NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA ELECTRONICS MEMORANDUM NO. 3

September 15, 1967

VLA CORRELATOR DESIGN STUDIES

John Rehr

1. Introduction

The purpose of this report is to evaluate several possible correlator types for use in a system requiring large numbers of good, relatively inexpensive, reliable units. The correlator specifications as specified in Table 18.1 of Chapter 18 in the VLA Proposal are copied below for convenience.

Table 18-1

Correlator Specifications

1. Output Level and Scales	The unit must have an output level capability of ± 10 V into a 5000 ohm load. Two scales as selected by a relay must give a +9 ± . 5 V output for two perfectly correlated input signals. The second scale must give +9 = . 5 V output for input signals which have 10 percent of their power correlated. The second scale should be selected by applying +28 V to a control terminal.
2. Input Levels	The inputs of the correlator will be Gaussian white noise signals at a level of 0 dBm into 50 ohms and a bandwidth of 1 dB points of 2 MHz to 50 MHz. The amplitude and phase variations with frequency in this band caused by the correlator should be less than ± . 5 dB and ± 10°.
3. Noise	With zero input signal the noise output of the correlator should be less than 1. 0 mV rms in the band, . 01 Hz to 3. 6 Hz on the first scale. The noise may be 10 times greater on the second scale.

continued --

Table 18-1 (continued):

4. Drift	With zero input signal or with two uncorrelated input signals held constant to within ± .01 dB, the output on the first scale should be 0 ± 1 mV for a 24 hour period with temperature variations of ± 1 °C. The drift on the second scale may be 10 times greater. If the level of either input is changed by 0.1 dB, the output change should be less than 10 mV on the first scale.
5. Non-Linearity	The output need not be linear with respect to the product of the inputs. However, the departure from linearity must not be greater than ± 20 percent for outputs up to ± 9 V and the output vs. input-product curve must be identical to within 2 percent for all correlators.

The work included the development of several possible correlator designs with some emphasis placed on a correlator design similar to that presently used in the NRAO interferometer. For this particular correlator several types of hybrid transformers and a transistor hybrid were considered. Also several types of square law detectors were evaluated. Little time was devoted to the selection of low drift operational amplifiers; however, a multiple feedback low pass filter was designed and a FET multiplex switch was constructed.

2. Test Data

The performance of the correlators was measured using the test set described in VLA Electronics Memorandum No. 4. The following data were noted:

a. Offset voltage (e_o with uncorrelated power into the correlator).

b. Correlator output voltage vs. amount of signal correlated; i.e., e_o vs. P_{corr}.

2. (continued):

c. Sensitivity to Uncorrelated Power: With the correlated component of the correlator test set output set at 0.5 mW (P_{corr} = -3 dBm) the sensitivity defined as the percent change in correlator output voltage with a 1 dB decrease in N_A or N_B whichever is larger, is measured using the procedure described in VLA Electronics Memorandum No. 4.

3. <u>NRAO Correlator</u>

A very simple type of correlator has been developed at NRAO which consists of a single hybrid transformer and two matched square law detectors. A block diagram is shown in Figure 1.

NRAO Correlator

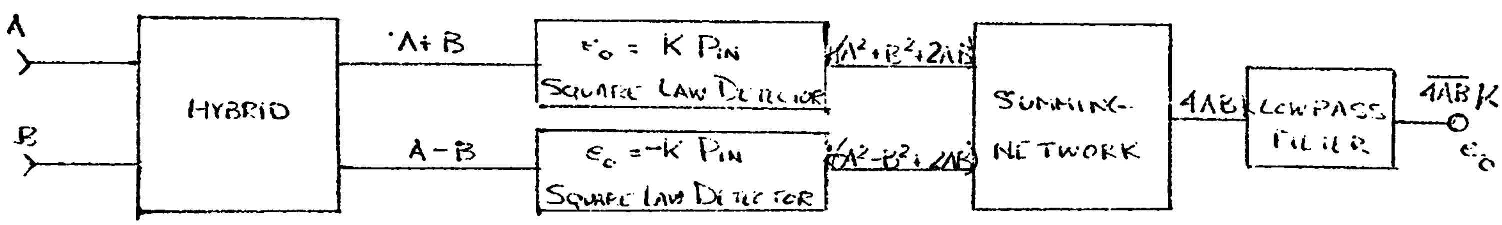


Figure 1

This section of the memo deals with the hybrids and detectors used in this correlator.

3.1 <u>Square Law Detectors</u>: Several types of detectors were evaluated and the test data presented on the attached pages. Hot carrier diodes appear to be the best choice of those tested as they operate at 0 dBm with good output characteristics, although their square law performance

3.1 (continued):

is poor. An inexpensive diode which costs $ 3 in small quantities (HP 2900) seems to be adequate. (These were not tested in the correlators since only three units were available.) Back diodes exhibit superior square law characteristics and have good output characteristics but fail to be useful much above input levels of -5 dBm. A redeeming feature is that a correlator using back diode detectors should be very insensitive to uncorrelated power variations. Ordinary signal diodes were found to be unsatisfactory because of their sharp cutoff characteristics.

3.2 Hybrids: The hybrid performs the function of adding and subtracting voltages at the input terminals of the correlator. Three types of hybrids were considered: transformer hybrids, transistor hybrids, and integrated circuit hybrids.

3.21 Transformer Hybrids: Transformer hybrids which have all ports terminated in the same impedance are relatively expensive as internal impedance matching transformers are required. A typical large quantity price for this type of hybrid is about $70 (Adams-Russell MHH-50); the response of a correlator using this hybrid is found on page 9.

A simpler hybrid may have a sum and difference port impedance of either twice or half the input impedance. Such devices are available for $13 in quantity (Relcom MT8). A circuit diagram is shown in Figure 2.

Inexpensive Hybrid

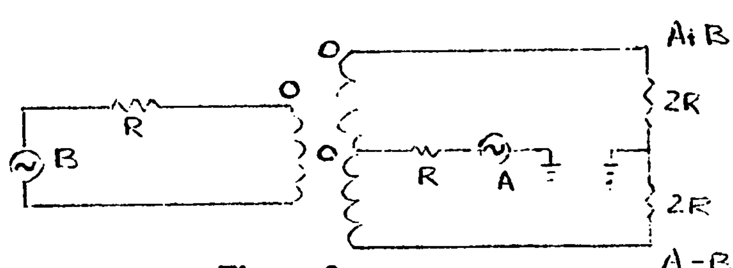
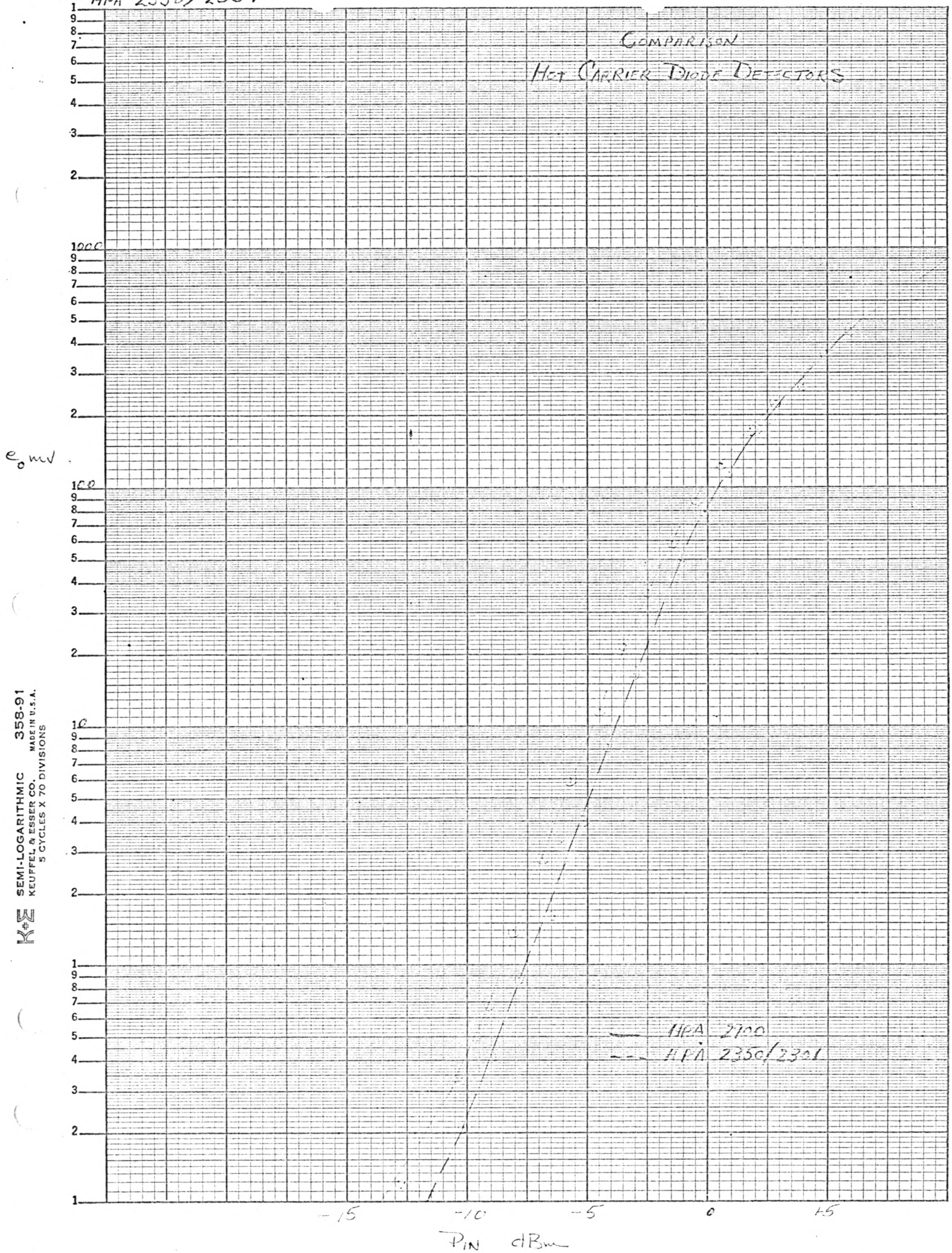


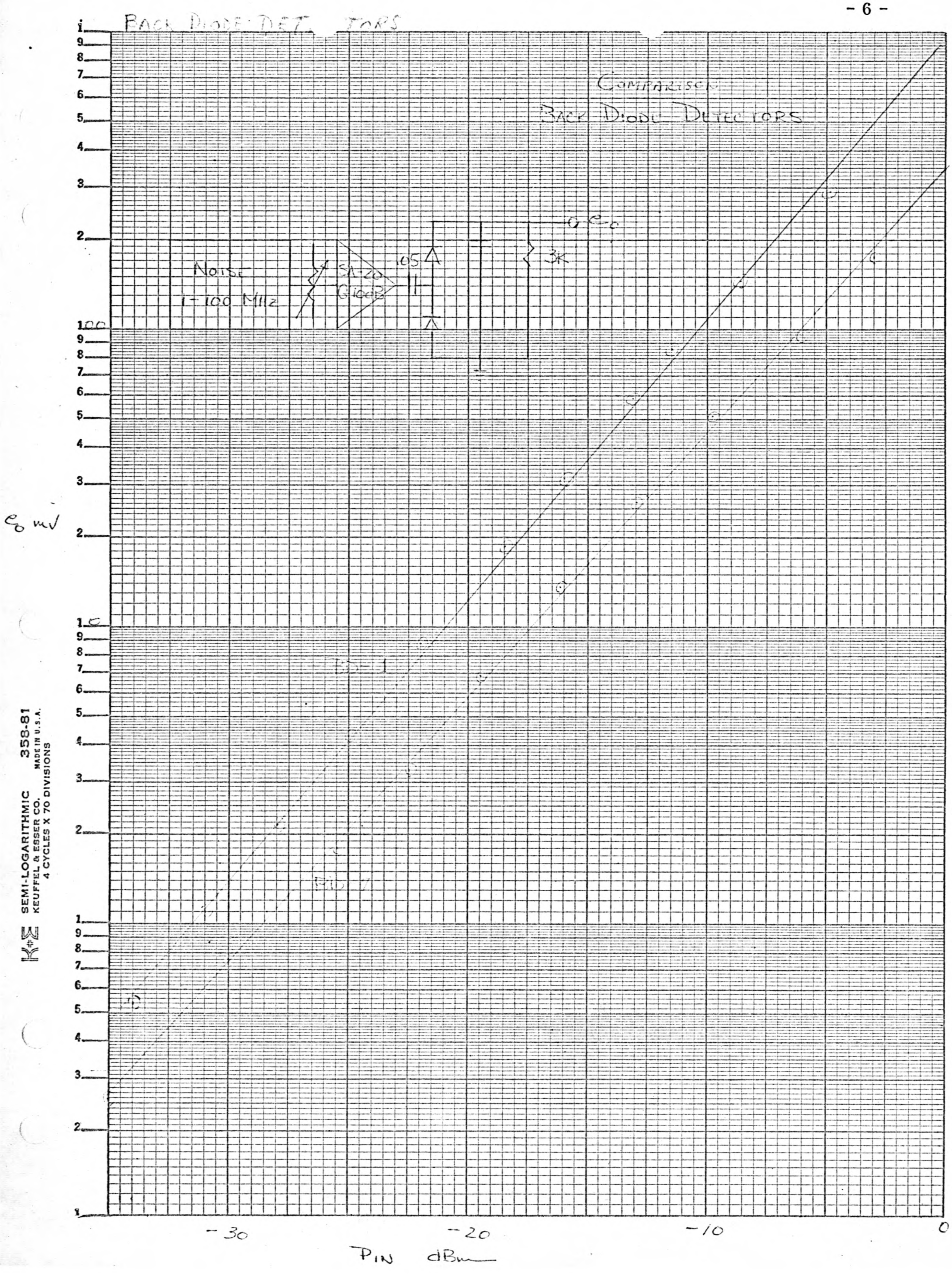
Figure 2

HOT CARRIER DIODE DETECTOR

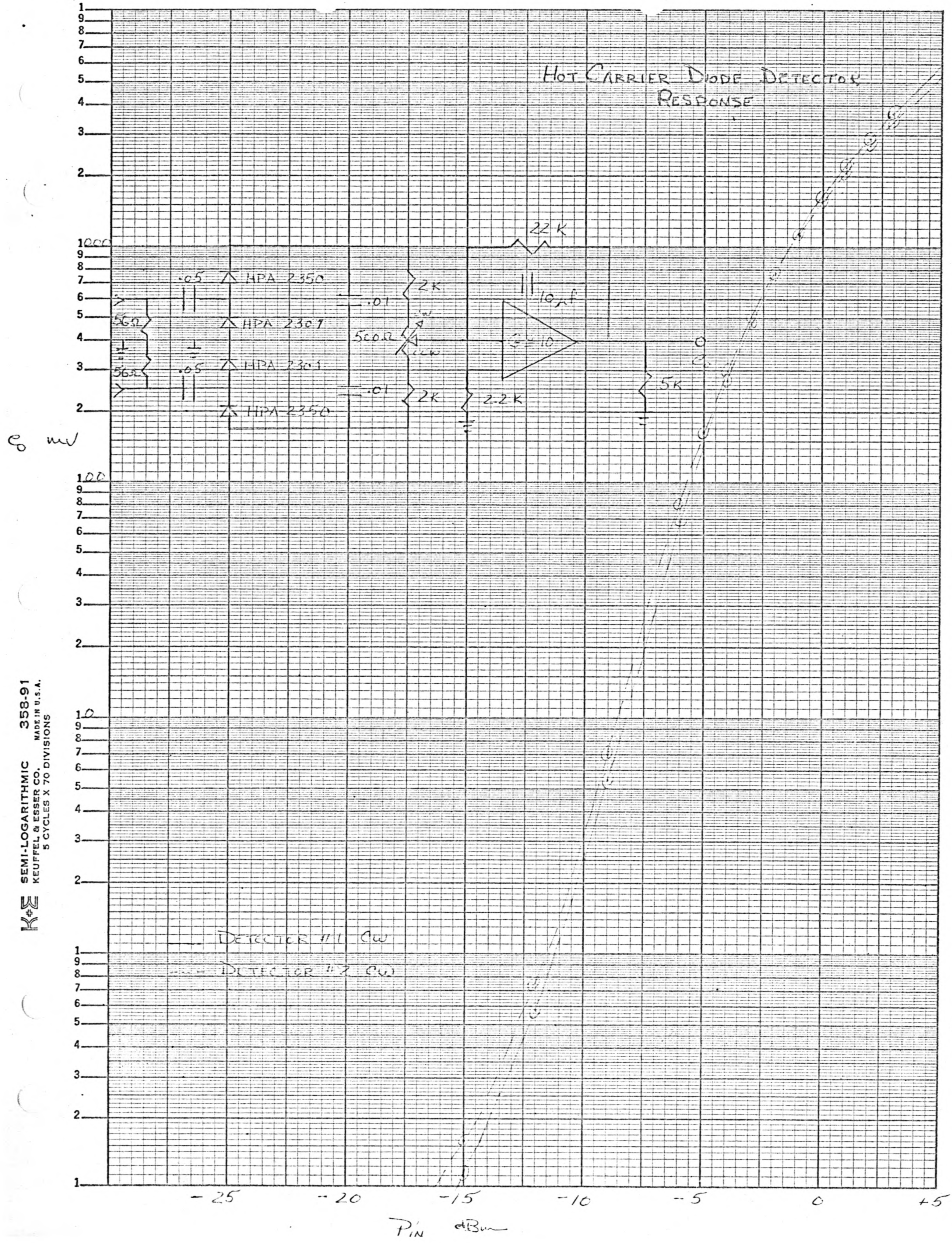
— HPA 2900

-- HPA 2350/2301

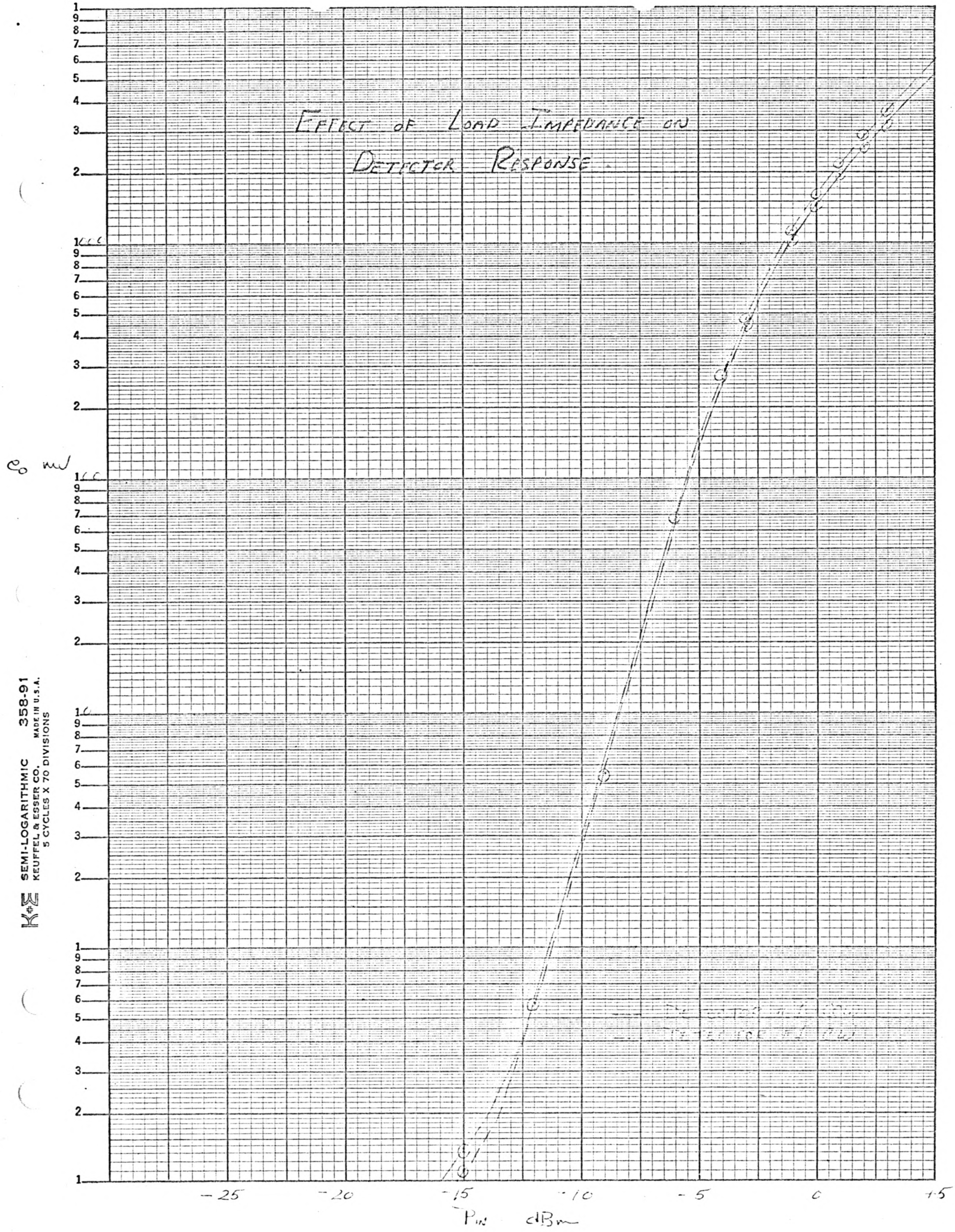



BACK DIODE DETECTORS
COMPARISON
BACK DIODE DETECTORS
NOISE
1-100 MHz
SA-20
G100B
.05
3K
e_o
e_o mV
BD-1
-30
-20
-10
0
P_{IN} dBm
SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS

— Detector #1 CW
--○ #2 CW



— • DETECTOR #1 CW
-- ⊙ " CW



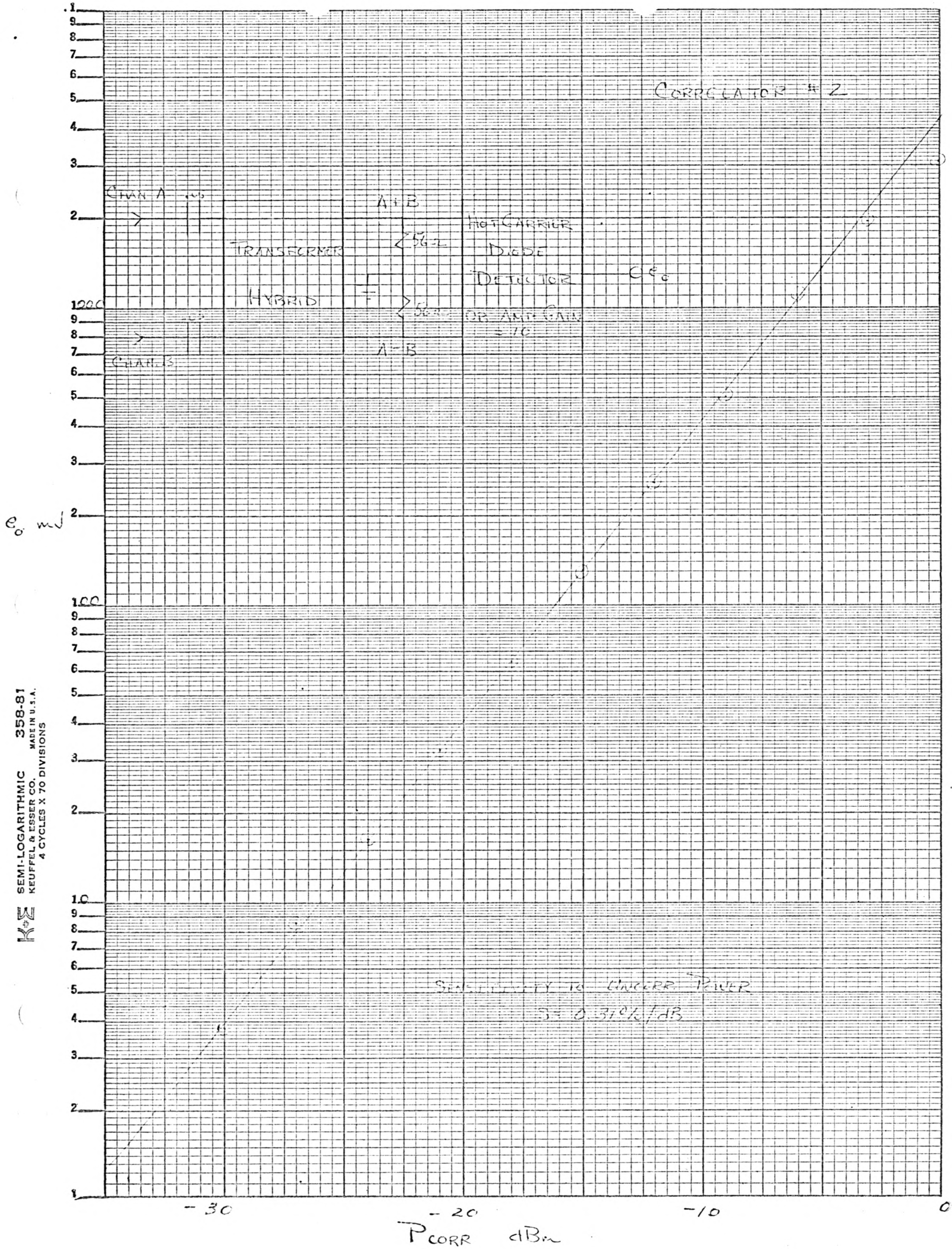
3.21 (continued):

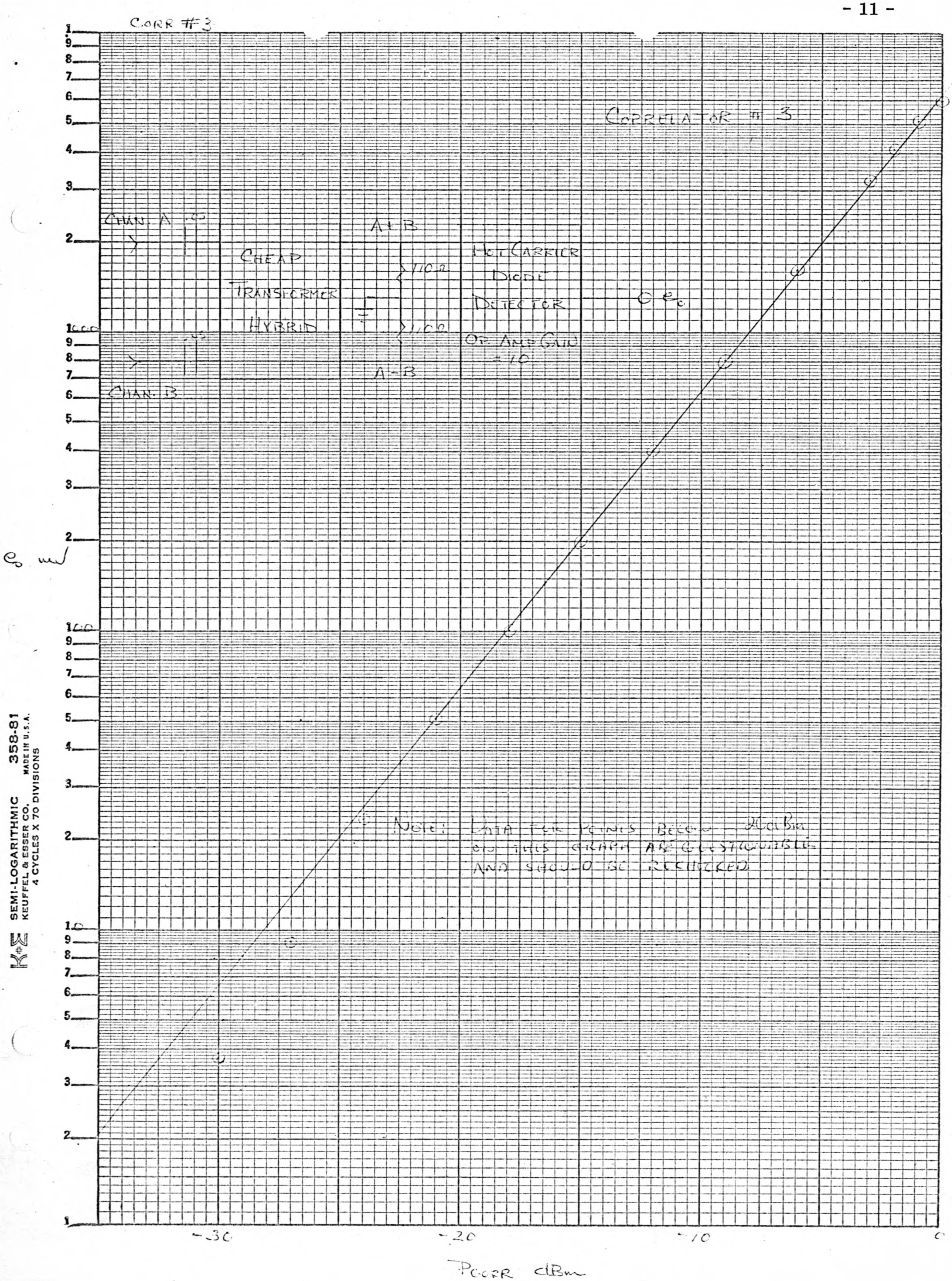
A correlator using a similar hybrid (Adams Russell MHH-50-100) was built and the test results listed on page 11. This hybrid has the advantage that the output voltage is not reduced by 3 dB as is the case with conventional hybrids; therefore, the output voltage of the correlator is twice that measured for the correlator which uses an ordinary hybrid.

3.22 Transistor Hybrid: Considerable effort was expended to develop a good, inexpensive transistor hybrid. The circuit described in Chapter 18 of the VLA Proposal was modified for improved phase response and flat gain from 2 to 50 MHz and is shown in Figure 3, page 12. The present gain is -0.8 dB ± 0.1 dB, and consequently the correlator output is slightly lower than that from the transformer hybrid. By increasing the 200 ohm collector resistors in Figure 3, the gain can probably be raised without seriously degrading the performance of the device. Performance curves are given on page 13. The hybrid was built in printed circuit form with no provision for adjustments; correlator test data is shown on page 14. Several types of RF transistors were used in the circuit with best results obtained with MPS918 and MPS 6507. RCA 2N4936's were rejected for excessive phase shift and GE 2N3663 showed a tendency to oscillate.

3.23 Integrated Circuit Hybrid: No attempt was made to develop an integrated circuit hybrid because of excessive delivery time from the manufacturer (6 mo. typically). It should be possible to develop a hybrid similar to circuit in Figure 3 using the RCA CA3004 or RCA CA3006 integrated circuits.

CORRELATOR #2




CORR #3
CORRELATOR # 3
CHAN. A
CHAN. B
CHEAP
TRANSFORMER
HYBRID
A+B
A-B
HOT CARRIER
DIODE
DETECTOR
OP. AMP GAIN
= 10
e_o
NOTE: DATA FOR POINTS BELOW -20 dBm
ON THIS GRAPH ARE QUESTIONABLE
AND SHOULD BE RECHECKED.
e_o mV
P_{CORR} dBm
-30
-20
-10
0
1000
100
10
SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS

TRANSISTOR HYBRID

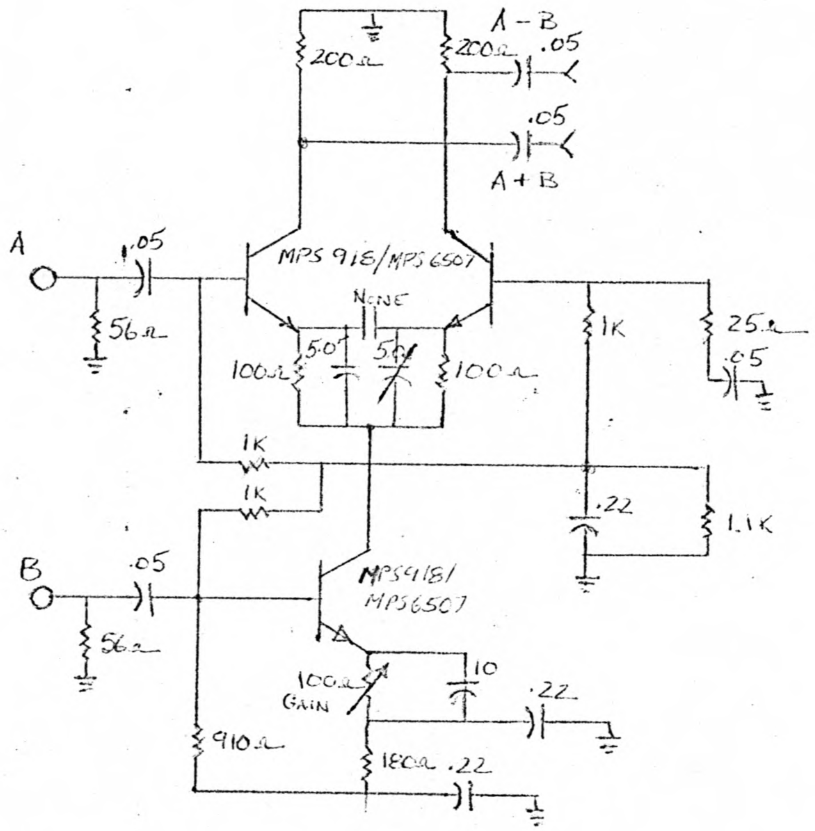
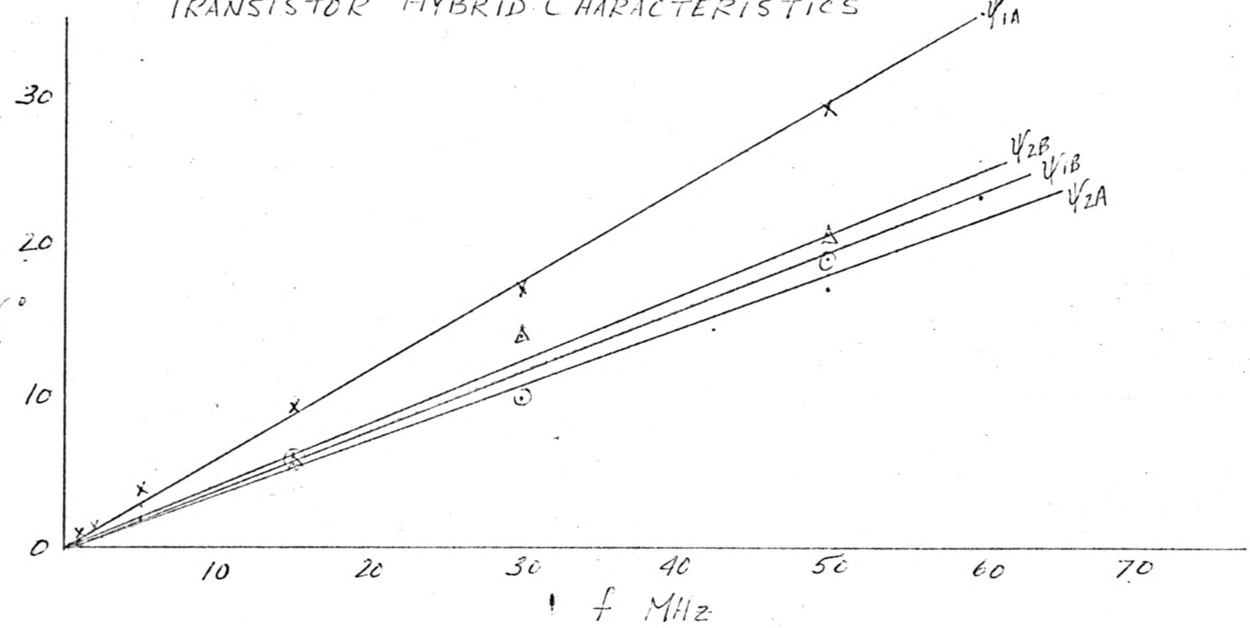
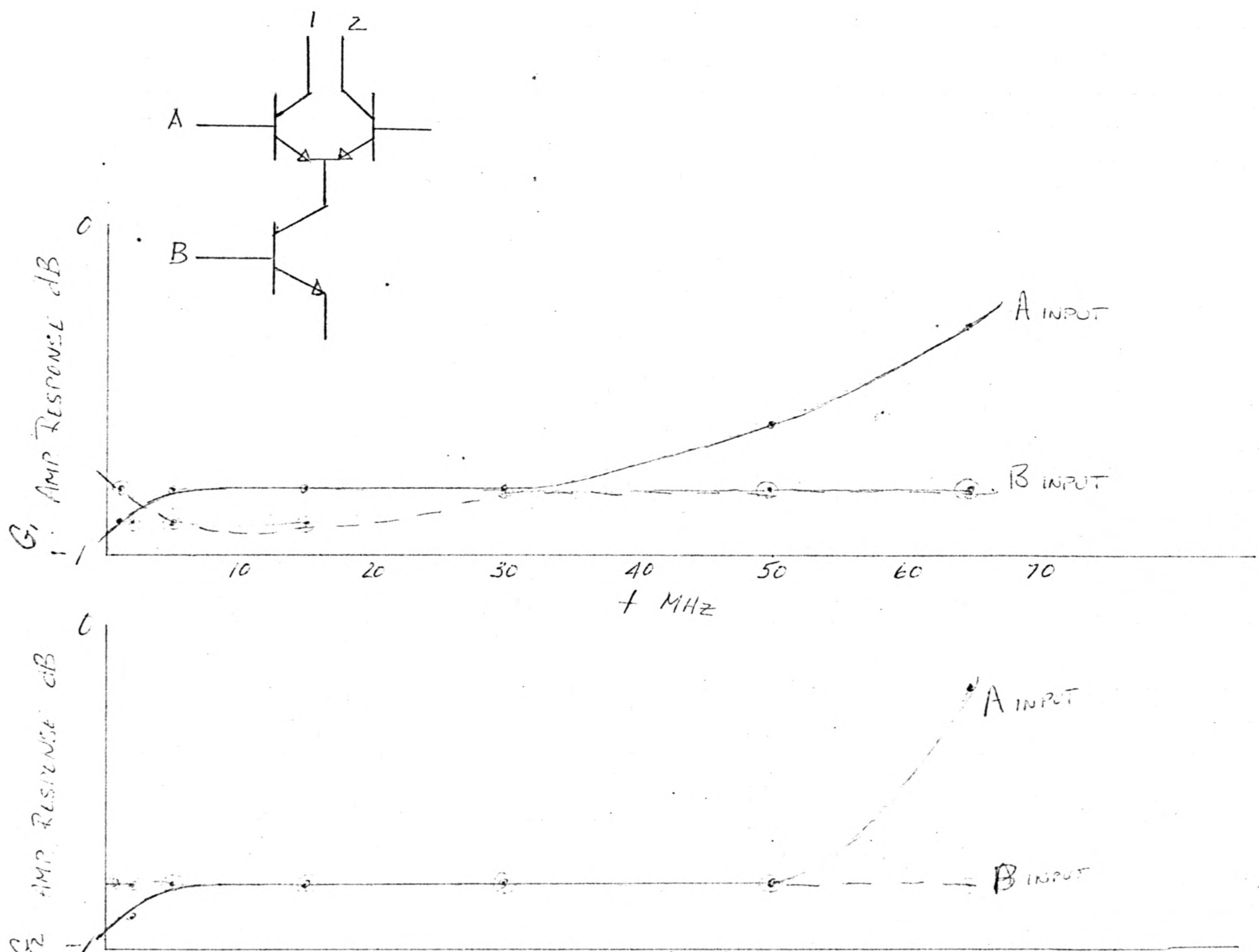


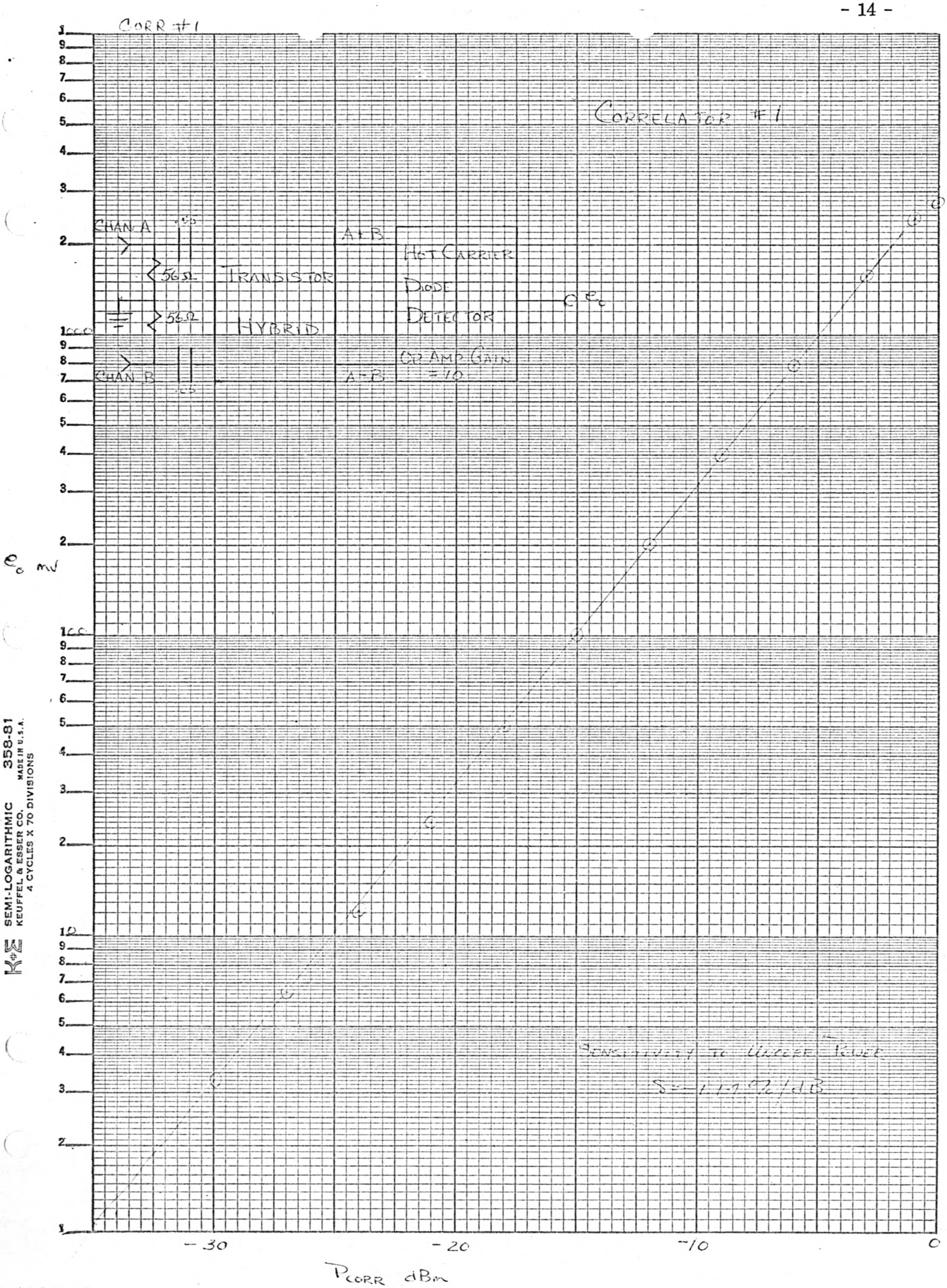
FIG 3.

TRANSISTOR HYBRID CHARACTERISTICS





AMP RESPONSE VS. FREQ.


CORR #1
CORRELATOR #1
CHAN A
CHAN B
56Ω
56Ω
TRANSISTOR
HYBRID
A+B
A-B
HOT CARRIER
DIODE
DETECTOR
OP AMP GAIN
=10
e_o
e_o mV
1000
100
10
-30
-20
-10
0
P_{CORR} dBm
SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS

4. Balanced Mixer Correlators

Inexpensive double balanced mixers have become available only recently because of reduced matched diode costs. The basic schematic of such a mixer is shown in Figure 4.

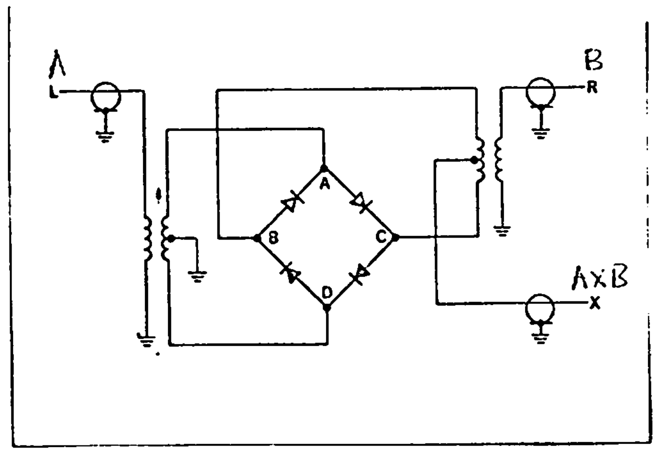
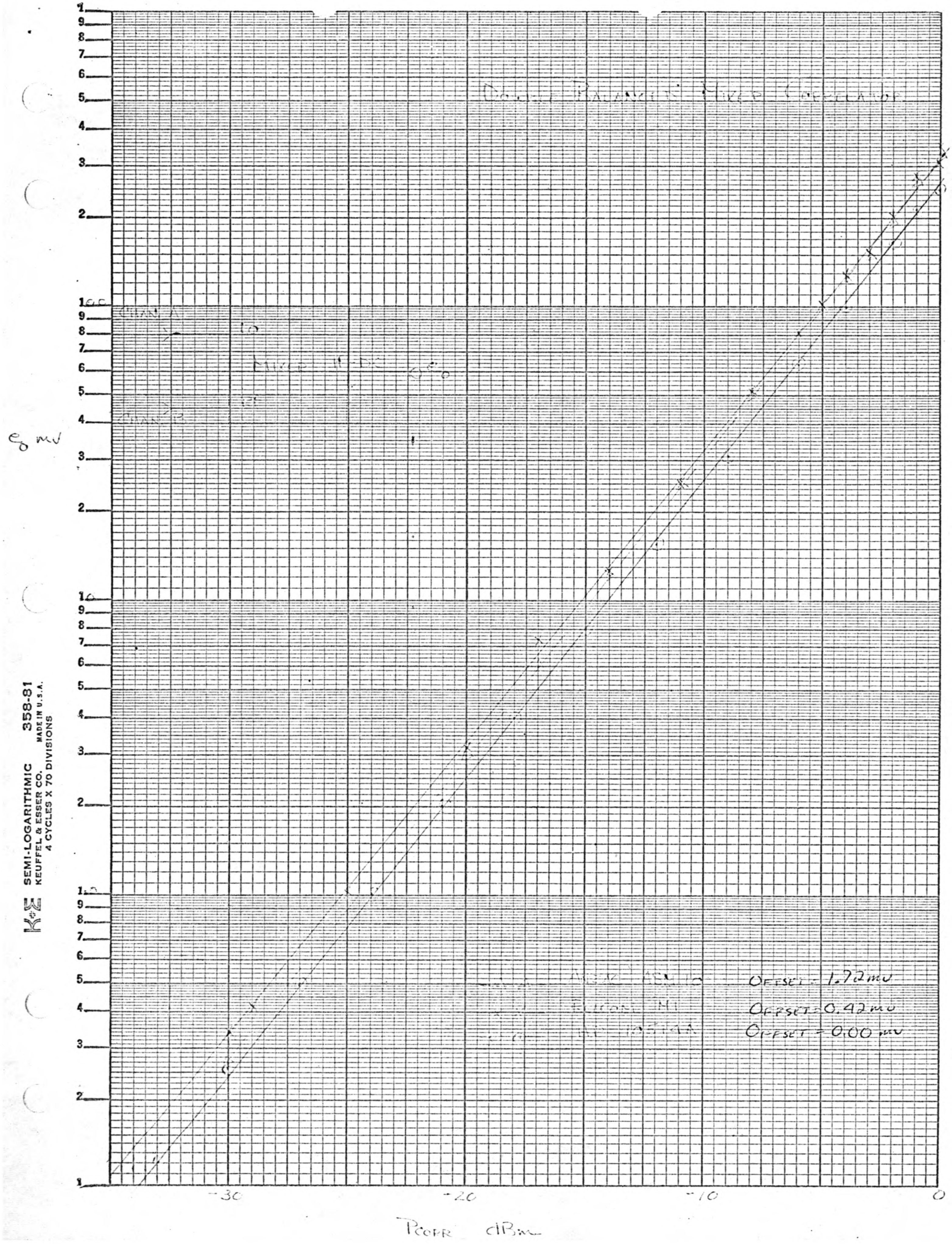
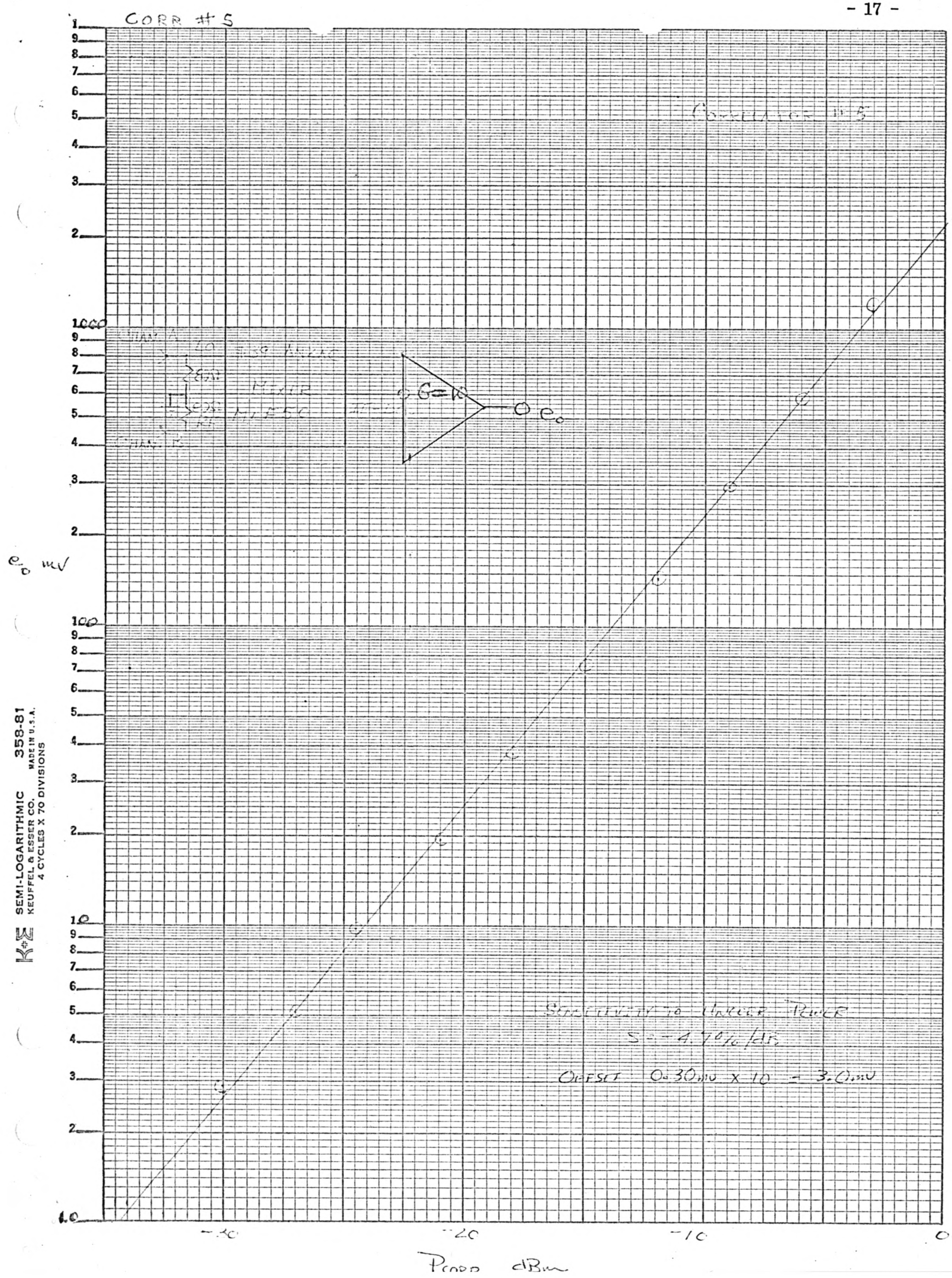


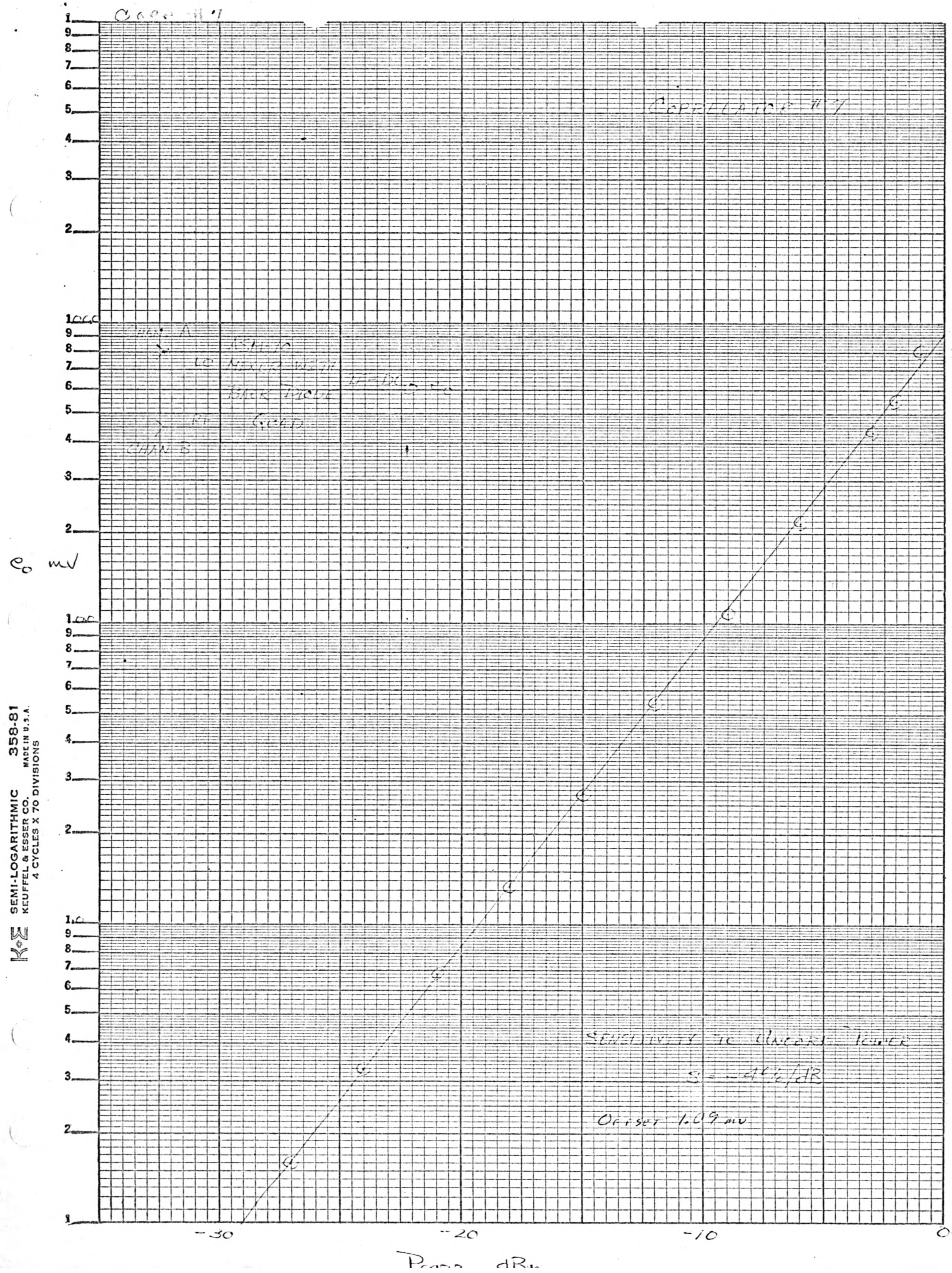
Figure 4

These circuits perform fairly well as correlators; several units were tested and the results given on the following pages. All units tested showed more sensitivity to uncorrelated power than did the NRAO correlator described in 3. Also because each unit required 2 hybrid transformers the minimum cost is greater than that for the NRAO correlator. Typical small quantity prices for the Adams Russell MLF-50 are $39. Hence work must be done to reduce the sensitivity to uncorrelated power before mixers can be considered a superior choice to the NRAO correlator.

Another possible mixer type correlator uses a circuit similar to that shown on page 19. The circuit tested (see page 20) was by no means optimized. An integrated circuit form of this circuit should be easily obtained if the circuit continues to show promise.


OFFSET = 1.72 mv
OFFSET = 0.42 mv
OFFSET = 0.00 mv
e_o mV
-30
-20
-10
0
PCORR dBm
SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS


CORR #5
G=10
e_o
OFFSET 0.30mv x 10 = 3.0mv
e_o mV
Pcorr dBm
-30
-20
-10
0
SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS


CORRELATOR #7
CHAN A
LO
MIXER WITH
BACK DIODE
RF
GOOD
CHAN B
Offset 1.09 mv
e_o mV
-30
-20
-10
0
1000
100
10
1
SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS

and dissolved minerals in ground water. Reliable and effective operation follows when the source provides constant current over a predetermined variation in load resistance.

For geophysical applications only low frequency square waves of 0.1 to 4 hz are usually required. However, by proper choice of timing capacitors the circuit may be used to 100 hz. Above this frequency circuit losses become severe.

The low-frequency relaxation oscillator consists of transistor Q_1 and unijunction transistor Q_2. The time constant R_TC_T determines oscillator frequency. Switch S_1 and potentiometer R_1 in combination with resistor R_2 allow the time constant to be varied by a factor of 40 to 1. Transistor Q_1, which has a very low collector leakage current, supplies constant current to charge capacitor C_T.

Pulses generated at the base of Q_2 synchronize the free-running, emitter-coupled multivibrator consisting of Q_3 and Q_4. The multivibrator's pulsed output is coupled through transformers T_1 and T_2 to the gate of the four scr's. This quartet is arranged in a bridge circuit that controls the power across load terminals, A and B.

When the voltage from transformer T_1 fires SCR_1 and SCR_3, the load current flows from left to right across terminals A and B. Autotransformer action in the center-tapped coil, L_1, charges capacitor at AB to approximately twice the supply voltage. When the voltage from transformer T_2 fires SCR_2 and SCR_4, the capacitor across AB charges in the reverse direction through these two scr's.

During the process of reversing the charge, SCR_1 and SCR_3 are back-biased and turned off. While SCR_2 and SCR_4 conduct, current flows through the load in the opposite direction.

Power supply capabilities rather than the scr circuit limit power levels.

Cross-coupled transistors form balanced mixer

By Leonard E. Geisler

Radio Astronomy Laboratory,
University of Michigan, Ann Arbor

A mixer circuit with two transistors offers advantages over the conventional diode quad: the costly transformer required with the diode quad is eliminated and the cross-coupled transistor mixer exhibits some conversion gain; the quad is inherently lossy.

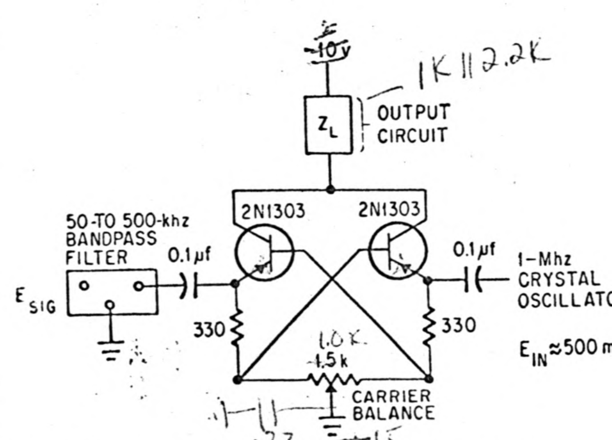
The collectors of the two transistors (2N1303) are wired together to share the output load and their bases and emitters are cross-connected. Thus a positive-going carrier wave turns on one transistor while the other is kept in the off position. This produces a positive pulse across the common collector load.

When the phase of the carrier wave is reversed, the two transistors switch conditions, again producing a positive pulse across the common load. In effect frequency-doubler action is achieved without a phase-shifting transformer. When a signal is applied to the input terminal at the right a frequency-doubled output also results.

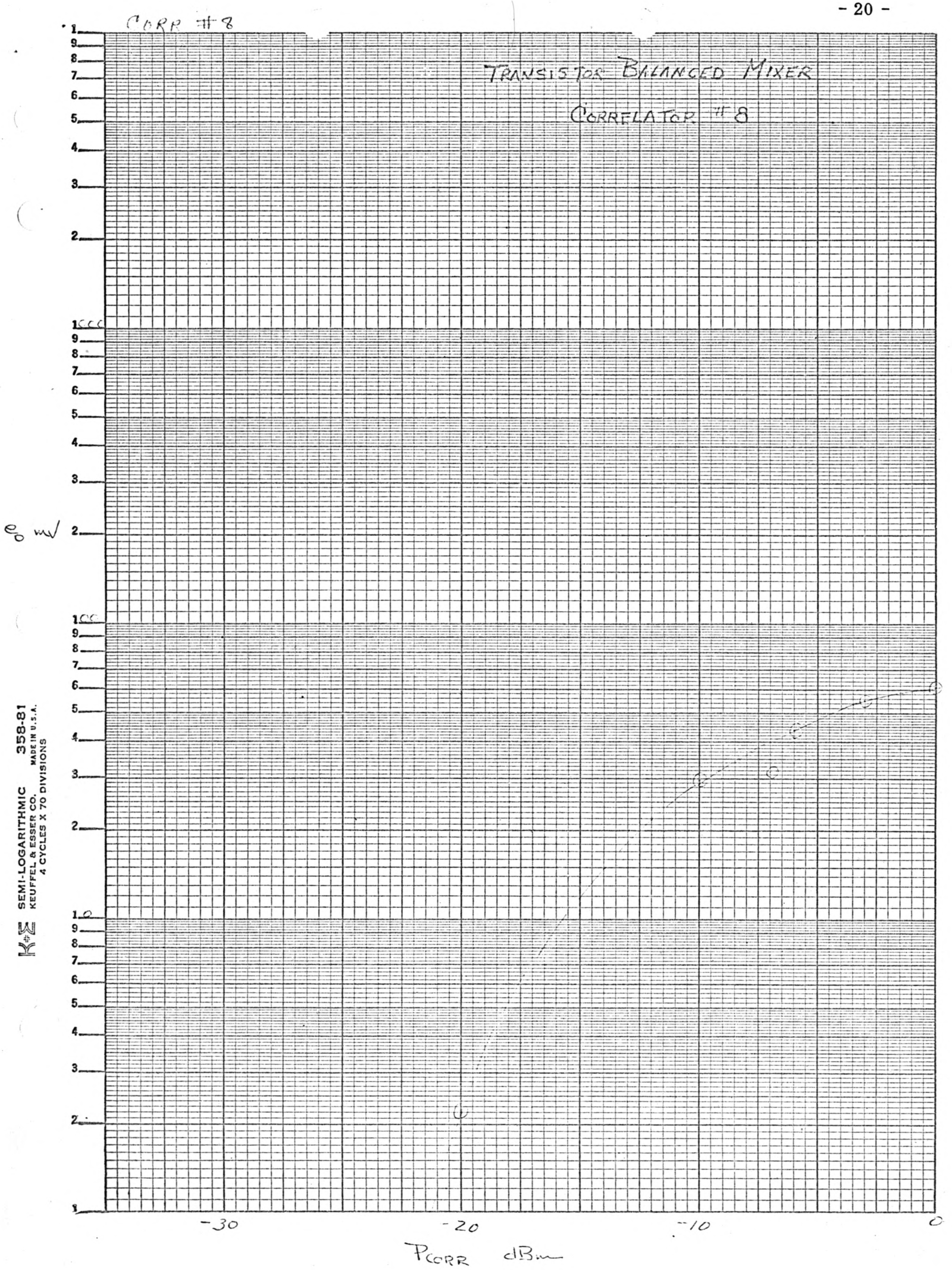
The result is a mixture of frequencies dependent on the ratio of signal levels. The mixed signals that appear across the output load are the upper and lower sidebands of the two input signals—the even order harmonics of the input and the carrier. No component at the fundamental frequency appears in the output once the balance control is adjusted to null the carrier.

The circuit was found to function best when driven from a low impedance source of approximately 50 ohms. Signals were applied for mixing through a 50- to 500-kilohertz bandpass filter. A 1-megahertz carrier was obtained from a crystal-controlled oscillator using a capacitive voltage divider. The ratio of crystal oscillator amplitude to signal amplitude was 10 to 1. The 1-Mhz oscillator had an amplitude of 600 millivolts. Signals were amplified to produce 60 mv at the mixer input.

Because of the inherent wide bandwidth of the mixer input, the input circuits and the crystal oscillator must be shielded. This prevents external mixing of the signals before they are applied to the balanced mixer. The output of the mixer is approximately 600 ohms.



Cross-coupled transistors perform as balanced mixers without expensive transformers. Configuration cancels fundamental frequency and produces two sidebands.


CORR #8
TRANSISTOR BALANCED MIXER
CORRELATOR #8
e0 mV
1000
100
1.0
-30
-20
-10
0
PCORR dBm
K+E SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS

5. FET Correlator

A correlator using field effect transistors was built from the circuit in Chapter 18 of the VLA Proposal. Although the unit exhibited good insensitivity to uncorrelated power, the output voltage was a factor of ten smaller than the NRAO correlator. Test data is shown on page 23.

6. Operational Amplifier Low Pass Filter

A low pass filter was developed for use in the second stage of the correlator DC amplifier. The circuit which allows a gain of 10 has 40 dB of attenuation per decade.

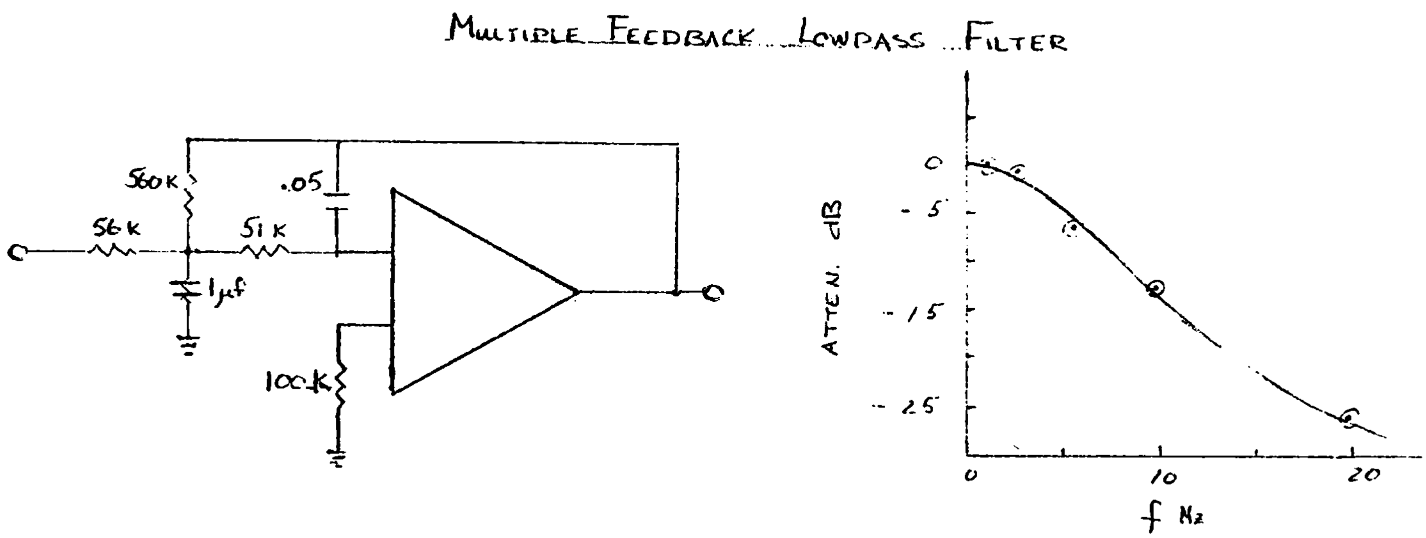


Figure 5

7. FET Multiplex Switch

A FET multiplex switch similar to that described in Chapter 18 of the VLA Proposal was built and tested. The circuit is shown in Figure 6.

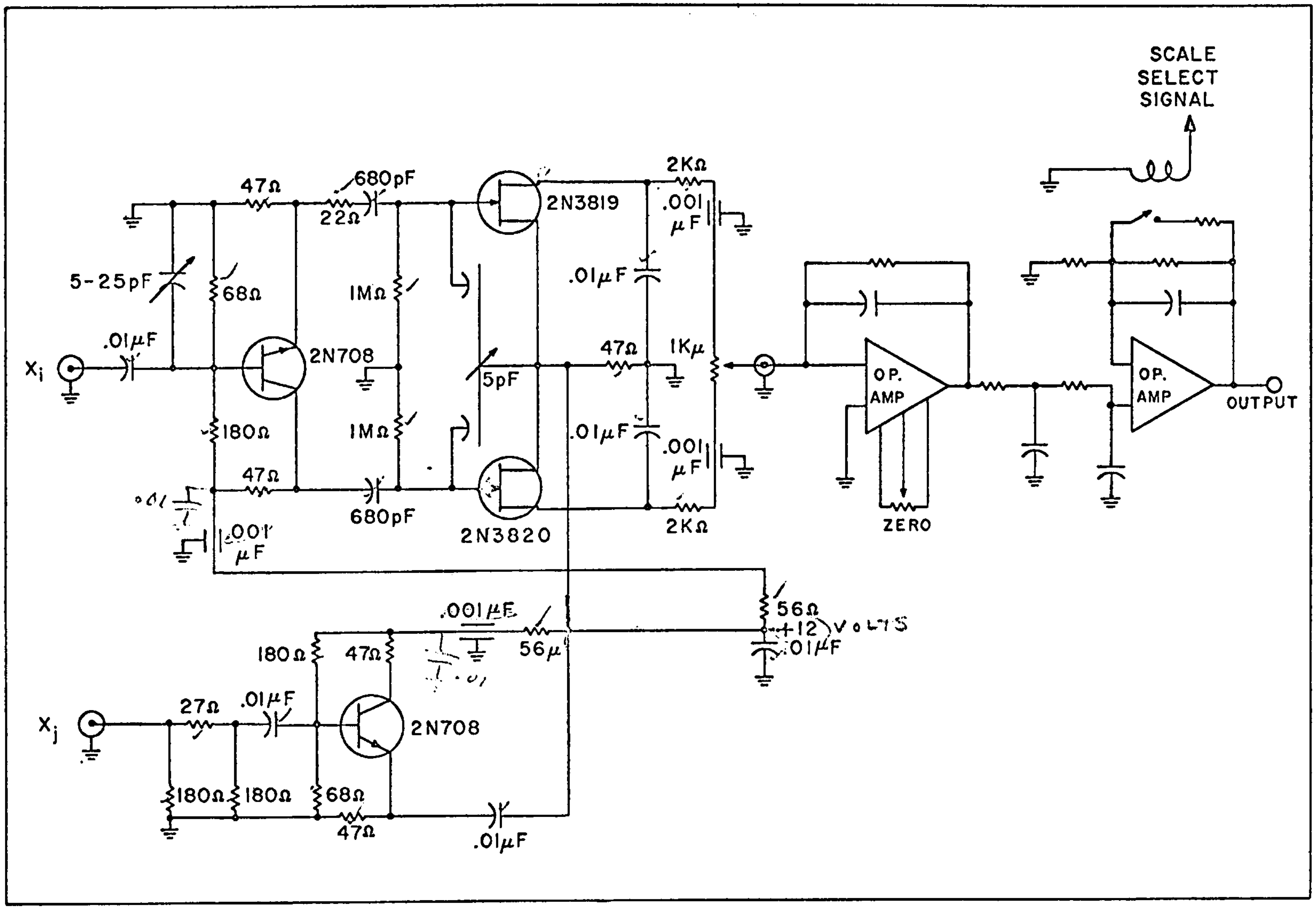
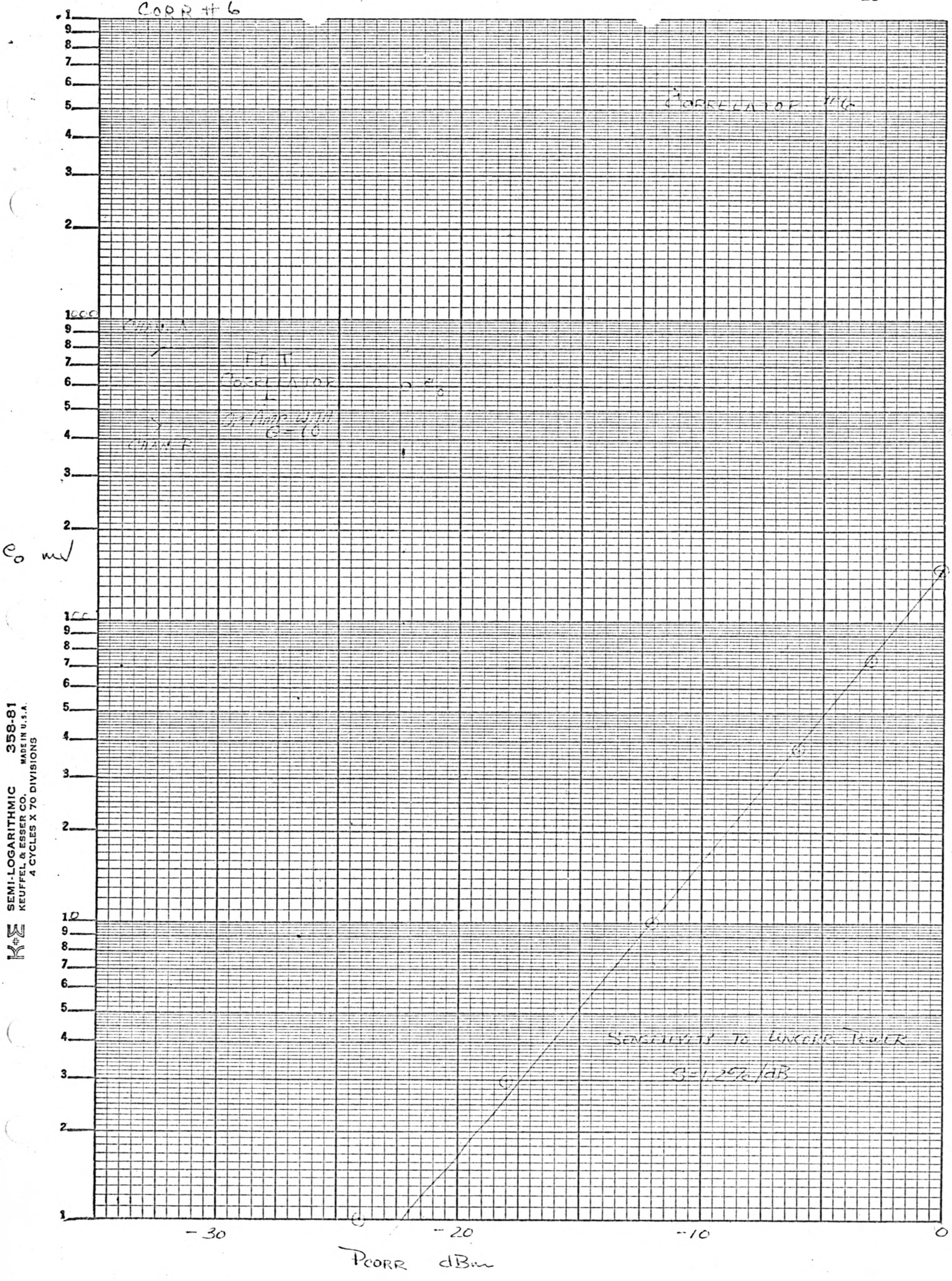


Figure 18 - 2. Correlator design based upon field-effect transistor design developed at the University of Bologna.


CORR #6
CORRELATOR #6
1000
CHAN. A
FET
CORRELATOR
OP AMP WITH
G=10
CHAN. B
e_o
e_o mV
100
10
1
SENSITIVITY TO UNCORR POWER
S=1.29%/dB
-30
-20
-10
0
PCORR dBm
SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS

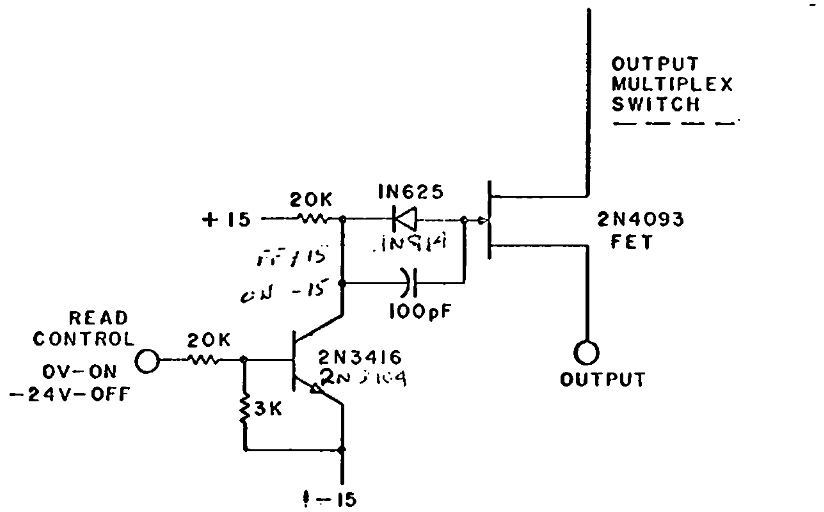


Figure 6

It should be possible to use an integrated circuit for this purpose; however, most of the devices now available commercially (such as the Philco pL4501) will not switch signals greater than ± 5 V.

8. Conclusions

At this point the best correlator appears to be a device which combines an inexpensive hybrid transformer such as the Relcom MT8 and inexpensive hot carrier diodes such as HP 2900 in matched pairs. The price of the hybrid compares favorably with the cost of a possibly less reliable transistor hybrid. In addition to excellent gain and phase characteristics, this type of transformer doubles the correlator output. Also, this type of correlator has shown the least sensitivity to uncorrelated power.

It should be worthwhile to pursue the possibility of using back diode or FET square law detectors as an alternative to hot carrier diode square law detectors to minimize sensitivity to uncorrelated power. Double balanced mixers should only be considered if their sensitivity to uncorrelated power can be reduced.