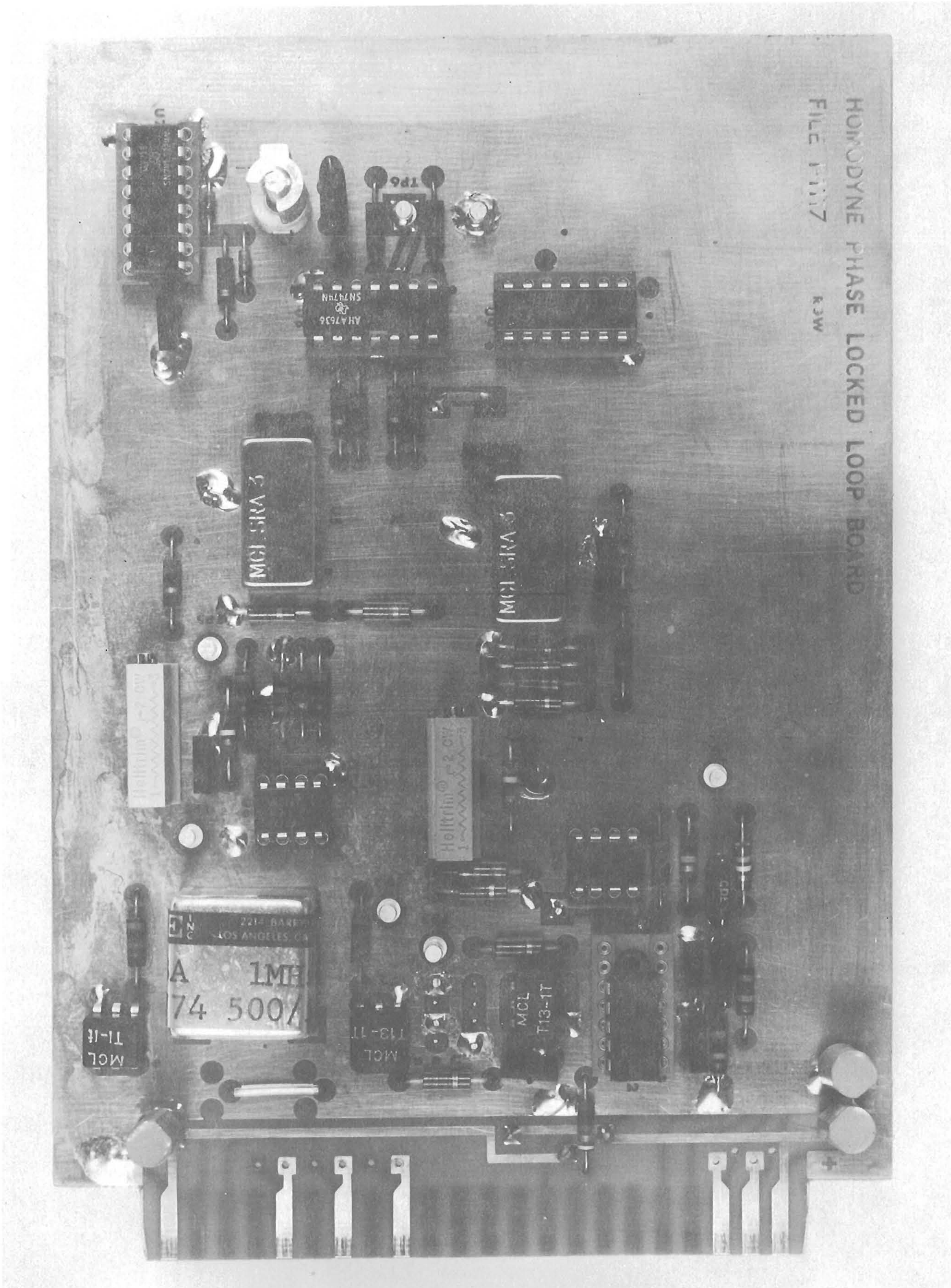
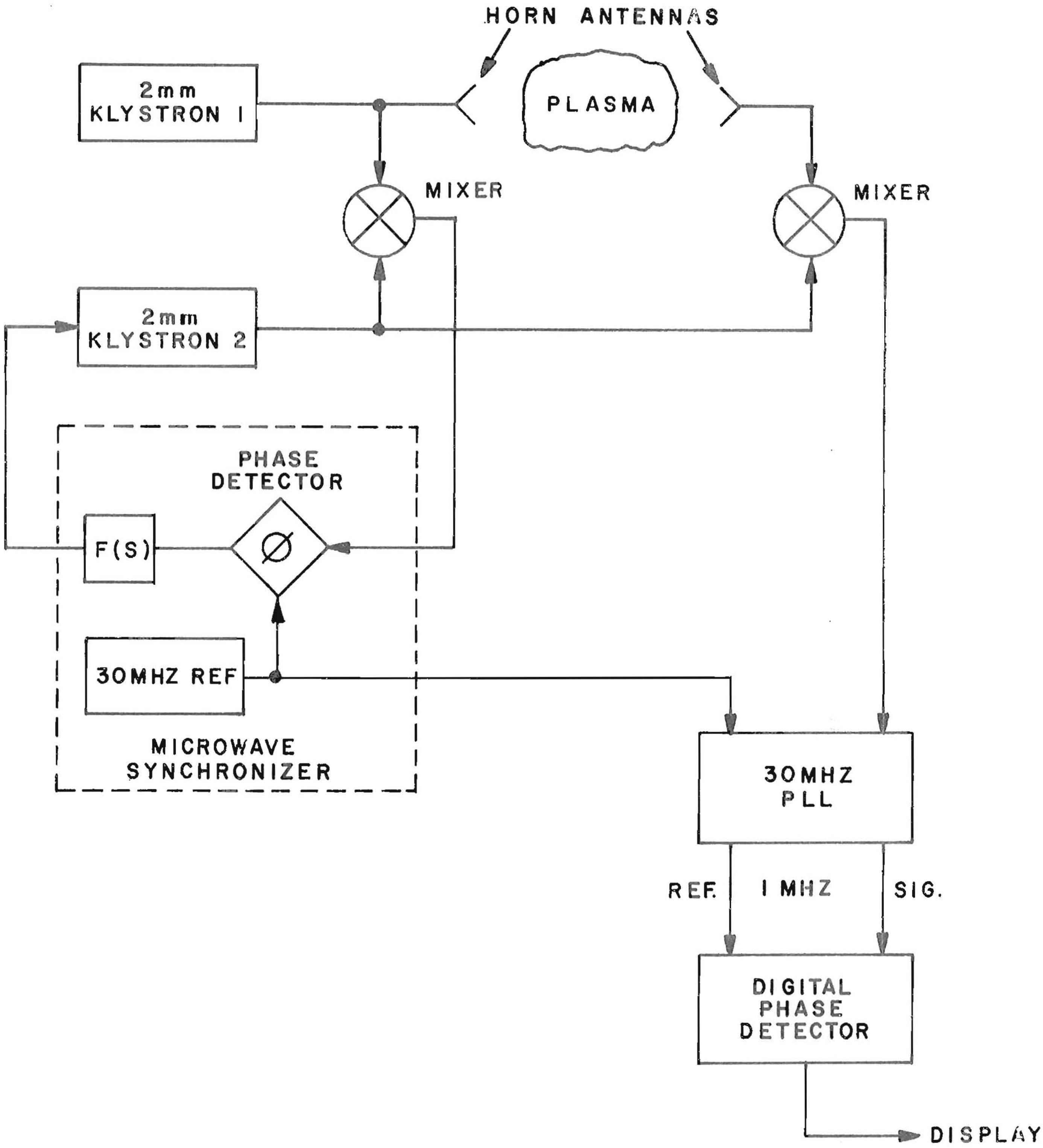
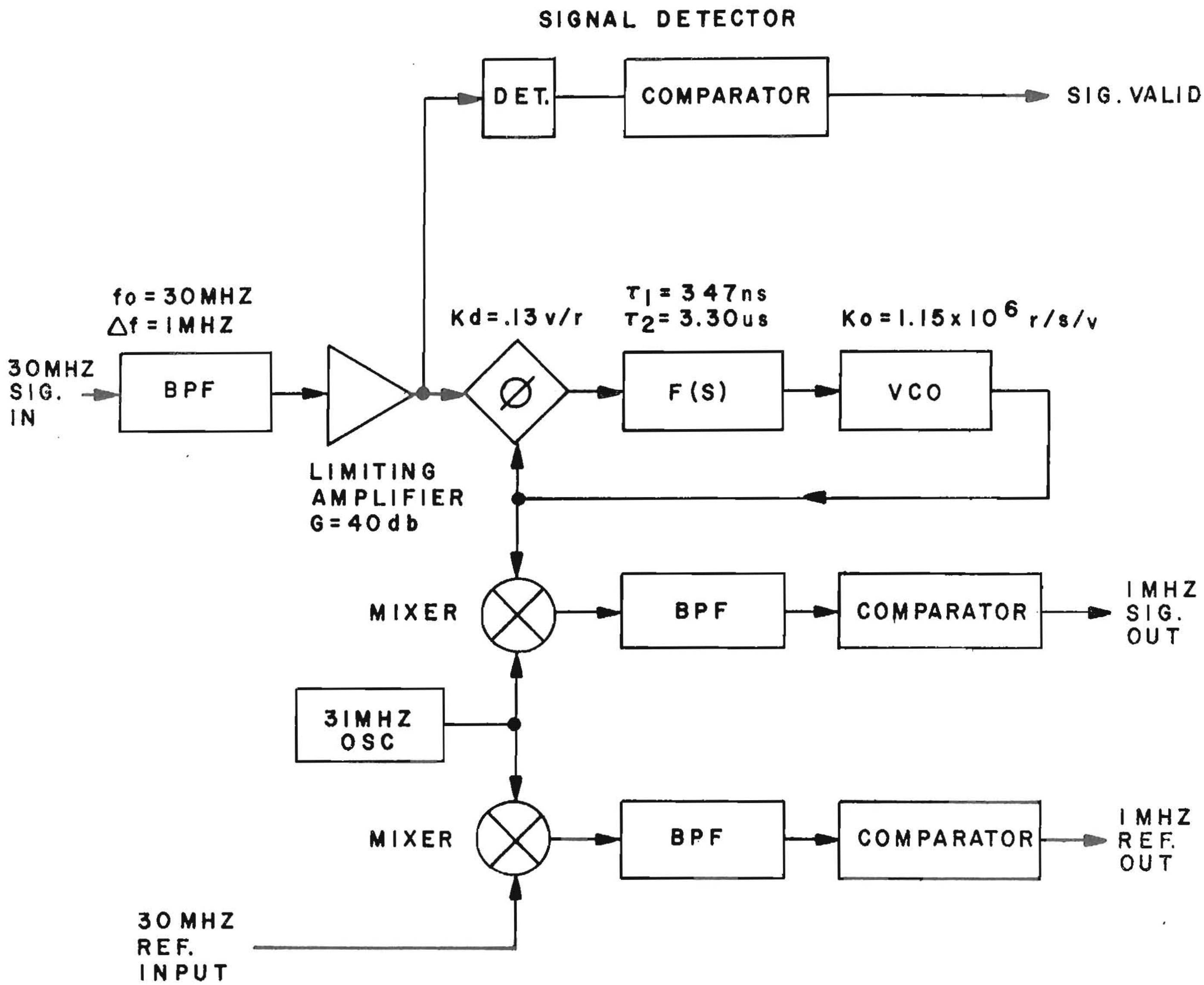

HOMODYNE PHASE LOCKED LOOP BOARD
MCL SRA 3
MCL SRA 3
MCL T13-1T
MCL T1-1t

FIGURE 6




BASIC HETERODYNE MICROWAVE INTERFEROMETER

FIGURE 7




$$\omega_n = \sqrt{\frac{K_o K_d}{\tau_1}} = 657 \times 10^3 \; r/s = 105 \; KHZ$$

$$\zeta = \frac{\tau_2}{2}\,\omega_n = 1.05$$

30MHZ PHASE LOCKED LOOP

FIGURE 8

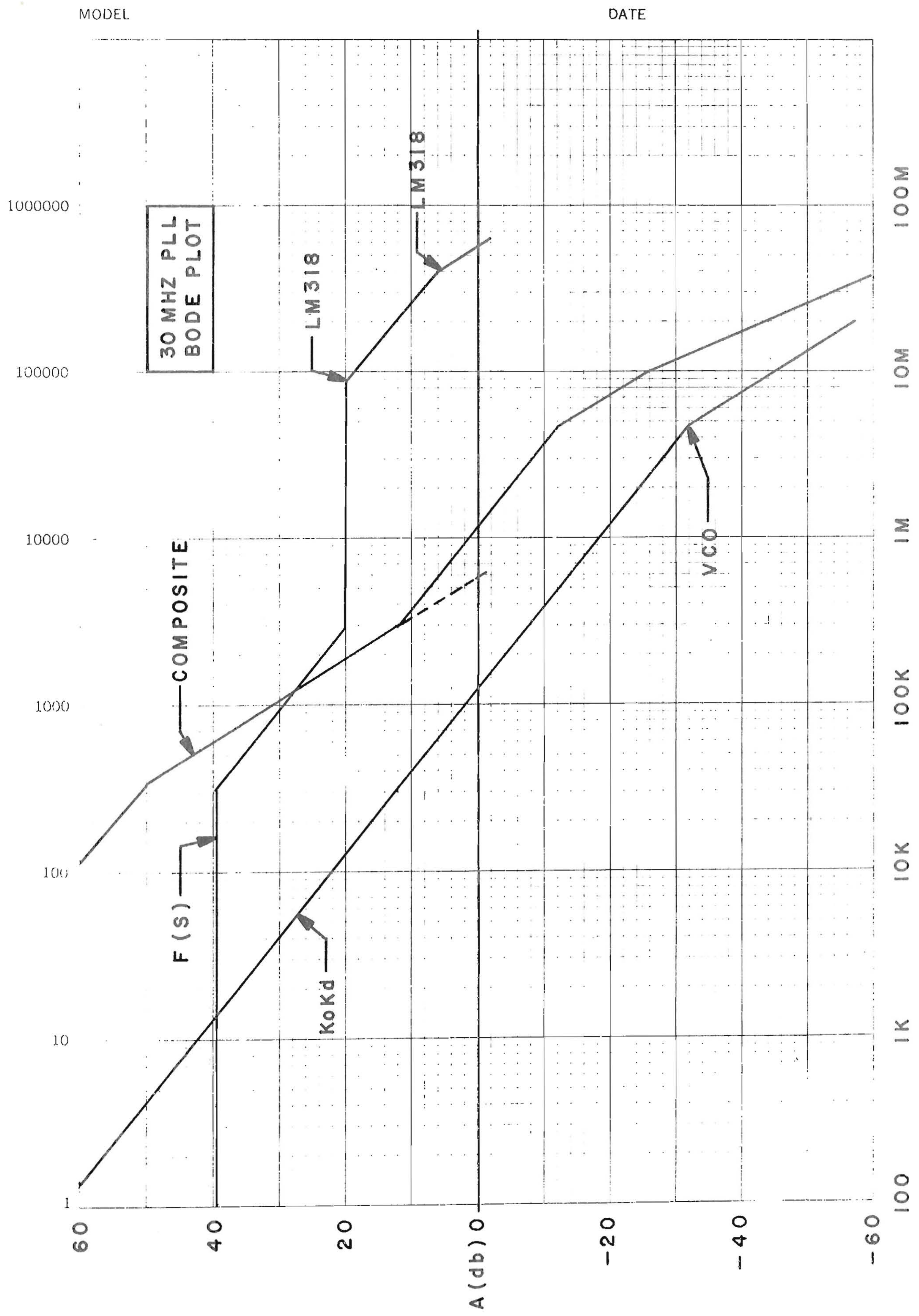
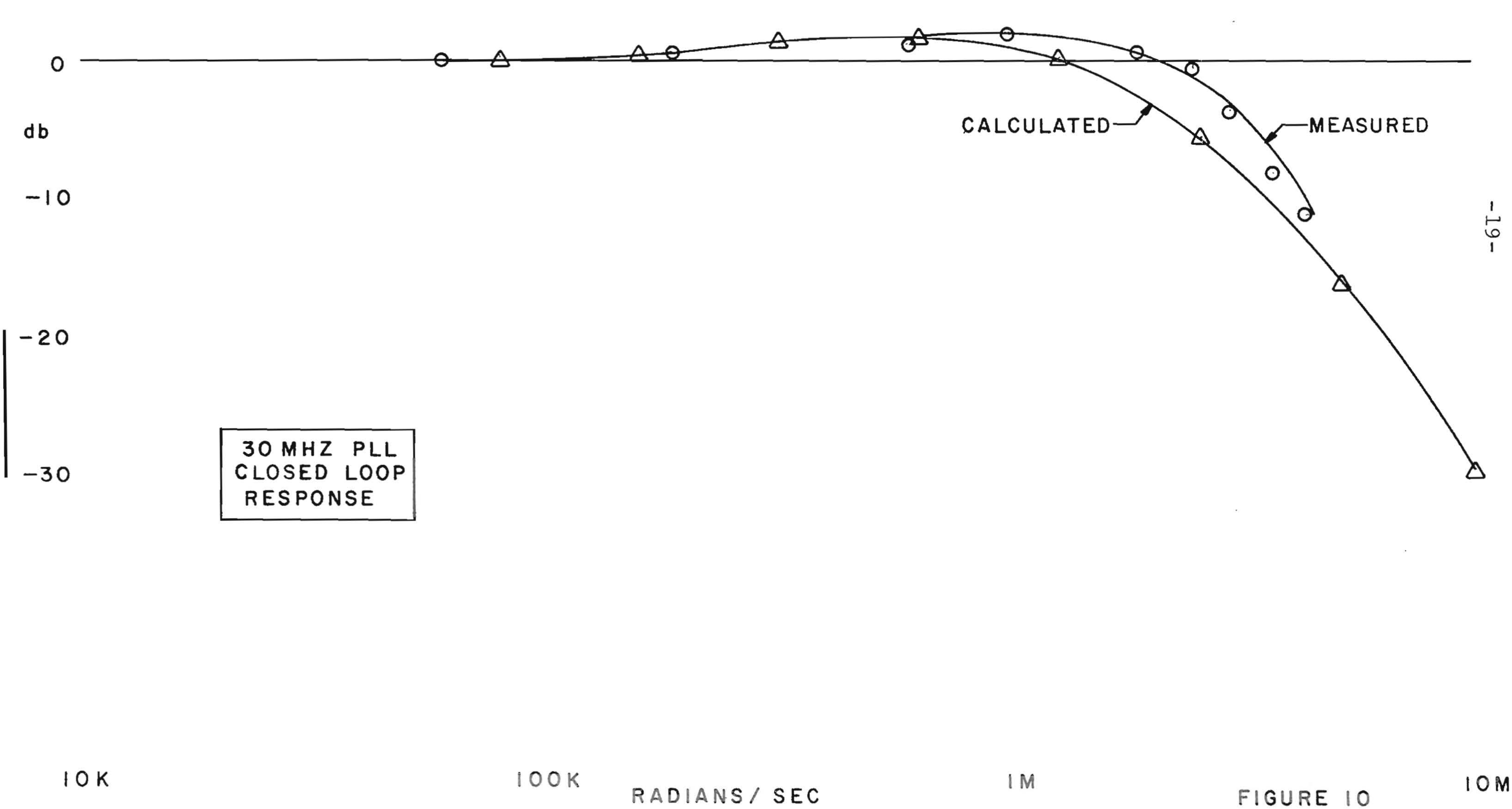

MODEL
DATE
30 MHZ PLL
BODE PLOT
LM318
LM318
COMPOSITE
F(S)
KoKd
VCO
1000000
100000
10000
1000
100
10
1
60
40
20
A(db) 0
-20
-40
-60
100
1K
10K
100K
1M
10M
100M
RADIANS / SEC

FIGURE 9



0
db
-10
-20
-30
30 MHZ PLL
CLOSED LOOP
RESPONSE
CALCULATED
MEASURED
10K
100K
1M
10M
RADIANS/ SEC


FIGURE 10

HETERODYNE PHASE LOCKED LOOP BOARD

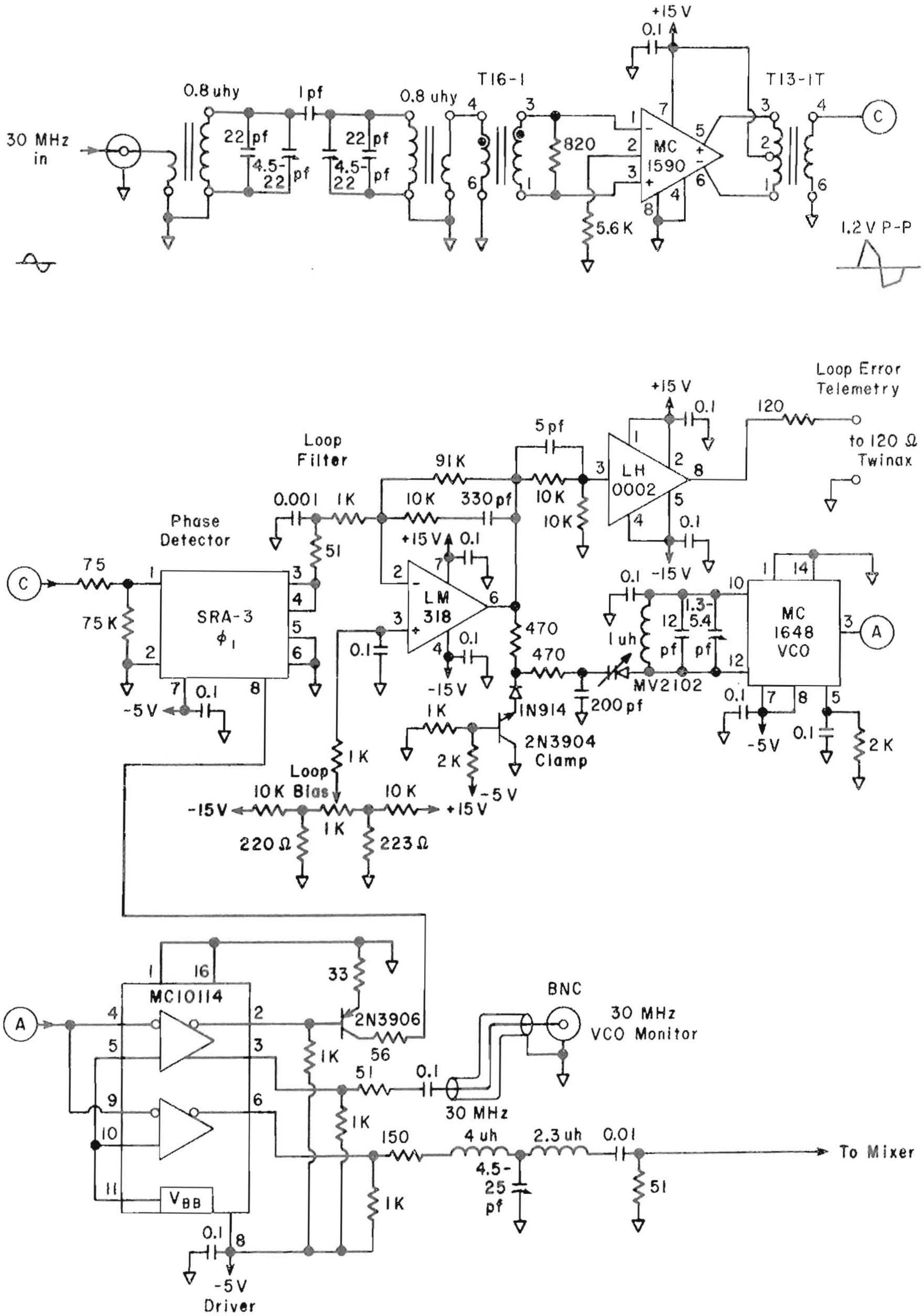



FIGURE 11 794289

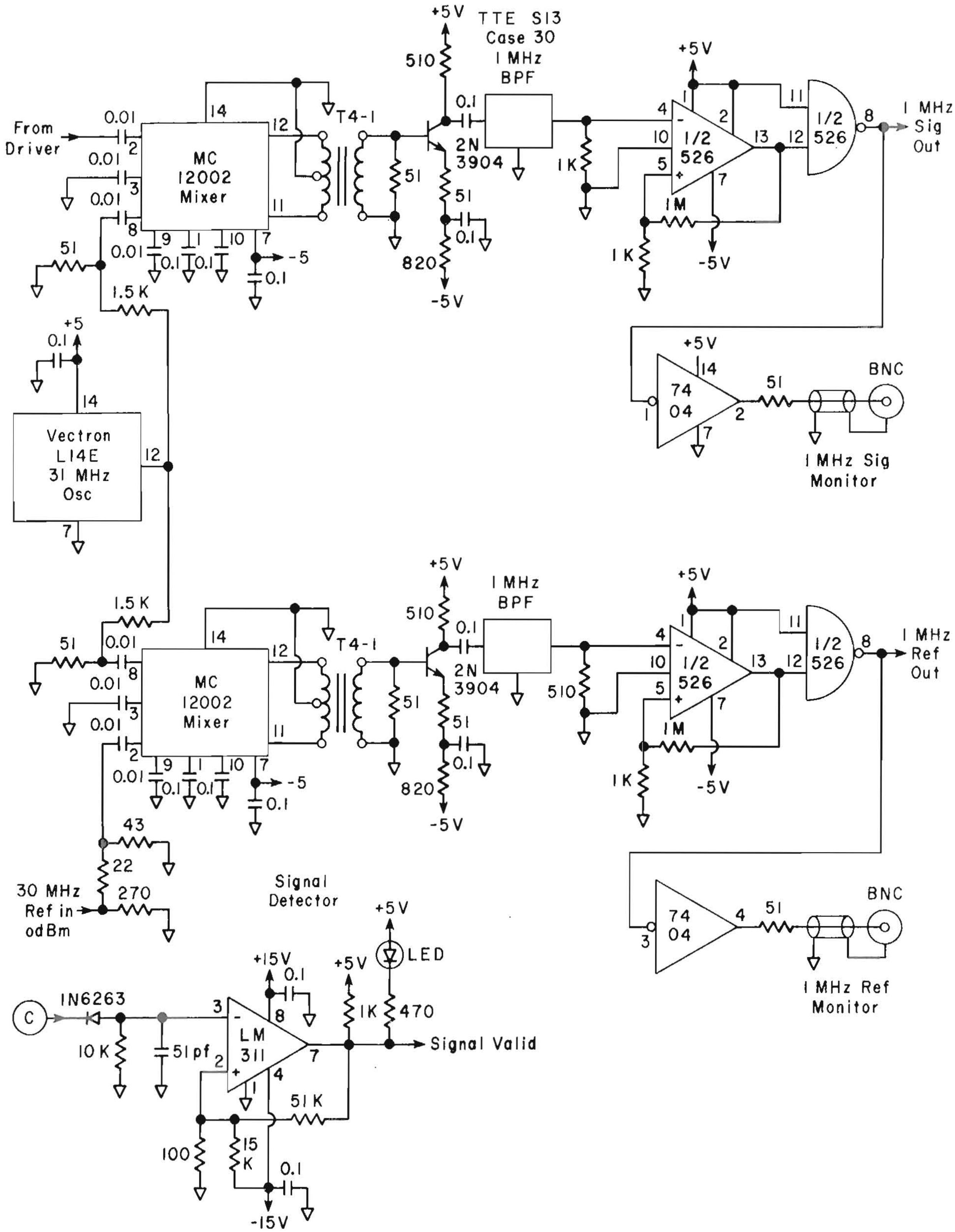
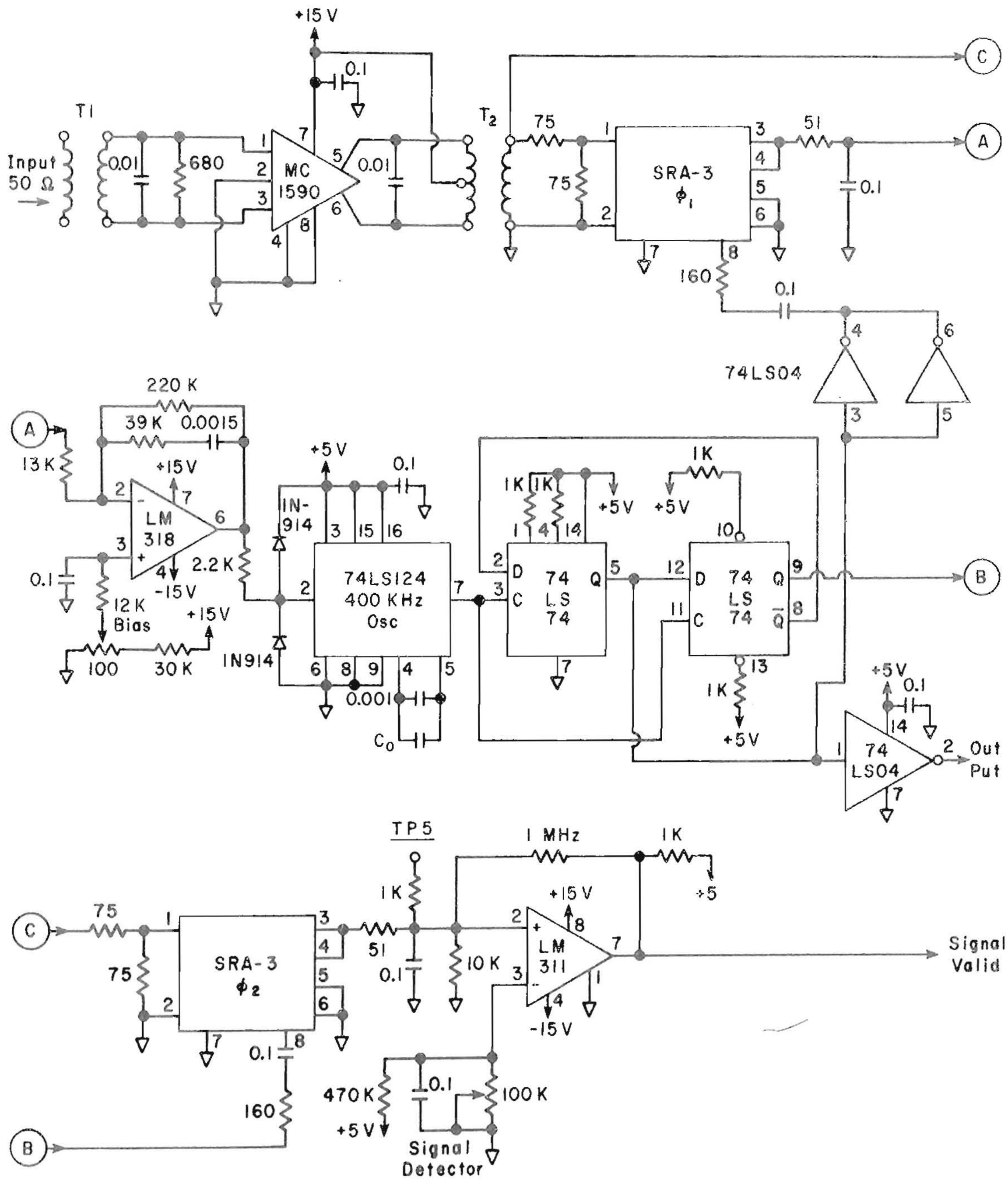



FIGURE 11a 794290

HCN LASER PHASE LOCKED LOOP BOARD




$T_1$ & $T_2$
HI-Z Winding: Bifilar, 25 T
50 Ω Winding: 6 T
Core I.G. F627-8 H
(Adjust # of Turns for
Resonance At 100 KHz)

Loop Adjustment

1. With No Input Signal Adjust Bias For 2.5 VDC Out of LM 318.
2. Select Co For 100 KHz Out of 74LS124.

FIGURE 12 794291

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