The Development of a New Broadband Square Law Detector

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A new broadband constant law detector has been developed for precision power measurements, radio metric measurements and other applications. It has a wider dynamic range and a more accurate square law response than has been available in the past. Other desirable characteristics are high-level dc output with immunity to ground loop problems, fast response times, ability to insert known time constants, and good thermal stability. This article briefly reviews the history of this development work and describes in detail the new detector and its performance.

I. Introduction

Broadband square law detectors are required for precision power measurement and a wide variety of other detector applications such as the Noise-Adding Radiometer (Ref. 1), the 64-m antenna servo boresighting system, antenna gain measurements, etc. All of the following detector characteristics are important and are desired in a single device:

(1) Wide dynamic range.

(2) Accurate square law response over the dynamic range.

(3) Good thermal stability.

(4) High-level dc output with immunity to ground loop problems.

(5) Ability to insert known time constants for radio metric applications.

(6) Fast response times compatible with computer-oriented systems.

No known commercial device has all of these characteristics in a single compact unit. Over the past ten years the Radio Frequency Techniques (RFT) Group (Section 333) has used two types of detectors in an attempt to fulfill the above requirements. Development proceeded slowly over the years, but recent work has culminated in a detector which has all of the above characteristics with acceptable accuracy. This article briefly reviews the history of this development work and describes in detail the new broadband square law detector and its performance.

II. The Early Models

Prior to 1965 a germanium diode detector (Type 1N198 or similar) was used which was matched to a 50-ohm input. Since no dc amplification was used, this detector fulfilled conditions (5) and (6) adequately, but the other conditions were not satisfied. The square law response varied from diode to diode and the accuracy obtained was seldom better than 10%. The detector law varied as much as 20% with temperature. Due to the low operating voltages (about 10-mV maximum output), the dynamic range was restricted to less than 20 dB. The magnitude of ground loops often exceeded the dc output signal level. Figure 1 is a circuit diagram of one of these detectors and Fig. 2 shows its measured performance. Input power in −dBm is plotted against output voltage in mV in Fig. 2 for three different bandwidths. The response of this diode was not identical with CW and noise input signals (Refs. 2 and 3). In order to solve this problem for the CW power calibration program (Refs. 2 and 3), a different type of detector was used. This was the power meter detector.

Figure 3 is a photograph of the field model of this detector. The detector consists of a commercial power meter/thermistor combination and is still in use in the DSN. Square law response is excellent, and the higher operating voltages (about 1 V) result in immunity from most ground loops. Known time constants consist of simple RC circuits. The power meter detector still has the following severe problems:

(1) *Thermal drift.* The square law characteristic of the power meter relies on a balance between a detection thermistor and a reference thermistor. Any environmental temperature change upsets this balance and reduces the accuracy. The device, therefore, requires frequent zero adjustments.

(2) *Dynamic range.* This is limited to less than 10 dB unless scale changes are made.

(3) *Response time.* The response time, to 67.5% of full value, to an input level change is greater than 100 ms.

III. Recent Detector Development

When low-drift dc amplifiers became available, the construction of a diode detector with high-level output, good thermal stability, and good square law response became feasible. Several approaches were attempted before a practical device was developed. Figure 4 shows a block diagram of one of the recent detectors. The input is fed through step attenuators with an 80-dB range, a wide-band IF amplifier (1 to 110 MHz) with 45-dB gain, and into a detector/amplifier unit. The dc output from this unit is available through a variety of time constant and filter circuits, a typical example of which is shown in Fig. 4. Two outputs have time constants, one of which is variable; two outputs are fast, and the fifth has a frequency proportional to voltage.

Figure 5 is a detailed diagram of the diode detector and dc amplifier block in Fig. 4. This entire circuit is enclosed in a mumetal box for radio frequency interference (RFI) and magnetic shielding. The RF portion of this circuit is RFI-shielded from the remainder, as shown. All outputs from shielded enclosures are through capacitive feed-through connectors. The inner shielded box contains the diode and an isolation transformer. Considerable effort was expended in determining the best diode type from various manufacturers for this detector application. The objective was to find the optimum compromise between sensitivity, repeatability, square law characteristics, stability, drift, etc. A tunnel diode was chosen, type BD-3. The amplifier is an Analog Devices Model 234L.

The entire circuit is packaged in a standard chassis for rack mounting. Provision is made on the front panel for adjustment of the meter sensitivity and detector time constant as well as a dc bias offset. Figure 6 is a photograph of the engineering model.

IV. Performance

A. Dynamic Range and Square Law Response

The square law response of the detector is plotted in Fig. 7. Figure 7 shows output error in dB for a 1-dB input level change as a function of output level. A high-power broadband noise source was fed through a variable attenuator and a measured 1-dB step. The output from this step switch was connected to the input of the detector and the output was monitored in the usual way. The detector was taken over the whole range of its output voltage (0 to 2 V) by adjusting the variable attenuator. Each point on the curve was measured by switching the 1-dB step in and out. The response of a perfect detector would be a line parallel to the x-axis which intersects the y-axis at the 1-dB point. It may be seen from the figure that over the first 10 dB of detector dynamic range the deviation from square law is 0.009 dB, whereas over the whole of the measured dynamic range (60-mV to 2-V output) of 15.6 dB, the error is 0.032 dB. Figure 8 shows the detector square law response for a 30-dB input range. A true square law characteristic is shown by the straight line. This method of presenting the detector response does not have sufficient resolution to show the detector characteristics nor is it accurate, but is shown here for comparison with Fig. 2. It must be noted that the detector is more linear than the IF attenuator used to change the input signal level over the 30-dB range, and, therefore, this figure is more an attenuator characteristic than a detector characteristic. (This detector has been used in a program to measure IF attenuator characteristics; this is reported elsewhere (Ref. 4)). The data of Figs. 7 and 9 were not taken this way. Each data point in these two figures was obtained by switching the same 1-dB step in and out. Thus neither the accuracy nor the linearity of this step affects the detector output data. With the above reservations in mind, the following departures from square law have been taken from Fig. 8: 0.25 dB over a 20-dB dynamic range and 0.35 dB over a 30-dB dynamic range.

B. Thermal Drift

The Model 234L amplifier shown in Fig. 5 is a chopper-stabilized dc amplifier with a specified drift of 0.1 μV/°C, referred to the input. For a gain of 200 the drift, referred to the output, is 20 μV/°C. Measurements have indicated that the total drift in field installations at Goldstone is less than 0.1 mV per week.

Figure 9 shows the effect of dc offsets on the detector performance. These data were taken and plotted in the same way as the data of Fig. 7. That is, the graph is a plot of detector output error against output signal level for a 1-dB step change in input signal. It may be seen from the figure that detection performance can be improved only over a small operating range by imposing a dc offset.

The time constant networks shown in Fig. 4 are made up of resistance–capacitance circuits and are inserted by using isolation amplifiers. Since these amplifiers operate at a gain of 1 or 5, thermal drifts are insignificant.

C. Ground Loops

Since the voltage levels in the detector are all about one volt, most ground loops are insignificant.

D. Response Time

Full voltage (to 99.9% output level) rise time is less than 300 μs. Faster low-drift amplifiers are now becoming available and it is expected that this response time will soon be lowered to less than 10 μs.

E. High-Level Output

The 0- to 10-V output shown in Fig. 4 is used for operation with an analog-to-digital converter for computer applications (Ref. 1). This output, therefore, has a low-pass filter to prevent clock feedback from the computer.

V. Thermal Stability

Figures 10 and 11 show the effect of temperature changes on the detector output. They are plots of output voltage drift as a function of detector chassis temperature.

The detector chassis was placed in an oven and the output voltages monitored with the input terminated. The oven temperature was changed in a series of step functions, and measured at a representative point on the detector chassis. The detector temperature and outputs were recorded on a strip chart recorder. Temperatures were allowed to stabilize for several hours before data were taken. When a step change was made in the oven temperature, the detector required some settling time before coming to a steady output voltage. For a 25°C step change in temperature, the detector settling time is approximately 60 min, and typical peak transient deviations are approximately 200 μV.

Figure 10 shows voltage drift data for a typical production model of the detector and Fig. 11 shows similar data for a selected good unit. In both figures the crosses are for the 10-V output, and the circles are for the 2-V V/F output. The output voltage scales for the two sets of data are, therefore, different. It must be noted that even in the production unit the use of the amplifier to yield a 10-V output does not seriously detract from the stability of the detector.

VI. Conclusion

A broadband constant-law detector has been constructed for precision power measurements, radio metric measurements, and other applications. It has a wider dynamic range, and a more accurate square law response over that dynamic range than has been available in the past. It has other desirable characteristics such as high-level dc output with immunity to ground loop problems, fast response times, ability to insert known time constants, and good thermal stability.

A subsequent article will discuss the operation of this detector in a programmable system which accounts for detector deviation from square law response to yield an instrument whose accuracy is 0.3%.

References

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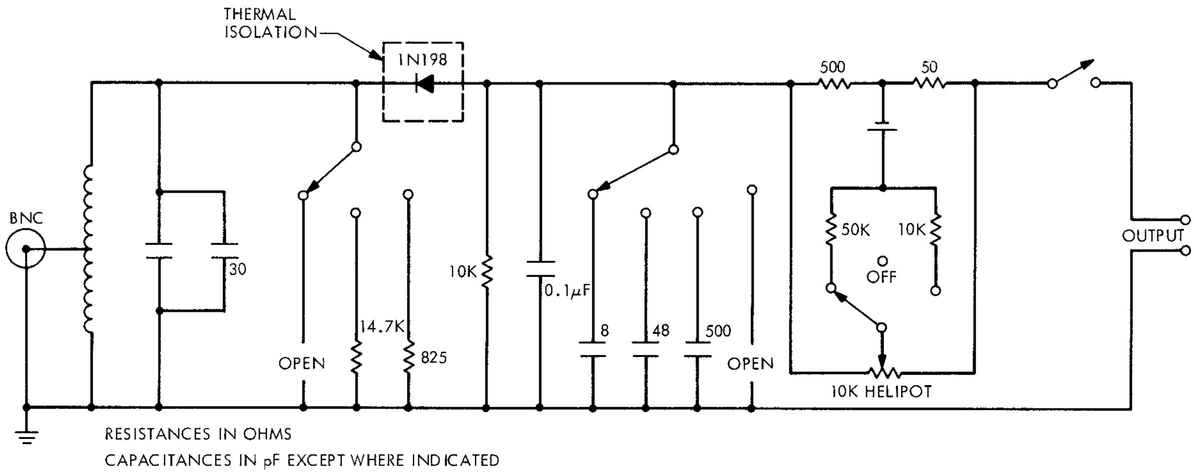

Fig. 1. Circuit diagram of early diode detector

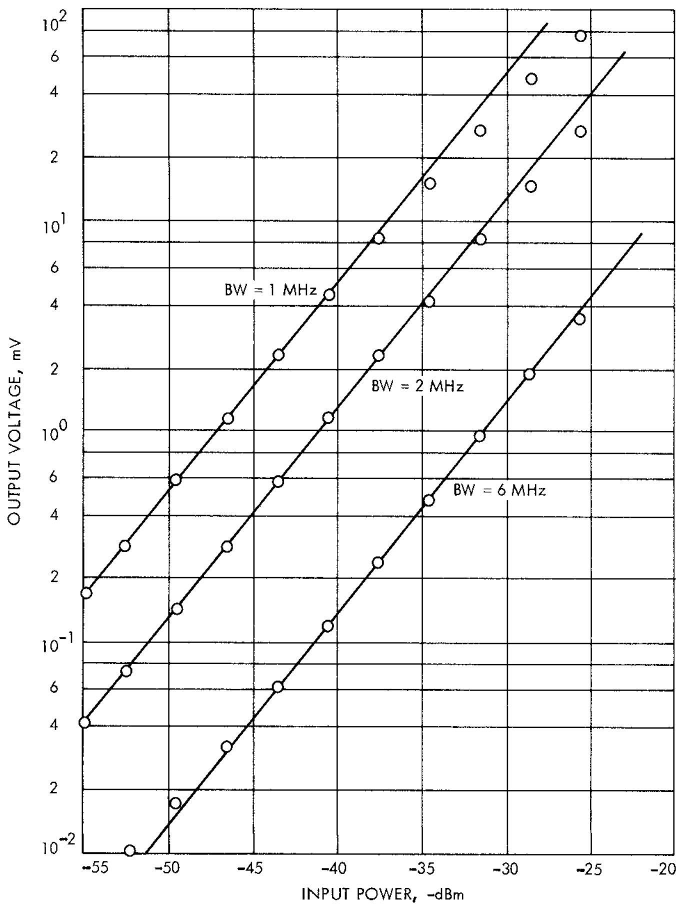

Fig. 2. Performance characteristics of an early detector

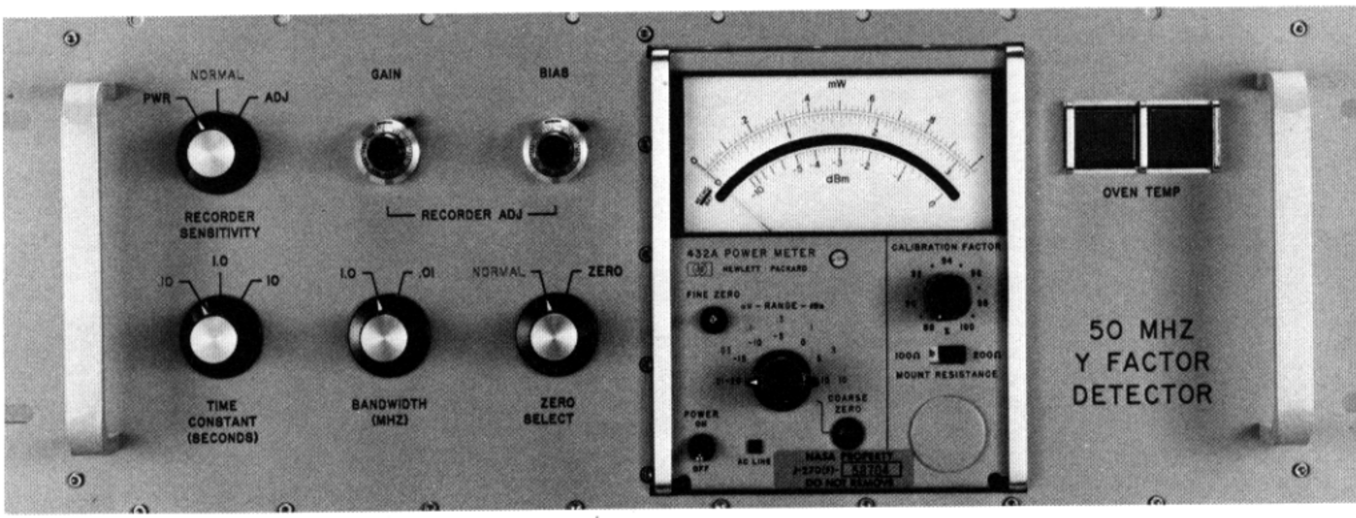

Fig. 3. Field model of the power meter detector

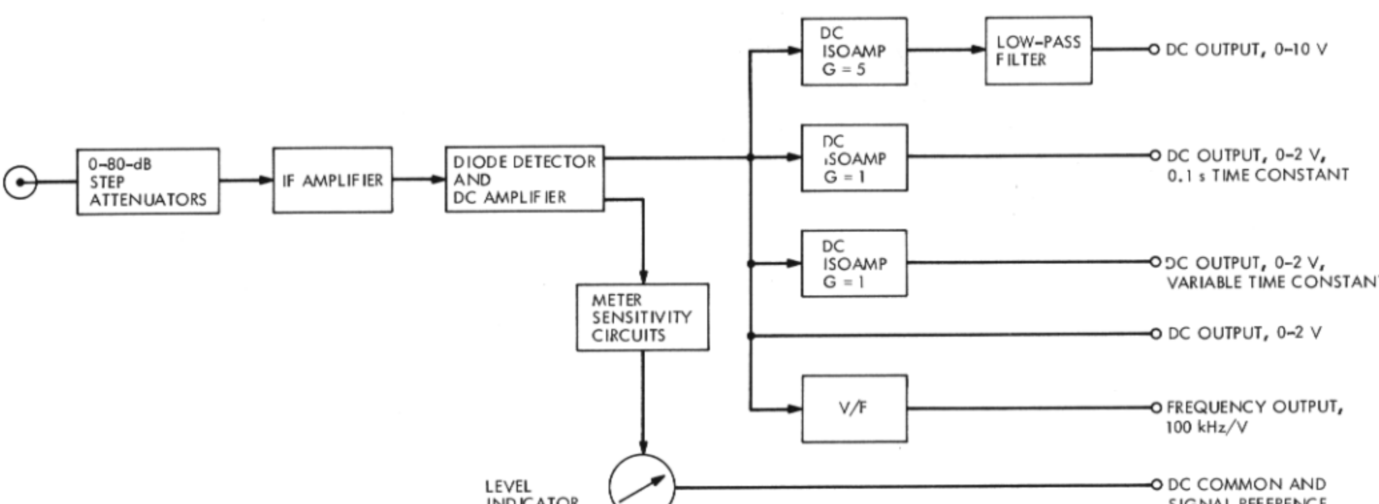

Fig. 4. Block diagram of the broadband square law detector

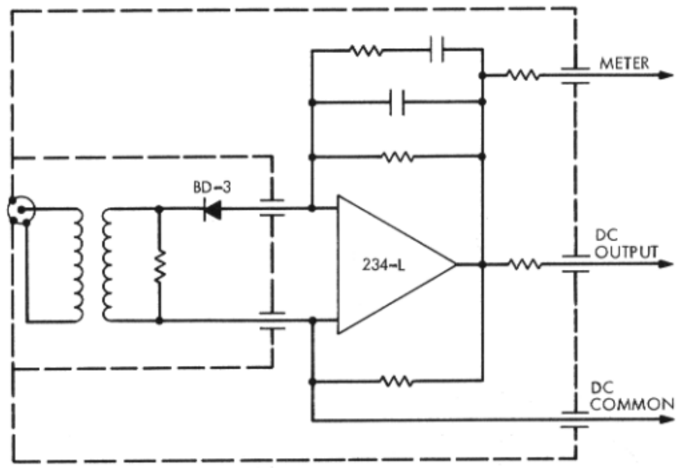

Fig. 5. Diode detector and dc amplifier

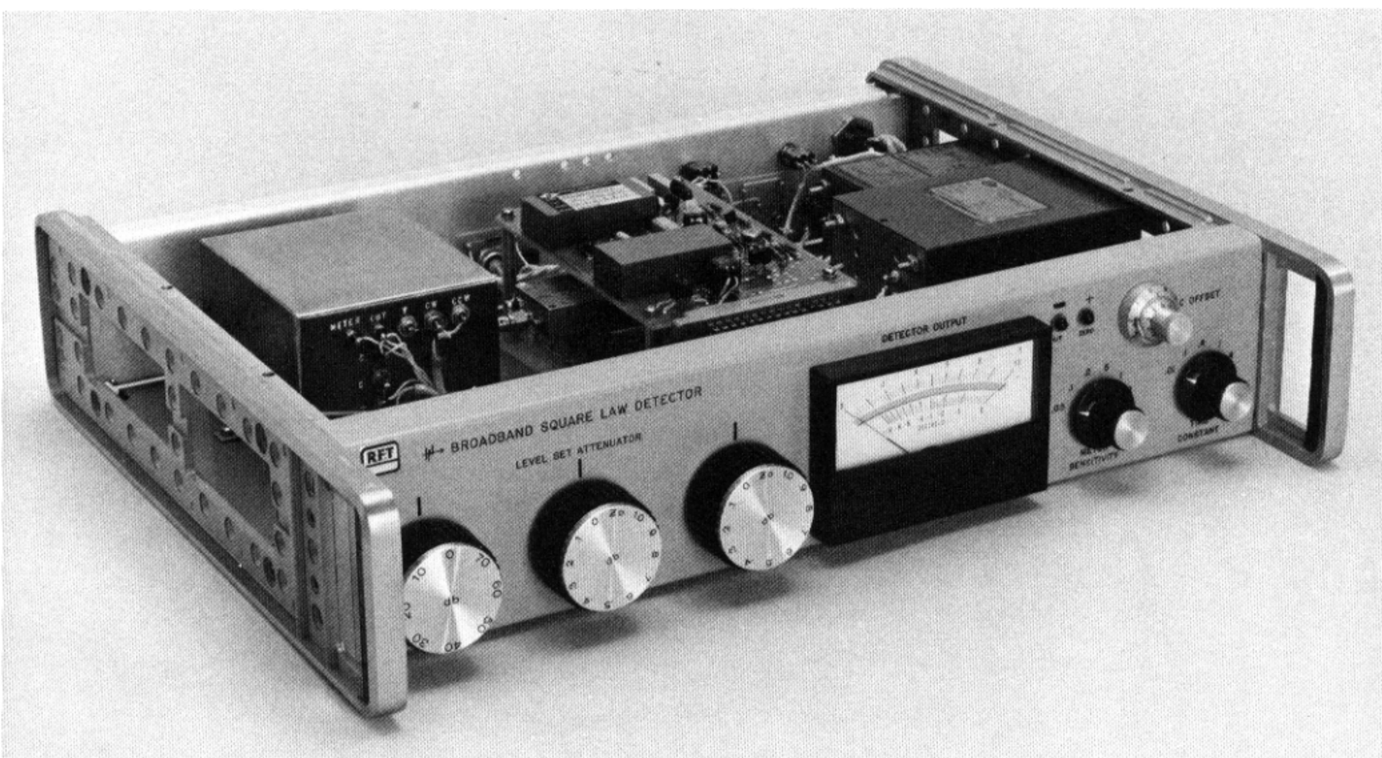

Fig. 6. Photograph of engineering model

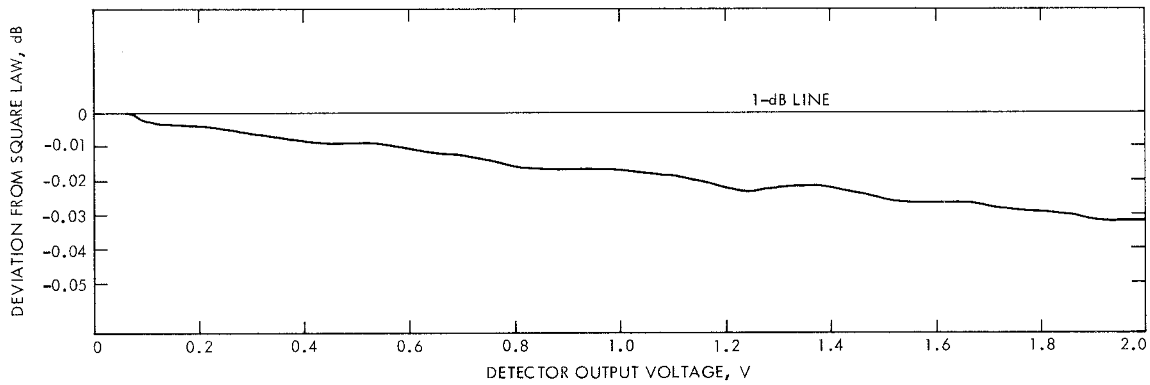

Fig. 7. Output error for 1-dB input level change as a function of output level

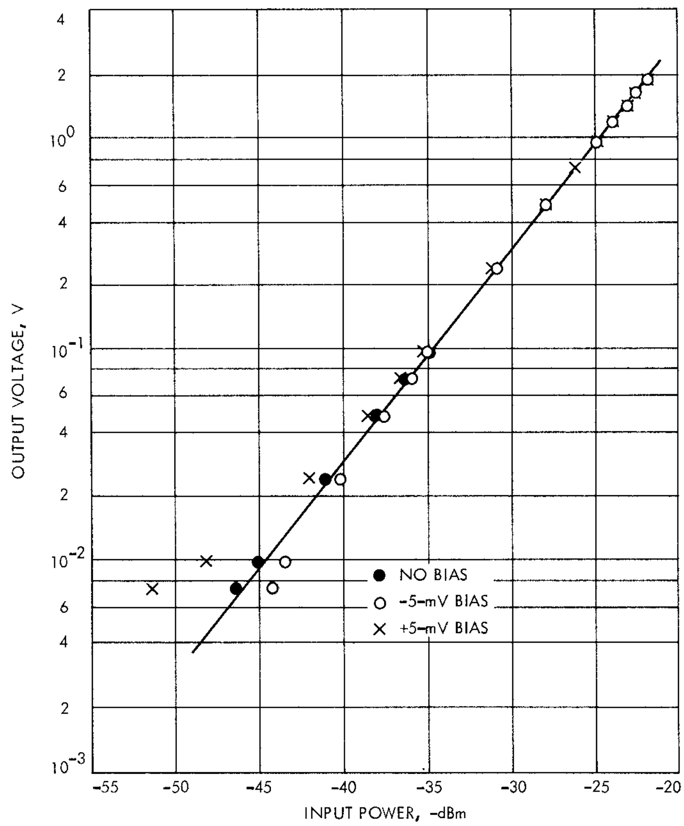

Fig. 8. Square law response for a 30-dB input range

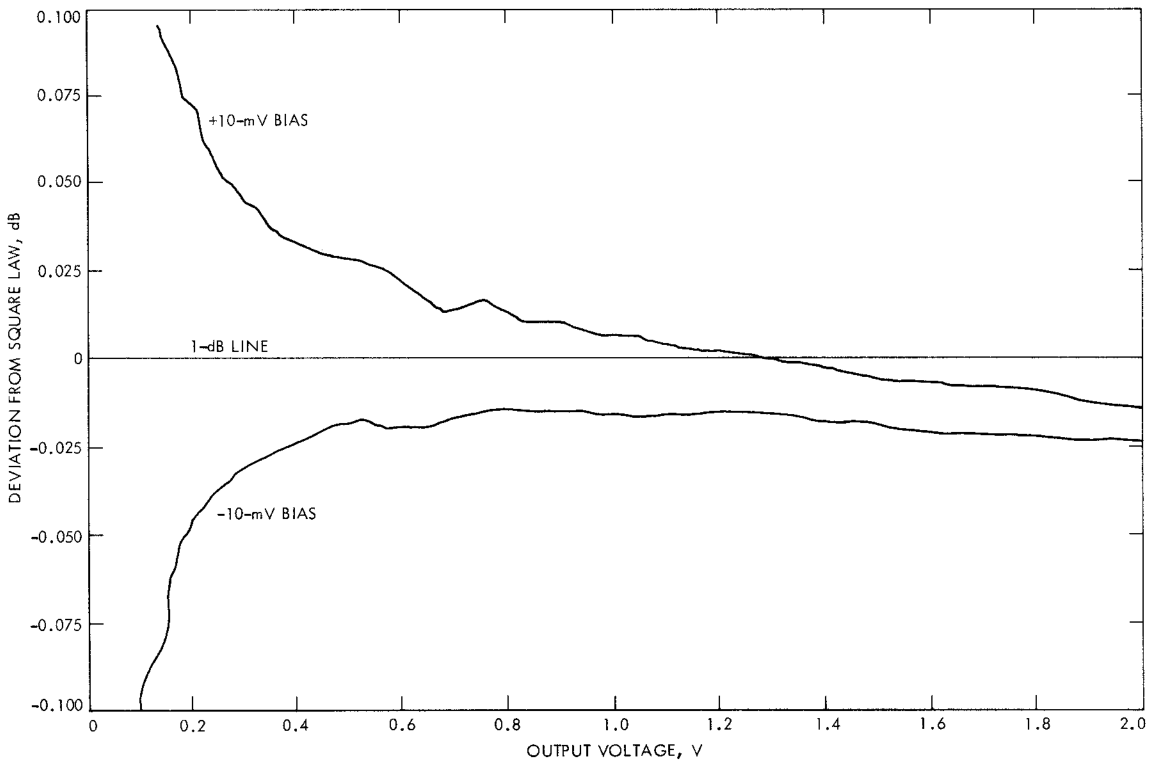

Fig. 9. The effect of dc offsets on the detector response

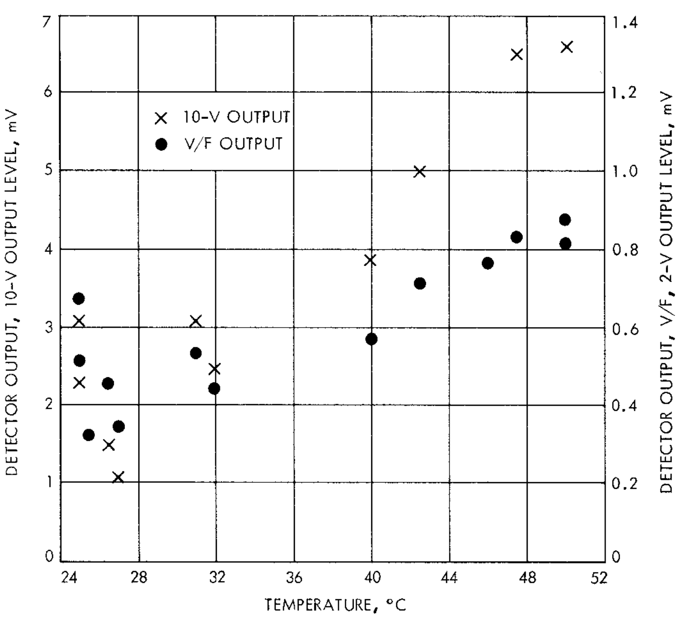

Fig. 10. Output drift as a function of temperature: typical production unit

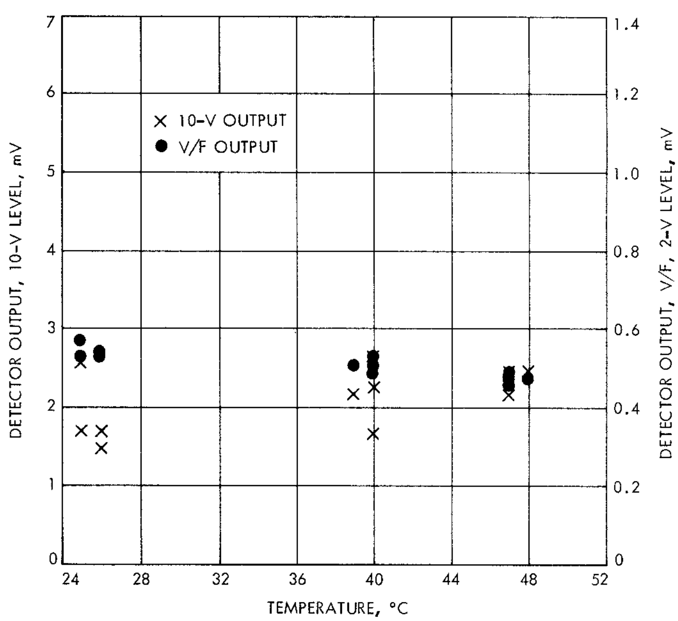

Fig. 11. Output drift as a function of temperature: selected unit