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COMSTAR Experiment:

The 19-GHz Receiving System for an Interim COMSTAR Beacon Propagation Experiment at Crawford Hill

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This paper describes the antenna and receiving electronics for the Bell Laboratories Crawford Hill 19-GHz COMSTAR *Interim Experiment. This experiment has collected essentially continuous 19-GHz attenuation data on the earth-space path to the* COMSTAR *A satellite since May 25, 1976. The receiver operates unattended, automatically reacquiring the beacon signals after deep rain-induced signal fades. A receiver bandwidth of 10 Hz allows accurate measurement of fade depth to the 40-dB level.*

I. INTRODUCTION

A receiving system for the 19-GHz COMSTAR beacons[1,2] has been operating since May 25, 1976, at the Bell Laboratories Crawford Hill facility at Holmdel, New Jersey. This system is less complex than the precision receiving system[3,4] also operating there, but uses the same overall system design and many similar components. This paper will discuss the antenna and receiving electronics for this system.

This receiving system was used initially for observations of the first COMSTAR beacon as it crossed the horizon at Crawford Hill. The main receiving system electronics[3] were operated for a short period in parallel with this system, while awaiting completion of the Crawford Hill millimeter-wave antenna.[4]

The interim receiving system is presently observing the beacon located at 128°W longitude. The propagation path from Crawford Hill to the beacon has an azimuth of 244.7° and an elevation of 18.5°. The beacon characteristics are similar to those given in Table I of Ref. 1; the incident polarizations are within 5° of vertical and horizontal at Crawford Hill. Beacon observations have been nearly continuous since the start of the experiment. Much useful information has already been obtained and has been reported elsewhere.[5,6,7] Since the main receiving system is observing the satellite at 95°W longitude, comparison of the two receiver outputs should indicate the efficacy of "satellite diversity" from a common earth terminal.

Future plans for the interim receiving system include its use as a remote space diversity site. This will allow accumulation of joint fading statistics to fade depths not achievable in previous radiometer experiments.[8]

In its basic configuration, this receiver records the amplitudes of two orthogonal components of the 19-GHz incident radiation. Two identical receiver channels are used. Narrow receiver noise bandwidths are used to maximize the measuring range. Automatic frequency tracking and reacquisition allow unattended operation. The receiving antenna beamwidth is sufficiently wide that no tracking of diurnal satellite motion is required.

The general design considerations for this receiving system are similar to those discussed for the main receiving system.[3] The receiving antenna is described in Section II. Section III discusses the receiving electronics. Receiver performance and some typical data are included in Section IV.

II. ANTENNA

The antenna and feed assembly were originally designed for a 20-GHz propagation experiment using a beacon on the ATS-6 satellite.[9] The feed assembly and antenna positioner were later modified for this experiment. The antenna is of Cassegrainian design, with a 12-foot-diameter aperture and two orthogonal linearly polarized feeds. Antenna positioning is controlled remotely from the equipment building. The complete antenna assembly is shown in Fig. 1.

The 12-foot-diameter spun-aluminum main reflector was manufactured for nominal use at C and X bands. After tensioning the reflector to correct a surface warpage, however, good performance was obtained at 20 GHz.

The 16-inch hyperboloidal subreflector is supported by four aluminum I beams, thinned for minimum depolarization. Both subreflector and support had nonessential material milled away to minimize weight.

Polarization diplexing is accomplished using a quasioptical polarization separator, as in the main antenna feed assembly.[4] This technique is shown in Fig. 2. The polarization separator is a grid of parallel copper strips on a thin mylar support membrane. The grid is oriented so that one polarization, B (polarized parallel to the page), is transmitted

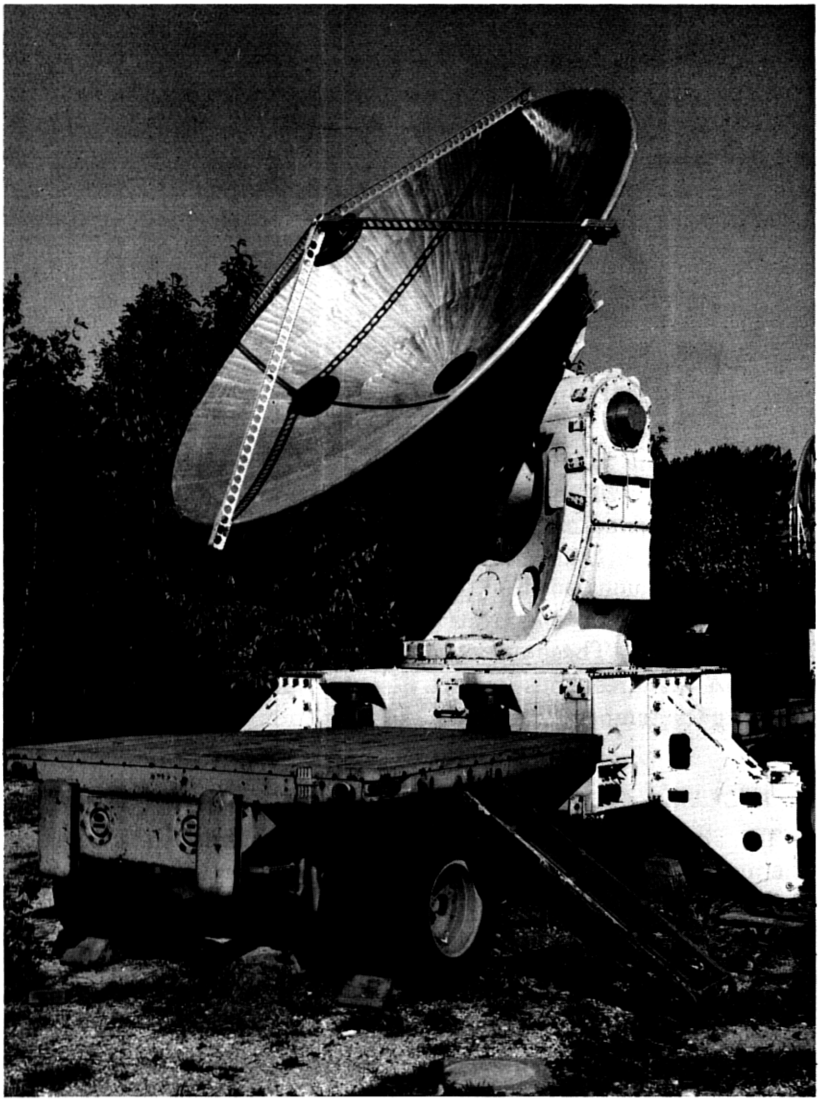

Fig. 1—View of 12-foot antenna for COMSTAR interim experiment.

through the polarizer to aperture I. The orthogonal polarization, A, is reflected to aperture II.

Short-focal-length paraboloids at apertures I and II reflect the received energy to dual-mode feedhorns. The feedhorn size produces a 20-dB edge illumination taper at the main reflector. The feed assembly is rotatable from the equipment building to allow alignment of the feed with the incident polarization angle.

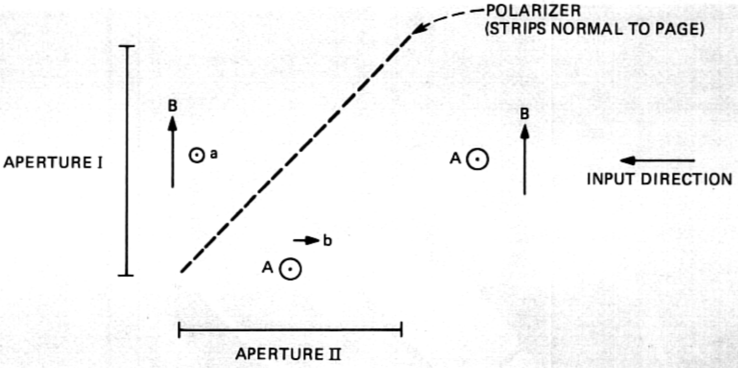

Fig. 2—Polarization separator geometry for 12-foot antenna.

The antenna is mounted on a modified Nike-Hercules elevation-over-azimuth positioner. New drive motors and position encoders allow positioning the antenna from within the equipment building to 0.01 degree precision. Since the satellite position is controlled to within 0.1 degree, continuous position tracking is not required.

The feed assembly and mylar rain window are shrouded with fiberglass weather covers. These are covered with reflective aluminum foil to minimize the "greenhouse" effect. Electric heaters and forced ventilation regulate the temperature within the enclosure.

III. RECEIVING ELECTRONICS

The electronics for the interim receiver are similar to those used in the main COMSTAR beacon receiver.[3] This section will rely heavily on the description of the main receiver electronics in this issue. The basic design philosophy and rationale behind the choice of IF frequencies, etc., is covered there.

A block diagram of the interim receiver electronics is shown in Fig. 3. The receiver consists of two unswitched 19-GHz receiver channels and somewhat simplified frequency control equipment. The first frequency conversion is performed at the antenna feed. All other equipment is located in a building alongside the antenna.

Throughout the receiver, care was taken to assure >60 dB overall isolation between receiver channels. Liberal component shielding was used, and isolators were used where necessary to avoid coupling through common local oscillator lines.

The two antenna feed outputs are down-converted to 1.003 GHz by Schottky-diode mixer-preamplifiers with 6.5-dB single-sideband noise figure. The 18.037-GHz first LO is generated at the feeds from an oscillator in the support building.

The two IF signals are fed to the support building through coaxial cable and are filtered by 0.3 GHz BW bandpass filters to avoid noise saturation of the following wideband IF stages. Down-conversion to 2.067 MHz is performed with image rejection mixers, which use phase cancellation to suppress image noise by >20 dB. Coarse frequency tracking is performed at this conversion, as will be discussed later.

After further amplification, the system noise bandwidth is further constrained with 5-MHz low-pass filters. Step attenuators set the clear-air signals to the desired levels. Amplifiers are used to isolate 6-kHz BW crystal bandpass filters, which provide image rejection at the next conversion.

Balanced mixers perform the next frequency conversion to 6.25 kHz. Short-term frequency instabilities are removed at this step with a phase-locked loop, whose operation will be described later. The 6.25 kHz signals are amplified and filtered by 250 Hz BW active bandpass filters. These and the following filters are mounted in temperature-stabilized ovens for improved gain and frequency stability.

The final frequency conversion to 325 Hz is performed by an active linear multiplier. The final predetection bandwidth is set by 10-Hz BW active bandpass filters. These filters exhibit a single-pole response with 16-Hz noise bandwidth. These filters strip off the 1-kHz polarization-switching modulation and pass only the carrier frequency.

Signal amplitudes are determined with linear amplitude detectors exhibiting ±0.1 dB linearity over 60-dB signal range. The detector outputs are processed by dc logarithmic amplifiers for better display resolution during deep rain fades. The two log amplifier outputs are recorded on a paper chart recorder operating at 4 inches/hour. These two outputs are also fed to the main receiver data recording equipment over telephone lines, using voltage/frequency and frequency/voltage converters. Log, rather than linear, recorder outputs are used to avoid dc offset problems at low signal levels.

Since a measurement of differential amplitude between the two received polarizations is desired, the two log amplifier outputs are subtracted and this difference recorded, with higher sensitivity, on the chart recorder. In addition, 1- and 10-minute timing markers are recorded from the main receiver to allow time synchronization of the two systems.

The receiver must track both the long- and short-term beacon frequency fluctuations. A digitally controlled AFC loop is used to track the thermally induced diurnal fluctuations. This loop is illustrated in Fig. 9 of Ref. 3. A sample of the 2-MHz vertically polarized signal is down-converted to 6.25 kHz and fed to a narrowband discriminator made from two stagger-tuned active filters. The discriminator output is integrated for 1 second. If the average frequency error exceeds 2 Hz, the output frequency of a digitally controlled frequency synthesizer is incremented

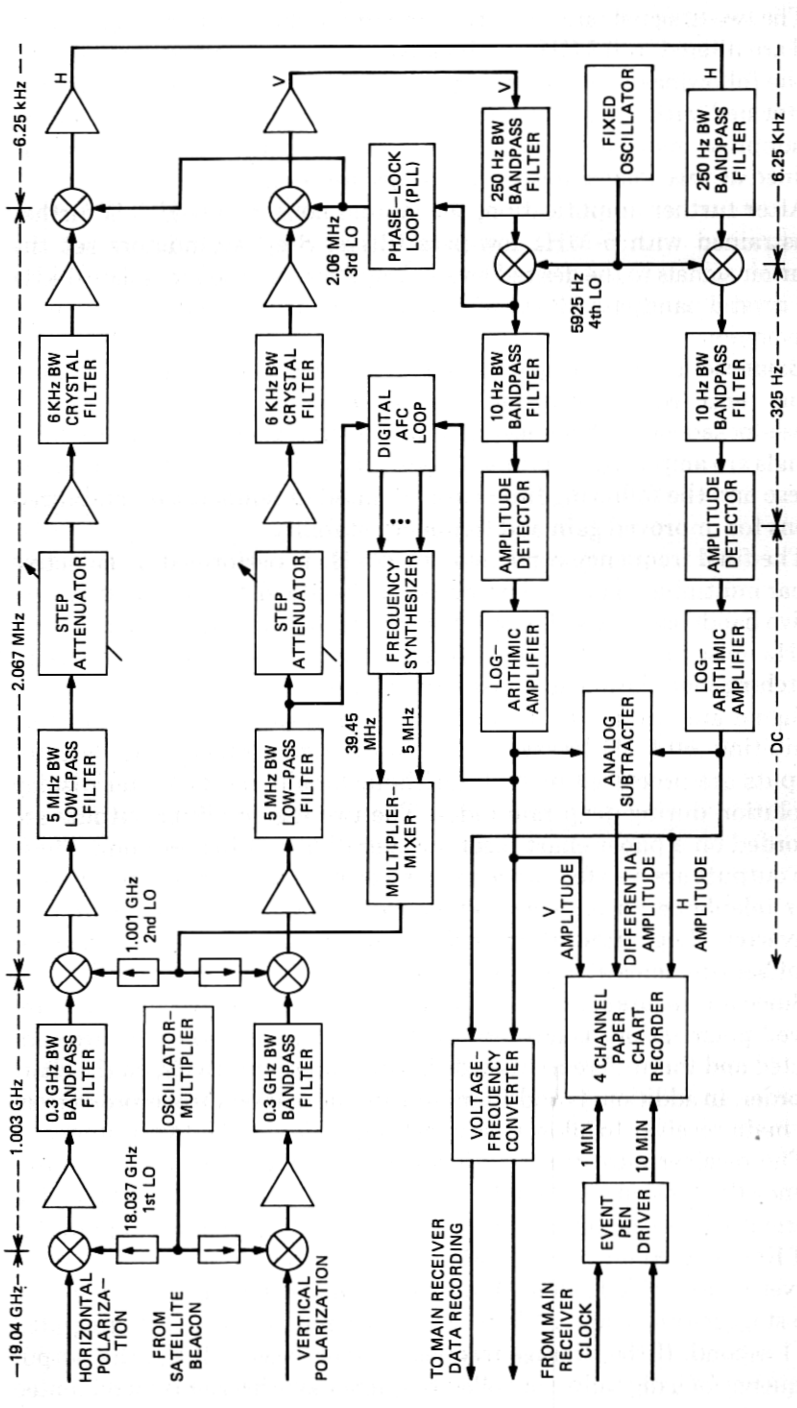

Fig. 3—Block diagram of COMSTAR interim receiver.

or decremented by 1 Hz. The synthesizer output is doubled and used to make up the second local oscillator. Thus, frequency corrections are made in increments of 2 Hz at 1 Hz rate. The loop will track a frequency excursion of ±2 Hz/sec, greater than that expected from the beacon.[1,3]

If the signal at the vertically polarized receiver output falls below a preset threshold, the AFC loop will be unable to maintain track and so initiates an ever-expanding search around the last known beacon frequency. When the signal is again detected at the receiver output, this search ceases and tracking resumes. This technique does not prohibit acquisition of a polarization-switching sideband, but performs adequately and is much simpler to implement than the technique used in the main receiver.

Short-term frequency fluctuations are tracked with a phase-locked loop (PLL). This loop locks the unfiltered 325-Hz vertically polarized received signal to a stable 325-Hz oscillator through adjustment of the 2-MHz third conversion oscillator. Since both vertical and horizontal signals are phase-coherent, the horizontally polarized signal will be locked as well. This loop has a 30-Hz bandwidth and is described in greater detail in Ref. 3.

IV. RECEIVER PERFORMANCE

The interim experiment has operated essentially continuously since May 25, 1976, and has met its design objective of collecting continuous 19-GHz amplitude statistics from the COMSTAR A satellite. Receiver failures have been minimal, and the conservative design approach taken allowed integration of the entire receiving system with no unexpected interactions between subassemblies.

Since most subassemblies for this receiver are identical to those used in the main receiver, most performance measures are identical for the two. Linearity and long-term stability are discussed in Section IX of Ref. 3.

Since this receiver operates without polarization switching using a smaller antenna aperture, the measured clear-air SNR is 50 dB. The AFC loop threshold is set at the 40-dB fade level; below this level the AFC initiates a frequency search to attempt to reacquire the beacon signal. Reacquisition is accomplished reliably to 11 dB SNR, corresponding to a fade depth of 39 dB.

Since the receiving antenna does not track the satellite motion, small diurnal amplitude variations are observed as the satellite traverses the antenna directivity pattern. These variations are generally less than 1 dB peak-to-peak. Since they are of long duration and repeatable on a day-to-day basis, they pose little problem during data reduction.

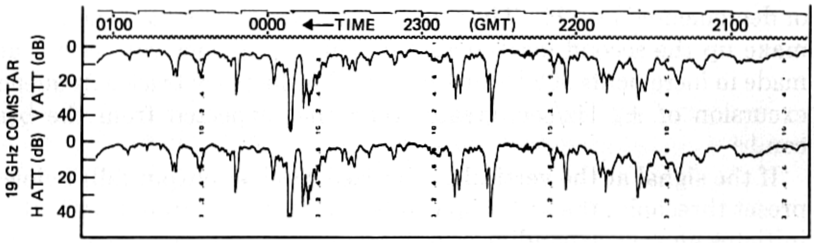

Fig. 4—Typical data obtained from COMSTAR interim experiment (Hurricane Belle, August 9, 1976).

An example of the data collected by this experiment is shown in Fig. 4. These data were taken August 8–9, 1976, during the passage of hurricane Belle 50–60 miles east of Crawford Hill. Time, indicated in GMT, runs from right to left. The upper and lower traces indicate the vertically and horizontally polarized received signal strengths and are calibrated in dB attenuation from the clear-air signal level. While this event is clearly not a typical one, the data shown indicate excellent receiver performance during periods of great environmental stress.

V. SUMMARY

This paper has presented a brief description of the antenna and receiving electronics for the Bell Laboratories Crawford Hill 19-GHz COMSTAR Interim Experiment. This equipment has collected essentially continuous amplitude data from the COMSTAR A satellite since it first became visible at the horizon on May 25, 1976. A received bandwidth of 10 Hz allows accurate measurement of fade depth to 40-dB level. These data, together with those collected by the main Crawford Hill COMSTAR propagation experiment, will be used to characterize earth-satellite propagation at 19 GHz.

VI. ACKNOWLEDGMENTS

Many people contributed to the timely operation of this experiment. The antenna and feed system were available through the encouragement of D. C. Hogg and the design and construction effort of R. H. Turrin. H. H. Hoffman contributed much to the receiver design. Assembly of the receiving electronics was done ably by R. H. Brandt, M. F. Wazowicz, and R. P. Leck; the latter has also aided in the continuing operation of the experiment. The continuing encouragement and support of D. O. Reudink has been invaluable.

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