NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

Electronics Division Internal Report No. 106

THE GE BD-7 BACK DIODE AS A SQUARE LAW DETECTOR

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SEPTEMBER 1971

NUMBER OF COPIES: 150

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As discussed in Hein Hvatum's report (EDIR No. 6), there is a need in radio astronomy instrumentation for a square law detector. This detector produces an output voltage directly proportional to the input RF power. Thus, with a constant input impedance the output voltage is proportional to the square root of the input voltage.

Most diodes will produce a square law response if they are operated with a low enough RF input. The V-I characteristic of the diode can be reduced to a Taylor series expansion, producing an equation for the current of the form:

$$I = A_0 + A_1 V + A_2 V^2 + A_3 V^3 + A_n V^4 + \ldots$$

If the input voltage V is a sinusoidally varying RF signal, the current I will have two types of components, terms with a DC component and terms without a DC component. The terms with even exponents of V will have a DC component since:

$$(V_0 \cos \omega t)^2 = V_0^2 (\tfrac{1}{2} + \cos 2\omega t)$$

$$(V_0 \cos \omega t)^4 = V_0^4 (\tfrac{3}{4} + \cos 2\omega t + \cos 4\omega t)$$

The odd power terms:

$$(V_0 \cos \omega t)^1$$

$$(V_0 \cos \omega t)^3 = V_0^3 (\cos \omega t)^2 \cos \omega t$$

have no DC terms. Thus, with a low pass filter after the diode rectifier the only components of the current left are the DC components of the even power terms:

$$I = A_0 + \frac{1}{2} A_2 V_0^2 + \frac{3}{4} A_4 V_0^4 + \ldots \frac{n-1}{n} A_n V_0^n$$

where n is even.

Thus, since a true square law is desired, there are two methods to use to increase the accuracy of the law:

1. Reduce V_0 (making V_0^4 insignificant) by reducing the input power.
2. Find a diode whose ratio $\frac{A_2}{A_4}$ is very large.

The first solution has the inherent problem that as you reduce the input power you approach the level of the noise in the diode which will also give erroneous outputs. The second attack is the one that was used, and it was found that the GE BD-7 diode was also quite low in noise at our operating levels also, so the first method was used.

A plot of the V - I characteristic of the GE BD-7 appears in Figure 1. This diode has a small negative resistance region, which in effect increases the A_2 coefficient while decreasing A_n. This gives an increase in the sensitivity of the detector and a wider range over which the response is square law. The sensitivity of the BD-7 was found to be 1 mV at -22 dBm or .7 mV/μW into a 10 K Ω load. This is somewhat more than the HP 432A with .4 mV/μW sensitivity into a 75 Ω load.

The detector law varies with the load resistance that it sees since it is this load across which it is developing the output voltage. As this resistance is increased, the RF range over which the detector is accurately square law shifts toward lower power input levels, Figure 2. For the 50-channel filter receiver application we chose to operate between -27 and -17 dBm; thus a load resistance variable between 0 and 2 K was used.

Two other advantages were also found for the BD-7. The noise of the diode was found to be very low — less than .2 μV peak to peak into the 10 K Ω load. This is less than the HP 432A which was observed to be close to .5 μV p-p. The second advantage, and an important one outside of the lab, was that the temperature coefficient was very good. The HP 432A as used in the standard receiver had a temperature coefficient of +2%/°C, i.e., the output rose 2% for each degree increase in temperature. The BD-7 coefficient was -.4%/°C in the worst case; it was typically only -.25%/°C.

The circuit that is used as an amplifier following the detector is shown in Figure 3. This amplifier has an input impedance of 0 - 2 K Ω adjustable and a gain of about 700. A low offset drift op-amp was employed (AD 741L) to keep the offset as low as possible.

This detector-amplifier was built and the total temperature change was less than -.3%/°C for the prototype. The detector-amplifiers were then built four to a box (2 1/4" x 3 3/4" x 1 1/4") for use in the 50-channel, 1.2 MHz bandwidth filter receiver.

The BD-7 detector with its low temperature coefficient, higher sensitivity and small size will make it useful for a good number of applications. The BD-7 is good up to about 800 MHz where its lead and case reactances become apparent. The BD-407 is a low inductance, low capacitance package for the same diode that could extend this range much higher.

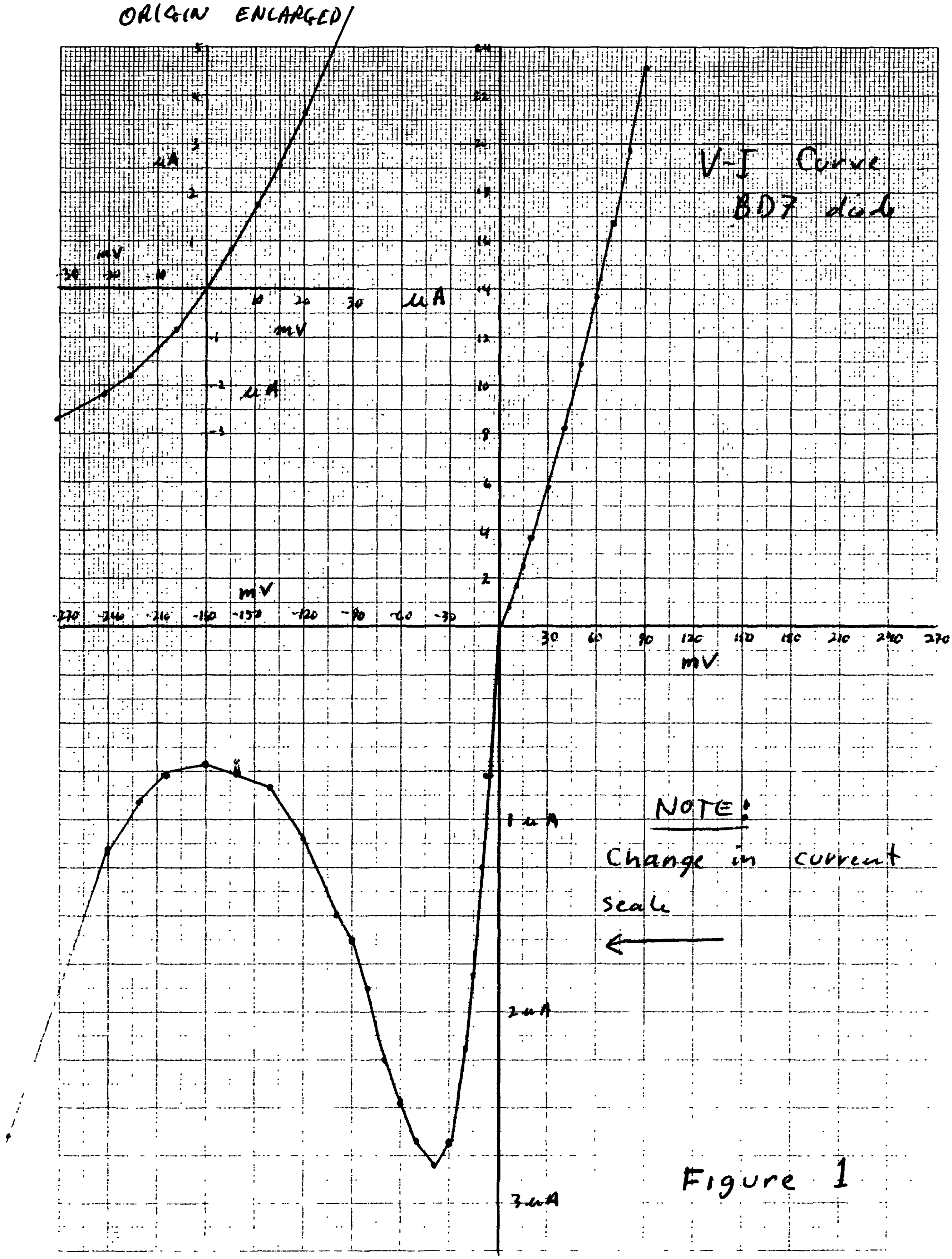
If ranges other than -27 to -17 dBm and output voltages different from 1 to 10 volts are derived, the circuit could be modified to contain two coarse adjustments. For gain, make the 1 meg resistor a pot, and for other input ranges, make the 10 K resistor to ground a 10 K pot. These changes could greatly widen the range of use of the BD-7 detector.

References

Bare, Claude, Power Detectors, February 1964, Electronics Division Internal Report No. 24.

Hvatum, Hein, Detector Law, December 1962, Electronics Division Internal Report No. 6.

Torrey, Henry C. and Whitmer, Charles A., "Crystal Rectifiers," M.I.T. Radiation Laboratory Series, McGraw-Hill Book Co., New York, 1948.



ORIGIN ENLARGED
V-I Curve
BD7 diode
mV
μA
NOTE:
Change in current scale
1 uA
2 uA
3 uA

Figure 1

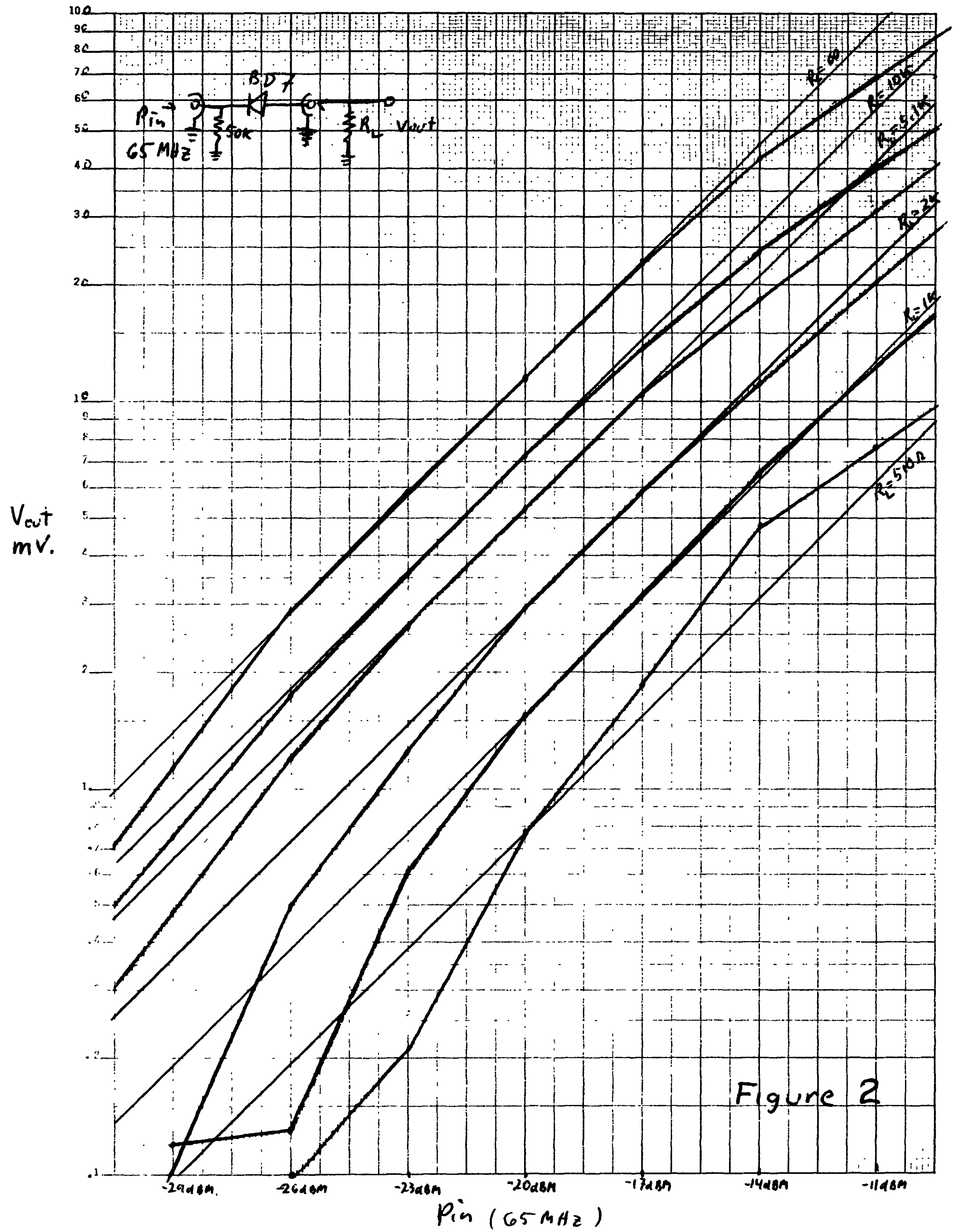
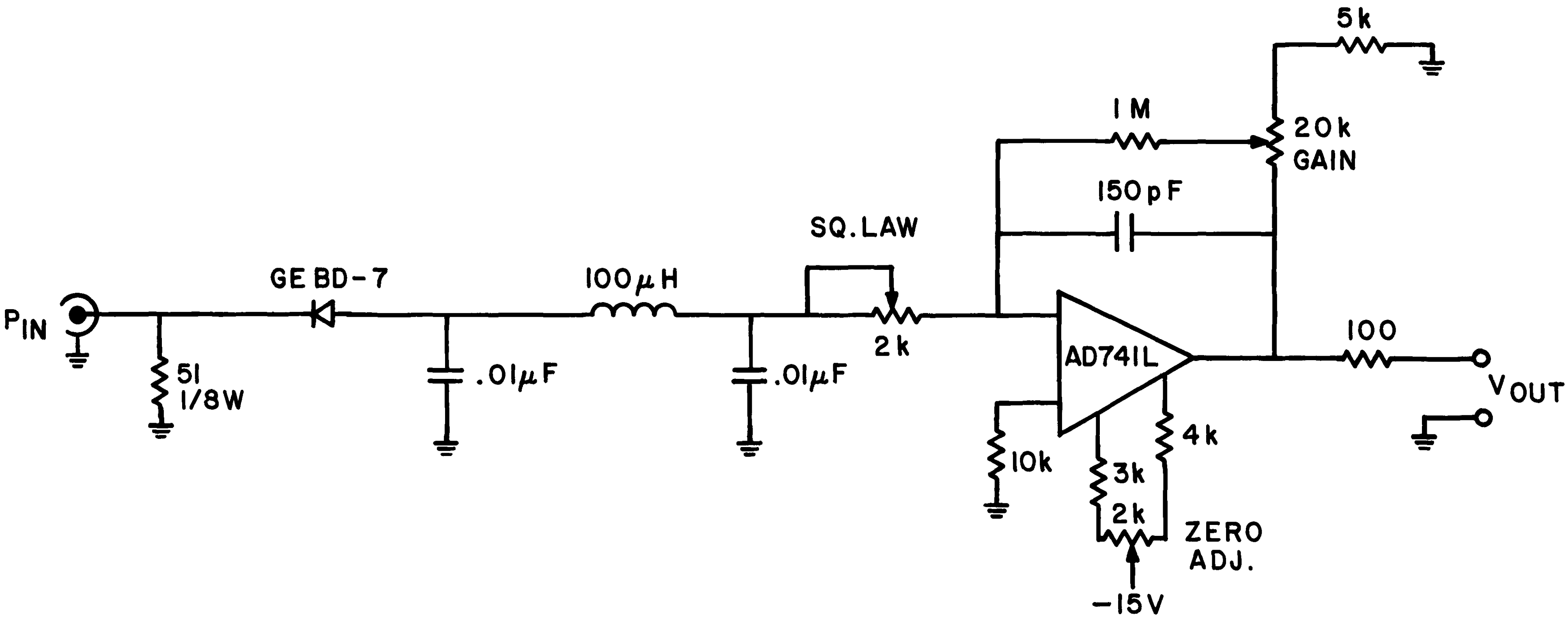

Pin
65 MHz
50K
BD 7
R_L
Vout
R_L = 60
R_L = 10K
R_L = 5.1K
R_L = 2K
R_L = 1K
R_L = 510 Ω
Vout
mV.
-29dBM.
-26dBM
-23dBM
-20dBM
-17dBM
-14dBM
-11dBM
Pin (65 MHz)

Figure 2



5k
1M
20k
GAIN
150pF
SQ.LAW
GE BD-7
100μH
P_{IN}
2k
AD741L
100
51
1/8W
.01μF
.01μF
V_{OUT}
4k
10k
3k
2k
ZERO
ADJ.
−15V

FIG. 3