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A Noise-Adding Radiometer for the Parkes Antenna

T. J. Brunzie
Radio Frequency and Microwave Subsystems Section

A new design for a noise-adding radiometer will be included as part of the reimplementation of the Parkes antenna microwave front end. Designed as an aid for antenna calibration, the Parkes NAR will support the Voyager–Neptune encounter in 1989.

I. Introduction

During the upcoming Voyager–Neptune encounter, the 64-meter Australian National Radio Astronomy Observatory at Parkes will once again assume the role of a DSN tracking station as part of the Parkes–Canberra Telemetry Array (PCTA). As with the earlier Uranus encounter, this requires outfitting the antenna with DSN-compatible hardware, ranging from microwave feedhorn to telemetry receiver. Although much of the hardware used during the previous encounter will be reimplemented for the Neptune encounter, the European Space Agency (ESA)-designed front-end monitor and control system will be replaced with a new system designed by JPL.

Among the ESA features that will be duplicated by the new Parkes Front-End Controller (FEC) is a Noise-Adding Radiometer (NAR), a device used to measure antenna system temperature. Its operation is based on the fact that receiver noise power is directly proportional to temperature. Thus, measuring the relative increase in noise power due to the presence of a calibrated thermal noise source allows direct calculation of system temperature. Although it is intended primarily to aid pre-pass antenna pointing calibration procedures, the Parkes NAR will also be capable of monitoring system temperature during telemetry tracks without significant degradation through the use of low-noise diodes.

II. System Configuration

The NAR implemented as part of the monitor and control for the Parkes antenna front end will consist of two basic subsystems: an array of noise diodes, located in the aerial cabin, for injecting noise into the system, and a precision power meter, forming part of the FEC computer, for measuring noise power. The noise diode assemblies are DSN standard equipment—duplicates of the diode ovens and power supplies that form part of the DSN Precision Power Monitor (PPM) assembly. The Digital Power Meter (DPM), a new design, is a functional replacement for the PPM's square-law diodes, employing digital signal processing techniques for noise measurement.

The heart of the system is the Parkes FEC, an 86/14-based multibus computer containing the DPM and configured for monitor and control of the front-end microwave electronics (Fig. 1). The FEC's tasks will include remote control of the noise diode assemblies and operation of the DPM for performing NAR temperature measurements.

Two noise diode assemblies will be provided for the Parkes antenna, one for each of the two X-band receive chains. Each assembly consists of a noise diode oven and associated power supply. Each oven contains three diodes, providing noise temperatures of approximately 0.25, 0.5, 1, 2, 4, 8, and 50 K (defined at the maser input). The diodes are controlled through their power supply assemblies, with relays being used to select the amount of diode current (allowing three noise levels per diode); a fourth TTL signal is used to modulate the diode on and off.

Each power supply assembly is monitored and controlled through 21 digital I/O lines, consisting of relay closures, closure sense, and diode modulation input. Both assemblies will be operated through an HP 3488A switch/control unit containing three HP 44474A digital I/O cards (16 channels per card). A coaxial cable run directly from the FEC will supply the modulation control signals.

Noise power measurements will be made at the inputs of the Parkes telemetry receiver. Each of the two 320-MHz RF signals will be split 3 dB in the receiver signal select drawer and then fed directly to the DPM in the FEC. The DPM consists of three multibus PC boards under FEC control that sample the inputs and accumulate measured power values. An averaged output is read over the bus by the FEC 86/14 CPU. Diode control, noise measurement, system temperature computation, and an analog output will all be handled by the CPU, with results included in FEC status displays.

III. Parkes NAR Operation

Noise-adding radiometers operate by periodically injecting a known quantity of noise into an antenna front end and then measuring the resulting increase in system noise power at the receiver. System temperature measured this way can be used for antenna pointing calibration (star tracking), system performance history, and spacecraft power measurement. Because these tasks usually require a continual stream of system noise temperature data, the Parkes NAR will measure noise levels and compute temperature repeatedly, and will return its results to the antenna pedestal in both digital and analog form.

The Parkes NAR operates by selecting a noise diode and diode current needed to achieve a desired additive noise temperature and then modulating the diode on and off while measuring power at the Parkes telemetry receiver. Two noise power measurements are needed to calculate system temperature: one while the diode is on and one while it is off. A simple calculation based on the diode temperature and the two measured values yields the unknown system temperature.

Although noise power measurements for NAR operation are ideally taken from the telemetry receiver IF, it will not be practical to do so in the case of the Parkes NAR. Measurement using the PCTA receiver 70-MHz IF would require operating the receiver subsystem in addition to the FEC. However, by taking measurements at the receiver 320-MHz inputs, the NAR becomes independent of PCTA operation. As seen in Fig. 1, the use of 3-dB power splitters within the receiver signal select drawer provides the needed signals.

The measurement process begins with control of the noise diode assemblies. This will be done using an HP 3488A switch control unit, rather than a PPM Noise Diode Controller assembly. Operated remotely over the IEEE-488 GP-IB bus, the HP 3488A sets the power supply relays that control diode current and monitors the relay closures to verify proper settings. Diode modulation is controlled directly by the DPM in coordination with noise power measurements.

Software operation consists of selecting the desired noise diode temperature (approximately 0.25, 0.5, 1, 2, 4, 8, or 50 K), selecting the desired measurement rate, and programming the type of analog output desired. System temperature readings will then be available through either status polls or time-dependent graphs. The entire process is initiated and timed by the FEC CPU, which includes in its loop a routine to drive a digital-to-analog converter with the results of the calculations. This analog output will be fed back to the antenna calibration facility in the antenna pedestal.

Within the FEC, the DPM (Fig. 2) performs noise power measurements in a fixed bandwidth of 320–340 MHz by averaging the square of a large number of sampled noise voltages. Under CPU control, an RF switch and a programmable attenuator select the input channel and adjust the noise level to a fixed gain. The attenuator not only has sufficient range for expected noise level variations but can also adjust for inputs from the antenna's ambient load, and will be used for making Y-factor measurements. Next, an on-board local oscillator fixed at 330 MHz mixes the input down to baseband, which is then low-pass filtered at 10 MHz. An 8-bit analog-to-digital converter generates the digital samples of the noise voltages, which are then fed at 20 MHz to a 34-bit-wide multiplier/accumulator for squaring and averaging. The resulting total noise power value is read from the board directly by the CPU.

Timing and control for each measurement is handled by the DPM; the CPU is needed only to read the resulting averaged noise power and to reinitiate the measurement process. The measurement time is variable and can be controlled by the CPU; measurement rate is determined by how often the CPU initiates the process. An interrupt and a status flag are available to signal the CPU each time the process is completed.

In order to achieve both a short measurement time and high accuracy, a total of 2^{18} samples (nominally) are taken at a rate of 20 million samples/second, yielding a 13-ms measurement time and a sampling accuracy of 0.2 percent. (Nyquist sampling theory does not apply to this case, since only noise power is of interest, not the ability to reconstruct waveforms.) Total time overhead includes an additional 2 ms "dead time" between the switching of the diodes and the start of each measurement; this gives the system a chance to settle and allows the CPU ample time to compute the results and restart the process. (Figure 3 diagrams the software loop timing coordinating FEC operation and NAR measurements.) Given that two noise measurements must be made to compute system noise temperature, with four measurements between switching, the nominal sampling rate for these T_{op} measurements is then twice (4 × 13 + 2) ms, or 9.5 Hz. Resolution is controlled through averaging of the T_{op} samples.

Periodically during NAR operation, the FEC inserts an extra measurement in the loop for determining DC offset. This is done by computing an average of noise voltage samples rather than the square of samples. This offset is used to eliminate the DC component from the total noise power measurement, yielding a purely AC noise power figure for computing T_{op}.

One advantage to implementing the NAR within the Parkes FEC is that the system can be either operated in a stand-alone mode in conjunction with the other front-end equipment or automated within the entire PCTA Receiver/Combiner subsystem. The range of low-noise diodes provided in the PPM diode assembly allows the use of the NAR during telemetry tracking with minimal degradation of telemetry data. Integrated system operation will be available to the Parkes receiver for real-time temperature measurement, and to CDSCC for remote operation and/or monitoring of system performance.

A second advantage provided by the FEC/DPM is the ability to coordinate with the Parkes front-end equipment during test/calibration procedures. The DPM has sufficient range to measure noise power from the antenna's ambient load as well as the cold sky. This makes it possible to reference the ambient load for calibrating the diodes and compensating for system nonlinearities using any one of several techniques [1]. Since the FEC controls the front-end equipment in addition to the NAR, waveguide switching, maser selection, and DPM operation can all be controlled by one program, either with a backup CRT terminal in a stand-alone mode post-pass or automatically as part of a PCTA precalibration configuration control file.

IV. NAR Temperature Calculations

Given the fact that noise power and noise temperature in an antenna system are directly proportional to one another, two equations can be formed from the presence and absence of a known additive noise source:

$$P_{off} = k(T_{op})$$

$$P_{on} = k(T_{op} + T_d)$$

where

P_{off} = system noise power with noise diode off, W

P_{on} = system noise power with noise diode on, W

T_{op} = operating noise temperature, K

T_d = noise diode temperature, K

k = proportionality constant, W/K

Combining these two equations to eliminate k,

$$\frac{P_{on}}{P_{off}} = \frac{T_{op} + T_d}{T_{op}} = 1 + \frac{T_d}{T_{op}}$$

Rearranging yields

$$T_{op} = \frac{T_d}{\left(\frac{P_{on}}{P_{off}}\right) - 1}$$

Thus, making two noise power measurements using a diode of known temperature allows a direct calculation of system noise temperature insensitive to low-frequency gain changes. It can be seen in the calculation of T_{op} that a sizable difference in noise power would help reduce sensitivity to errors in power measurement. While this can easily be accomplished through the use of large (50 K) noise diodes during antenna calibration, operating the NAR during a Voyager array pass would require the use of small diodes in order to prevent significant telemetry degradation.

An additional problem in present DSN NARs involves nonlinearities in measurements performed by the PPM. The problem lies with the PPM square-law diode detectors not being square-law. The Parkes NAR will attempt to improve noise measurement accuracy by replacing the nonlinear square-law diodes with the new linear DPM.

A third consideration in calculating antenna system noise temperature is resolution. The degree to which any NAR can resolve noise temperature is expressed by the following equation [2]:

$$(\Delta T_{\min})\,\mathrm{NAR} = \frac{2T_{op}}{(tB)^{1/2}}\left[1 + \frac{T_{op}}{T_d}\right]$$

where

B = detector bandwidth, Hz

t = total integration time, s

In the case of the Parkes NAR, a best-case system temperature of 21.5 K (maser 1, antenna at zenith), the 50-K noise diode for antenna pointing, the DPM bandwidth of 10 MHz, and a requirement on $\Delta T_{\min}$ of 0.01 K allow solution of a minimum integration time, $t_{\min}$:

$$t_{\min} = \frac{4T_{op}^2}{B(\Delta T_{\min})^2}\left[1 + \frac{T_{op}}{T_d}\right]^2$$

$$t_{\min} = \frac{4(21.5)^2}{10^7(0.01)^2}\left[1 + \frac{21.5}{50}\right]^2 = 2.64 \text{ s}$$

Total measurement time includes switching "dead time" in addition to total integration time. Similar calculations using a worst-case T_{op} of 26 K (maser 2, antenna at 25 degree elevation) yield a total integration time of 4.11 seconds. Since the DPM computes a T_{op} value in about 100 ms, a large number of samples would need to be averaged together by the FEC CPU to meet the total integration time. (Figure 4 illustrates the relationship between temperature resolution and integration time for a variety of diode temperatures using a typical case of $T_{op} = 24$ K.)

In addition to averaging T_{op} samples to meet resolution requirements, the FEC will also have the ability to automatically adjust integration time to continually compensate for variations in the computed T_{op}, thereby keeping noise temperature measurement resolution within specification at all times.

V. Conclusion

Although not yet out of the proof-of-concept phase the design of the Parkes noise-adding radiometer has generated enough support for inclusion in the Parkes Front-End Reimplementation Task. A thorough RF analysis has been completed, and plans call for testing a breadboard of the DPM in early 1988. Full-scale system testing with the front-end electronics is scheduled for mid-1988, with delivery of the completed system late in the year.

Acknowledgments

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References

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[2] P. D. Batelaan *et al.*, *A Noise-Adding Radiometer for Use in the DSN*, JPL Space Programs Summary 37-65, vol. 2, Jet Propulsion Laboratory, Pasadena, California, pp. 66–69, September 30, 1970.

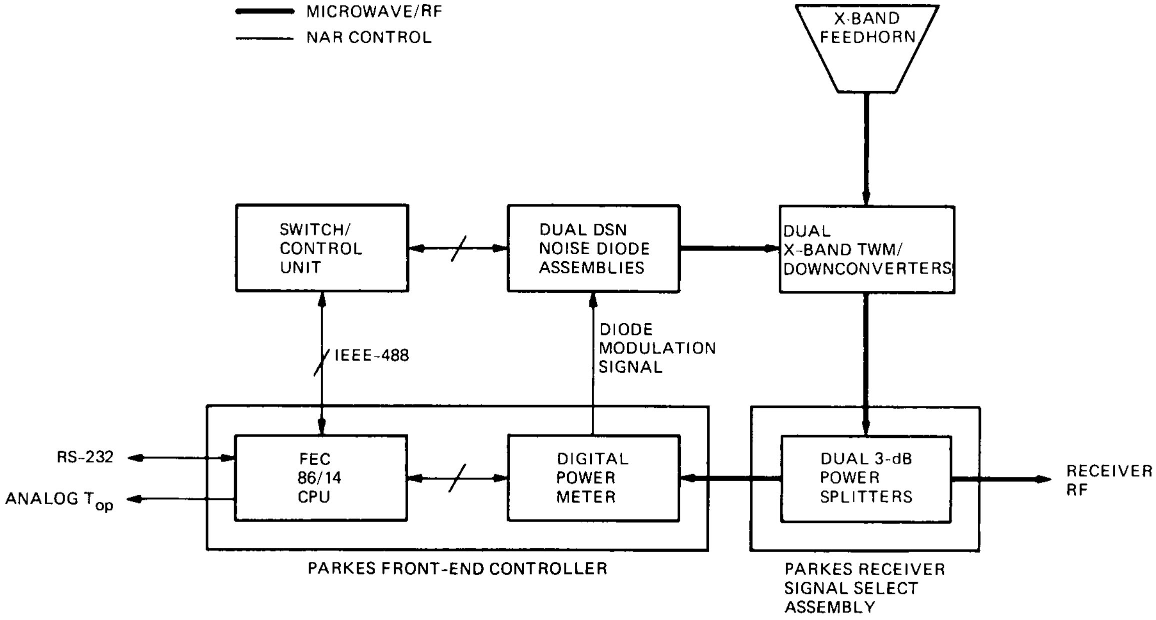

Fig. 1. Parkes noise-adding radiometer block diagram

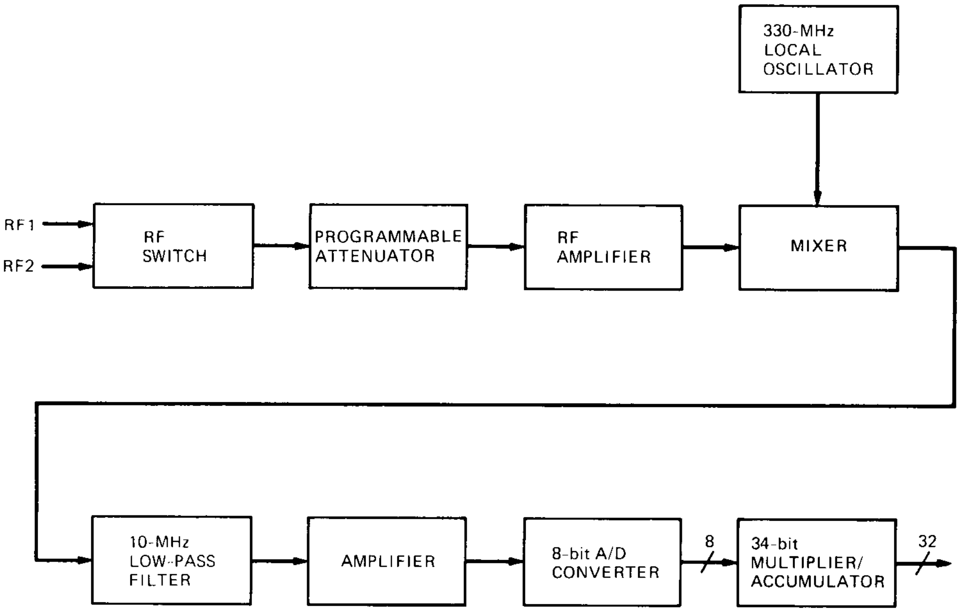

Fig. 2. Digital power meter block diagram

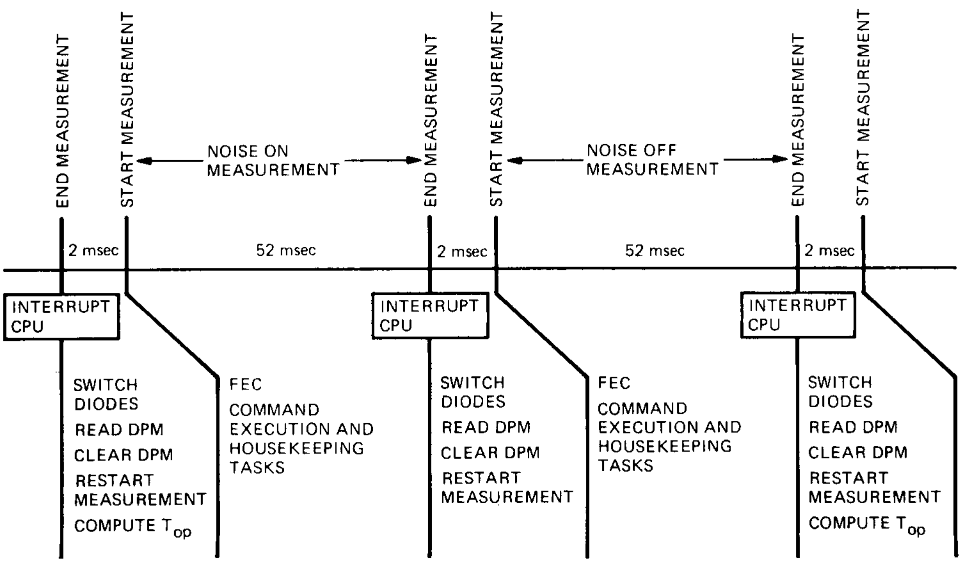

Fig. 3. Front-end controller/NAR loop operation and timing

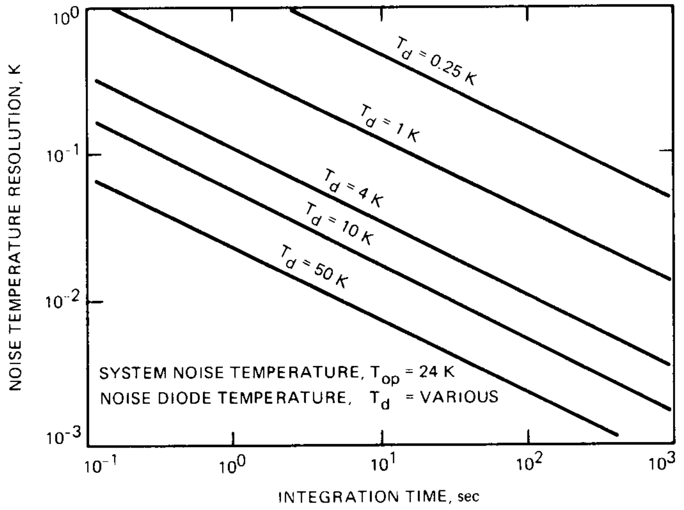

Fig. 4. NAR temperature resolution/integration time relationship