THE CENTIMETER WAVE BEACONS OF THE COMSTAR DOMESTIC COMMUNICATIONS SATELLITES*

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Abstract

COMSTAR satellites carry all-solid-state Beacons which transmit around 19 and 28.6 GHz for propagation studies. This paper describes the Centimeter Wave Beacon structure, signal characteristics, and electronics, emphasizing the output IMPATT amplifiers and other microwave circuits.

Description

COMSTAR domestic communications satellites[1] carry Centimeter Wave Beacons[2] which transmit around 19 and 28.6 GHz for propagation studies.[3] The Beacons are packaged in two components mounted on either side of the antenna support mast. The second-surface mirrors that radiate internally generated heat appear as white rectangles in Figure 1. The total combined weight of the two components is less than 30 pounds. The total DC power, taken approximately equally from two separate spacecraft buses, is less than 70 watts.

The weight requirements dictated aluminum construction for the containers and also for the waveguide assemblies and chassis within. Five Centimeter Wave Beacons, designated FS, F1, F2, F3, and F4, were manufactured. The signal specifications are listed in Table 1.

A fifth overtone crystal oscillator at 132.222 MHz was chosen for the source. Special effort was made to minimize source phase jitter, since jitter determines the minimum noise bandwidth of the receiver phase-locked loop and thus limits the minimum receivable signal.

Beacon Circuits

Figure 2 is a block diagram of the Beacon. The dashed line shows how the assemblies comprising the Beacon are divided physically between the two components.

The signal path begins with the 132.222-MHz crystal oscillator and doubler. The crystal is stabilized against temperature change by a barium titanate heat-dissipating thermistor. The thermistor is attached to the crystal can and holds the crystal temperature within ±4°C at 45°C over the ambient range of -10°C to +40°C. The signal path proceeds to a X9 transistor multiplier delivering 20 dBm at 2.38 GHz, and then goes through a power amplifier to make 26.5 dBm available at 2.38 GHz.

Two 2.38-GHz power amplifiers are connected to two ports of a 3-dB hybrid; one of the output arms of the hybrid leads to the 19-GHz multiplier chain and the other to the 28-GHz multiplier chain. Proceeding along the 19-GHz chain, the signal passes through a directional filter and then encounters a X4 multiplier of the step recovery diode type. The X4 multiplier uses a silicon step recovery diode, and the doubler a gallium arsenide varactor.

The signal at 2.38 GHz has now been multiplied to 19.04 GHz, the output frequency, at a level of 13 dBm. This signal drives the IMPATT amplifier, which consists of two circulator-coupled stages. The first stage has 10-dB gain and the second has 6-dB gain to give an output power of 29 dBm.

IMPATT amplifiers were selected for their solid-state reliability and low power supply voltages at reasonable DC-to-RF efficiency. Screening and testing techniques showed that the IMPATT diodes used in the 19-GHz amplifiers have a mean time to failure of the order of 500,000 years at the operating temperature levels. These diodes are of silicon flip-chip construction mounted on a diamond heat sink. Each IMPATT amplifier stage dissipates about 7.5 to 8 watts, which is removed through the baseplate on which the stages are mounted.

The signal is switched at a 1-kHz rate between two output waveguides. On the spacecraft, these output waveguides connect to antennas which radiate the signals in orthogonal polarizations. A loss of less than 1 dB is incurred in the switch so that the peak level delivered to each output flange is a nominal 28 dBm.

The driver/doubler accepts 264 MHz from the solid-state source, amplifies it, and sends it to the 28-GHz component, where it drives the phase modulator. For Beacon flight models F2 and F4, a transistor doubler follows the driver to raise the modulation frequency to 529 MHz.

The 28.56-GHz chain of Figure 2 receives a 23.5-dBm CW signal at 2.38 GHz from the 19-GHz component via an interconnecting semirigid cable. Another semirigid cable carries the modulation signal from the 19-GHz component to the 28-GHz component. A conventional wiring cable conveys telemetry and command signals between the two components.

The 2.38-GHz signal input to the 28-GHz component passes through a directional filter, is multiplied to 14.28 GHz by a X6 step-recovery diode multiplier, and then doubled to 28.560 GHz. The doubler delivers 9.5 dBm at 28.560 GHz to the phase modulator.

The phase modulator consists of a varactor mounted across a waveguide which terminates one port of a 3-port circulator. The phase modulator delivers a spectrum centered at 28.56 GHz with about 7.5-dBm total power to the IMPATT amplifier. The first-order sideband to carrier ratio was set at about -6 dB, an index of about 0.9.

The 28-GHz IMPATT amplifier has three stages; the first stage has about 10-dB gain, the second and third have about 6-dB gain each. The first and second stages are circulator coupled, but the third has an arrangement of four hybrid couplers that divides the input power for amplification by four IMPATT amplifier modules, and then combines the amplified signals to form a single output.

The physical arrangement of the 28-GHz amplifier is given in Figure 3, which shows the hybrid quad, current regulators, and IMPATT modules. The total output power

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is nominally 29.5 dBm, but actual Beacon systems tended to deliver about 1 dB more.

The F2 and F4 amplifiers, which operate with 529-MHz modulation, showed output sideband to carrier ratios about 4 dB lower than those at the input. Analysis indicated that this effect resulted from differential phase distortion between spectral components, which was caused by the complex nonlinearity of the IMPATT diodes. A passive spectrum conditioner devised to predistort the relative spectral phases was incorporated in the F2 and F4 IMPATT amplifiers to yield the same input and output sideband-to-carrier ratios.

The six 28-GHz IMPATT diode amplifier modules dissipated about 3.5 watts each. They were widely spaced on the component mounting surface to avoid heat concentrations.

The command hardware is designed into the power conditioners. Commands are activated as part of the normal spacecraft command system. Protection is provided against false command pulses and open or shorts on the command line and its return.

The telemetry uses conventional PN junction Schottky barrier microwave detector diodes in the coupler-detectors to monitor RF power levels. Temperatures are monitored with thermistor bridge circuits. Figure 4 is an external view of the Beacon components and their interconnecting cables.

Beacon System Performance

Table 2 summarizes typical Beacon performance values. The Beacon oscillators passed a go/no go jitter test in which it was observed that at least 90 percent of the oscillator signal power, referred to 19 GHz, was transmitted through a 10-Hz filter. The diurnal variation is typically about ±1 part per million at 28 GHz. The daily temperature variation of the 1.0-kHz switching frequency has also been observed to be about one part per million.

Figure 5 shows the telemetered 19.04-GHz output power of the F3 Beacon (D2 COMSTAR) over two days in the space environment. Figure 6 gives the thermal-vacuum test measurements of output power of the 28.56-GHz carrier and its two sidebands for the FS Beacon (D1 COMSTAR).

References

1. R. Briskman, "The COMSTAR Program," COMSAT Technical Review, Vol. 7, No. 1, Spring 1977.

2. W. J. Getsinger, "Centimeter Wave Beacon Transmitter Design," COMSAT Technical Review, Vol. 7, No. 1, Spring 1977.

3. R. D. Briskman, R. F. Latter, and E. E. Muller, "Call for Help," IEEE Spectrum, Vol. 11, No. 10, October 1974, pp. 35–36.

Table 1. Beacon Signal Characteristics

Item	19.04-GHz Component	28.5-GHz Component
Frequency, GHz	19.040	28.560
Long-Term Stability, ppm	<±1.0	<±1.0
Jitter	90% of power in 100-Hz band	90% of power in 150-Hz band
Modulation	Output switched between 2 ports at 1.0-kHz rate	264.4 MHz (FS, F1, F3) or 528.9 MHz (F2, F4) from carrier
Switching Time, ns	<10	
Switch Frequency Stability		
Long Term	<1 pp 10^6, -10°C to +35°C	
Medium Term	<1 pp 10^7 over 10 minutes	
Power, dBm	27 minimum (both ports)	28 minimum (carrier), 21 minimum (sidebands)
Power Stability, 0°C–40°C		<1 dB

Table 2. Typical Performance Values

Parameter	19.04-GHz Component	28.5-GHz Component	Both
Weight, lb	15.5	11.0	26.5
DC Power, watts (@ 30V)	33.6	33.6	67.2
Bus Range, volts			24.5–48
Low Voltage Cut-Off	17.8–20.6	19.5–20.5	
Generated Line Noise (10 Hz to 100 kHz)			<50 mV into 5Ω
Radio Frequency, GHz	19.040	28.560	
RF Frequency Stability			
Long Term			1 part in 10^6 (-10°C < T < 35°C)
Short Term			90% of power in 10-Hz band referred to 19 GHz
19-GHz Output Switching Frequency, kHz	1.00		
Switch Frequency Stability			
Medium-Term	<1 part in 10^7 over 10 minutes		
Long-Term	1 part in 10^6 (-10°C < T < 35°C)		
Switching Time, ns	4		
Switch Isolation, dB	40		
Spurious Output, -dBc		>40	>40
RF Output Power, dBm	28 (total, both outputs)	30.5 (total)	
RF Output Power, dBm			
Carrier		29	
Sidebands		22	
Power Stability (0°C–40°C), dB	<1.0	<1.0	
EMI Levels (3.7–6.5 GHz), dBW in 4 kHz	<-140	<-140	

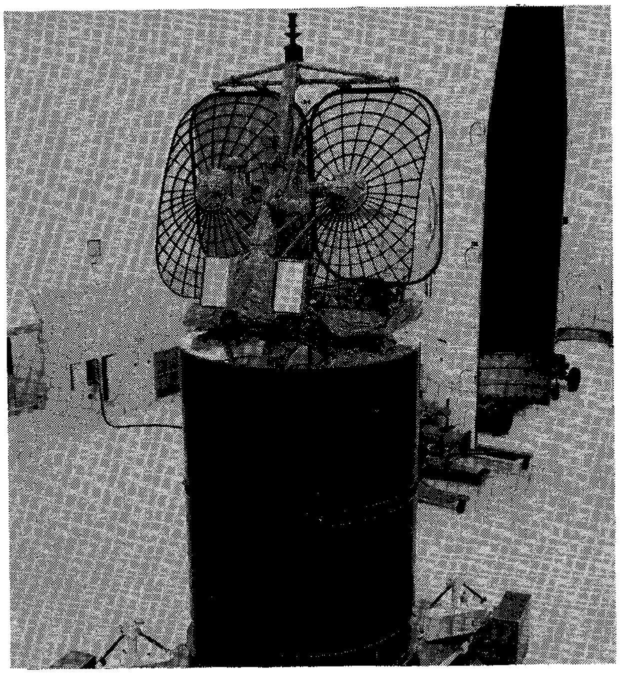

Figure 1. COMSTAR Satellite Showing Centimeter Wave Beacon Components Mounted on Antenna Support Mast

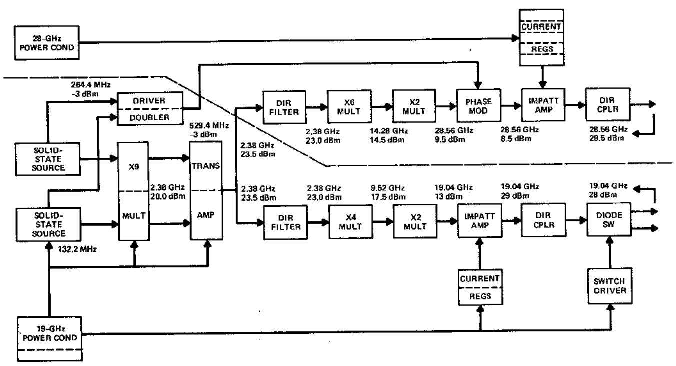

Figure 2. COMSTAR Centimeter Wave Beacon Block Diagram

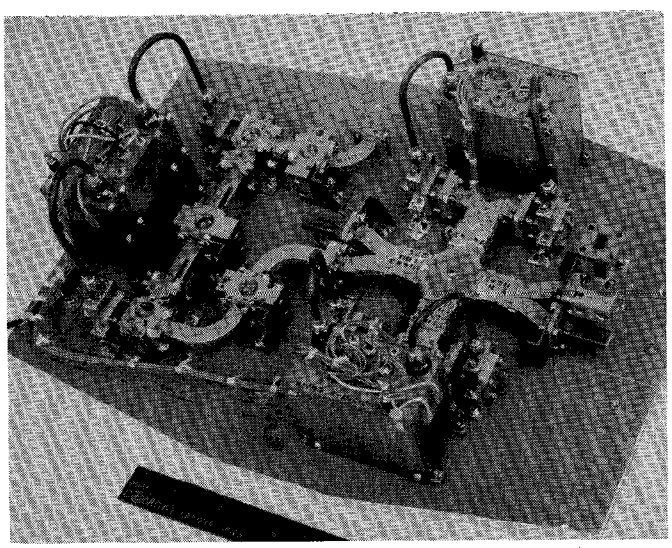

Figure 3. 28-GHz IMPATT Amplifier

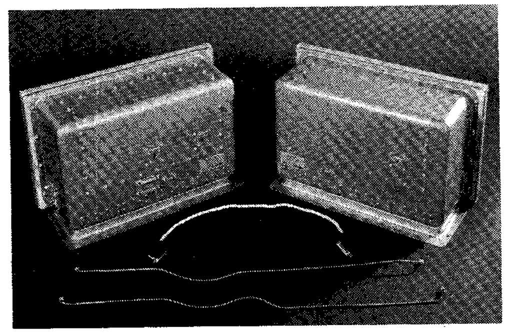

Figure 4. Beacon Components

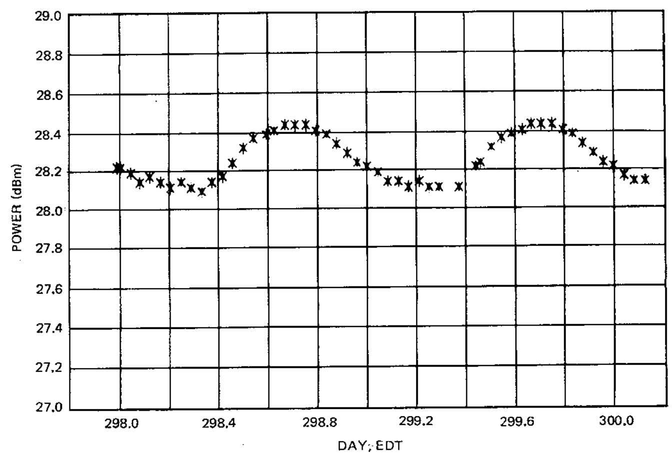

Figure 5. 19.04-GHz Power-Telemetered F3 Beacon

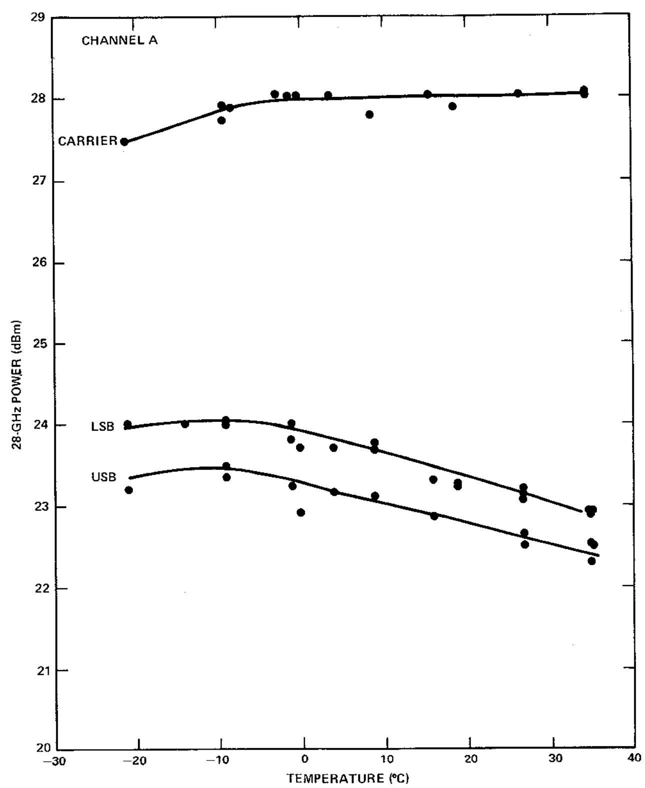

Figure 6. 28.56-GHz Power (carrier and sidebands, FS Beacon)