Radio Metric Applications of the New Broadband Square Law Detector

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Previous articles have discussed the development and performance of a new constant law detector. The new detector has a wider dynamic range and a more accurate square law response than has been available in the past. This article discusses the use and performance of this detector in a noise-adding radiometer system at DSS 13.

I. Introduction

Previous articles (Refs. 1, 2) have discussed the development and performance of a new constant law detector. This new detector has a wider dynamic range and a more accurate square law response than has been available in the past. Other desirable characteristics of the detector 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 discusses the use and performance of the new detector in a noise-adding radiometer (NAR) (Ref. 3) system.

II. The Noise-Adding Radiometer System

In a total-power radiometer, the output system noise temperature T_{op} is given by

$$T_{op} = GKV$$

where G is the system gain, V is the voltage output from the square law detector, and K is a scaling constant. In the total-power radiometer system, gain changes cannot be distinguished from real antenna temperature changes. In order to desensitize a receiving system from gain changes, a noise-adding radiometer may be used. If a known and constant amount of noise is added to the system and used as a reference, then it is possible to obtain a ratio of output powers (Y-factors) with the noise reference source on and off. Thus,

$$Y = \frac{G\,(T_{op} + T_N)}{G\,(T_{op})}$$

and

$$T_{op} = \frac{T_N}{Y - 1}$$

where T_N is the equivalent noise temperature of the noise reference. It has been found that a temperature-stabilized solid-state noise diode is sufficiently stable for noise-adding radiometer applications (Ref. 3). If the Y-factors are measured at a rate much faster than the gain changes in the receiving system, the effect of gain fluctuations is cancelled.

A noise-adding radiometer system has been designed and constructed at DSS 13 for operation with the 26-m antenna. The maser preamplifier operates in a closed-cycle refrigerator (CCR). The CCR compressor cycles at a 1.2-Hz rate which is determined by the ac power-line frequency. Since the maser gain fluctuates at this rate, it is desirable to switch T_X at a rate greater than 8 Hz. It is also important to choose a rate that will not cohere with the 1.2-Hz CCR rate. The resolution of the radiometer, for a switching rate of 8 Hz (which corresponds to a measurement time of 0.125 s), is given by

$$\Delta T = \frac{2T_{op}\left(1 + \frac{T_{op}}{T_X}\right)}{\sqrt{\tau B}} = \frac{2\,(20)\left(1 + \frac{20}{117}\right)}{\sqrt{40 \times 10^{-3} \times 10 \times 10^{6}}} \approx 0.1\text{K}$$

where τ is the measurement time for one Y-factor and B the system bandwidth. Thus, the resolution is 0.1K for a single measurement of T_{op} from one Y-factor for the DSS 13 radiometer. This resolution is improved, by averaging a number of individual measurements, by the factor $1/\sqrt{N}$. This results in a radiometer system with a measurement resolution on the order of a milli-Kelvin.

Figure 1 shows a block diagram of the DSS 13 NAR system. In the figure, ND is the solid-state noise diode in an oven. The detector is the unit described in Refs. 1 and 2. Any detector departure from true square law has two effects: (1) measurement inaccuracy and (2) susceptibility to gain fluctuation. Thus, all measurements are corrected by a factor α, as described in Ref. 2, so that the measurement Y-factor is given by

$$Y = \frac{T_{op} + T_X}{T_{op}} = \frac{V_2 + \alpha (V_2)^2}{V_1 + \alpha (V_1)^2}$$

where V_1 and V_2 are the detector output voltages with the noise diode off and on, respectively. The IF bandwidth at the input to the detector is 5 MHz. The frequency output from the detector is fed to the computing counter.

The computing counter is Model H.P. 5360A, and the computing counter programmer is Model H.P. 6376A. These two units comprise a small computing system with input/output capability, which is capable of executing 200 program steps with an average execution time of 15 μs per step. It is also capable of accepting input data in BCD form, reading an externally generated frequency, and performing various external functions by means of TTL-type signal levels. In addition, six-digit constants are available in thumbwheel form for use in the program. The programmer commands the noise source driver which turns the noise diode on and off.

The programmed controller, Model 601, commands the computing counter and interfaces with the station XDS 910 computer, as shown in the figure. The programmed controller commands the 910 with azimuth and elevation offset functions, and the 910 drives the antenna servo in the usual way. The programmed controller is described in detail in Ref. 4.

III. Method of Operating the NAR System

The detector correction factor α is first measured and then set on the thumbwheels as a system constant for the duration of the NAR observing period. To determine the correct value for the correction factor, the α-thumbwheels are first set to zero, the waveguide switch is switched to the ambient load, the NAR is run, and the detected output level is set to 1.8 V, with the noise diode on. The ambient load is connected to the maser input to ensure a constant system temperature during the measurement of α. There is the possibility of radio sources passing into or out of the antenna beam if the maser were connected to the horn at this time. The IF input level to the detector is then reduced by 10 dB, and a new system temperature is computed. If the system temperature at the lower gain setting is lower than the system temperature at the higher gain, a greater value for α is required. The correct value for α is found experimentally by determining that value of α which produces the same value of T_{op} for both gain settings.

The second system constant that must be determined is the correct value for T_X. When this is found, it is entered in the second set of thumbwheels and held constant for the duration of the experiment. With the ambient termination on the maser input, the system temperature is given by

$$T_{op} = T_P + T_M + T_F$$

where

T_P = physical temperature of the ambient termination measured with a quartz thermometer probe.

T_M = equivalent input noise temperature of the maser.

T_F = equivalent input noise temperature of the follow-up receiver.

If the maser is turned on and off, a Y-factor ratio Y_{00} is measured. This ratio is given by

$$Y_{00} = \frac{T_P + T_M + T_F}{T_P + T_F}$$

With a knowledge of T_M and T_P and a measurement of Y_{00}, T_F can be calculated. The system temperature with the ambient termination on the maser input is then known.

The T_N thumbwheel is adjusted until the NAR computes the correct system temperature. The maser input is then switched to the antenna, and the NAR computes the system temperature on the antenna.

The third thumbwheel constant to be determined is N, the number of measurements which are averaged to yield the output system temperature T_{op}. Since measurement certainty is given by

$$\Delta T_{\mathrm{RMS}} = \frac{\Delta T}{\sqrt{N}}$$

where ΔT is the measurement resolution as stated above, a value for N may be chosen that will produce the desired radiometer resolution. If the antenna is moving in elevation during the measurement, N should be kept sufficiently small so that the real change in antenna temperature does not exceed the desired ΔT_{RMS}.

The noise diode is enclosed in a constant-temperature (50°C) oven. Repeated measurements over an extended period of time have shown that the value of T_N varies approximately $\pm 2\%$ in a 24-h period in S-band systems. This fluctuation in the value of T_N seems to follow ambient temperature variations. Recent laboratory work indicates that the coupling factor of the waveguide coupler used to inject T_N varies as a function of ambient temperature. Further work is in progress on this problem.

A number of NAR programs are available for various engineering and radio science applications.

References

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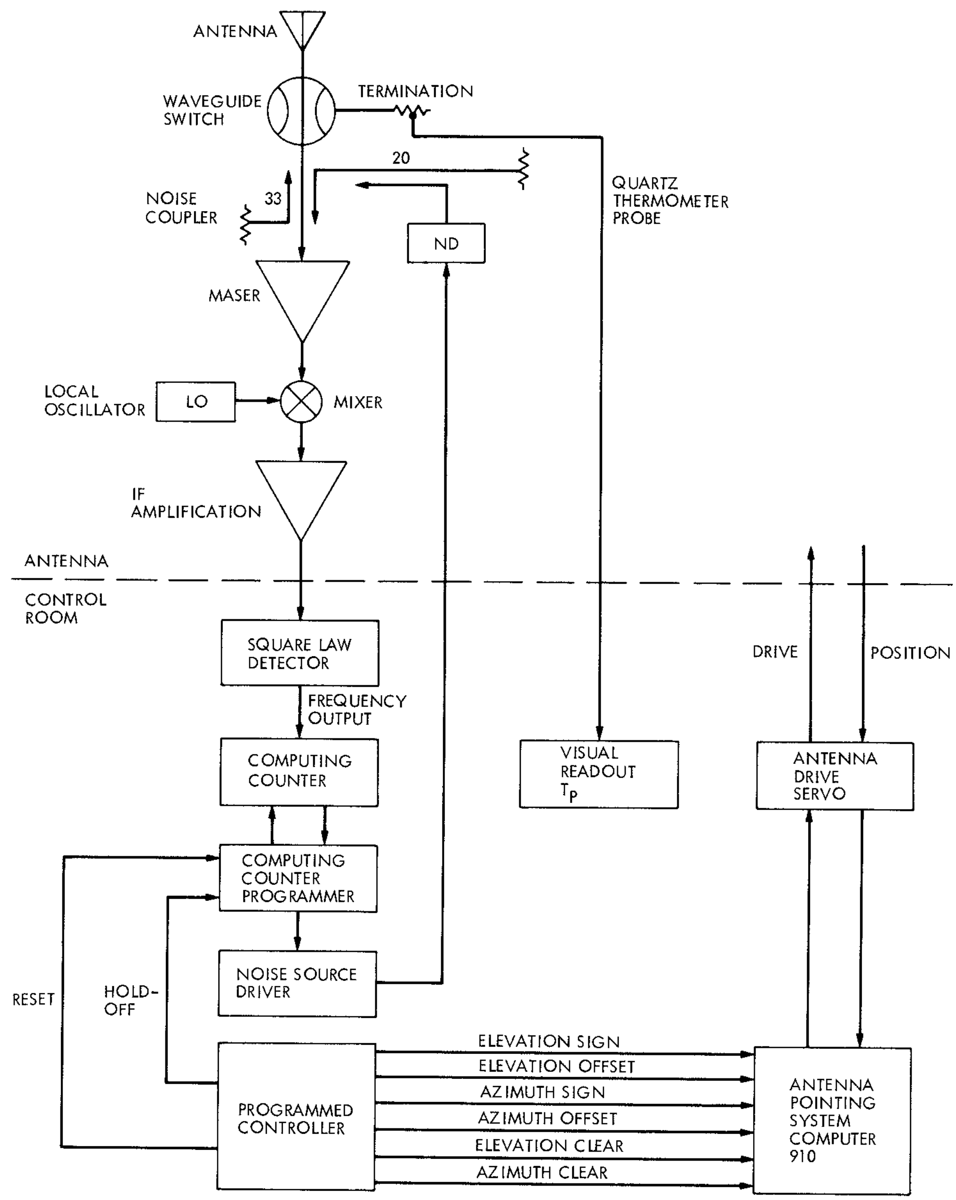

Fig. 1. Block diagram of DSS 13 NAR system