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Q-Band (37 to 41 GHz) Satellite Beacon Architecture for RF Propagation Experiments

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Abstract

In this paper, the design of a beacon transmitter that will be flown as a hosted payload on a geostationary satellite to enable propagation experiments at Q-band (37 to 41 GHz) frequencies is presented. The beacon uses a phased locked loop stabilized dielectric resonator oscillator and a solid-state power amplifier to achieve the desired output power. The satellite beacon antenna is configured as an offset-fed cut-paraboloidal reflector.

1.0 Introduction

A user community of ever-increasing size is consuming the available 25.5 to 27.0 GHz bandwidth allocations for Earth Exploration Satellite Service (EESS) downlink data transmission. In addition, high usage of the adjacent 27.5 to 30.0 GHz Broadband Satellite System (BSS) uplink allocation has resulted in unintentional interference in the EESS band. It is inevitable that additional frequency will be needed in the near future. The next available and unused EESS allocation is the 37 to 41 GHz frequency band (Q-band). Before deploying a fully operational Q-band system in space, it is imperative to undertake a rigorous study on the attenuation, fading, scintillation, and polarization effects of rainfall on the Q-band signals in space-to-Earth links.

The advantages of satellite communications at Q-band over the conventional Ka-band for data transmission includes reduced component sizes. In addition, the allocated bandwidth at Q-band is in excess of 4 GHz, which can enhance data transmission capacity by 10X or higher over current Ka-band systems. Furthermore, for a given antenna aperture dimension, the beamwidth is narrower and hence the spot size on Earth of a Q-band multibeam system is smaller, which enables greater spectral efficiency through frequency reuse.

In the past, NASA Glenn Research Center pioneered the development of Ka-band communications by deploying the Advanced Communications Technology Satellite (ACTS) (Refs. 1 and 2). The ACTS served as a test bed in space for several of the new technologies needed for an operational Ka-band system. In addition, the ACTS propagation experiments were instituted to investigate the effect of Earth's atmosphere on the propagation of Ka-band satellite signals (Ref. 1).

In this paper, we outline the design of a beacon transmitter that will be flown as a hosted payload on a geostationary satellite to enable propagation studies at Q-band frequencies.

2.0 Satellite Beacon Architecture

2.1 Q-band Beacon Transmitter

The Q-band satellite beacon transmitter block diagram is presented in Figure 1. The generation of the unmodulated RF carrier at 39.0 GHz takes place in the phase locked loop (PLL) stabilized dielectric resonator oscillator (DRO), which derives its input reference from a highly stable temperature compensated crystal oscillator (TCXO). A chain of monolithic microwave integrated circuit (MMIC) based amplifiers consisting of a pre amp, driver amp and a balanced power amp (PA) boost the output of the DRO to the desired power level. The output of the PA is coupled via a coax-to-waveguide transition and a circulator to the antenna. Typical beacon specifications are listed in Table I.

2.2 Satellite Beacon Antenna

The satellite beacon antenna provides coverage to the 48 contiguous states of the United States, which is also known as the CONUS, and will be located on the Earth deck of the spacecraft as illustrated in Figure 2. When viewed from a geostationary Earth orbit (GEO), at a longitude of around 100° W, the CONUS subtends an angle of about 6° in the latitude plane (West-East) and 3° in the longitudinal plane (North-South) (Ref. 3) as illustrated in Figure 3. An aperture antenna for producing a single beam with 3-dB beamwidths of 6° by 3° has dimensions approximately 13λ by 26λ, where λ is the free space wavelength at the operating frequency (Ref. 3). This translates to approximately 100 by 200 mm at 39 GHz. The on-axis gain of this antenna is about 32 dB assuming an aperture efficiency of about 40 percent. The gain of the satellite beacon antenna in the direction of a beacon receiver located at the edge of the coverage zone will be 3 dB lower, or 29 dB. To maximize heritage and minimize risk, the satellite beacon antenna is configured as an offset-fed cut-paraboloidal reflector analogous to the ACTS system (Ref. 1). The reflector edge is contoured to produce a quasi-elliptical shape, which helps to suppress minor lobes (Ref. 4). The quasi-elliptical reflector and the offset conical horn feed assembly are schematically illustrated in Figure 4. The offset cut parabolic reflector and feed configuration are modeled using GRASP 9 software package from TICRA (Ref. 5). The antenna system geometry from two view angles is illustrated in Figures 5(a) and (b). The computed radiation pattern in the

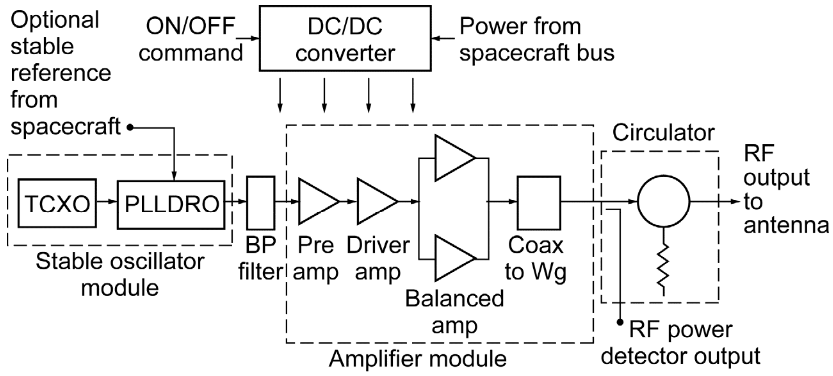

Figure 1.—Q-band satellite beacon transmitter block diagram.

TABLE I.—BEACON SPECIFICATIONS

Parameter	Specifications
CW carrier frequency	39 GHz
Output RF power	1.5 to 2.0 W (end of life)
Output RF power variation with temperature	0.2 dB
Output waveguide	WR-22
TCXO & PLLDRO phase stability	<5 ppm (alternatively reference acquired from spacecraft)
RF power detector output	Yes
Harmonics and spurs	<–40 dBc
Phase noise	–130 dBc/Hz at 10 KHz
OUTPUT VSWR	<1.5:1 with reference to 50 Ω
ON/OFF command and pulse duration	Yes, 20 msec
Bus voltage	28±7 V unregulated or 50 V regulated
Orbit	GEO
Mission life	3 to 4 years
Isolator or circulator at output	Yes

y-z plane, $\Phi = 90°$ at 39 GHz is presented in Figure 6. The 3-dB beam width is 3.9°. The cross-pol level is below 20.0 dB. The computed radiation pattern in the x-z plane, $\Phi = 0°$ at 39 GHz is presented in Figure 7. The 3-dB beam width is 5°. The side lobes are asymmetric because of the offset geometry and are below 23 dB. The notional far-field contoured radiation pattern of this antenna is illustrated in Figure 8. The gain of the satellite beacon antenna in the direction of a beacon receiver at the edge of the coverage zone will be 3 dB lower, or 29 dB.

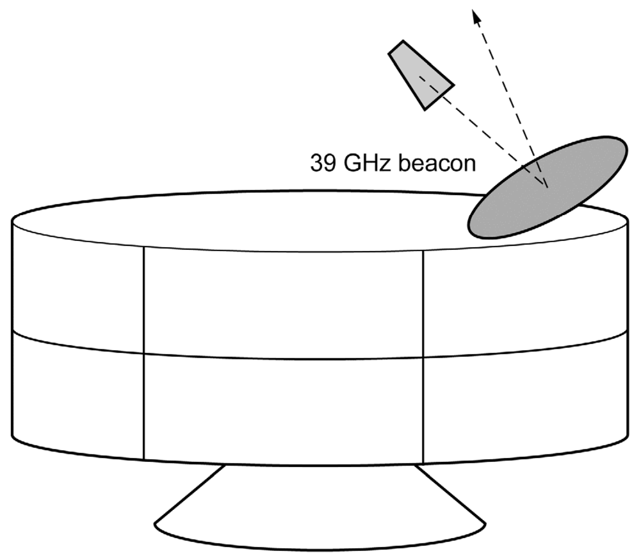

Figure 2.—Schematic illustrating the location of satellite beacon antenna on spacecraft Earth deck.

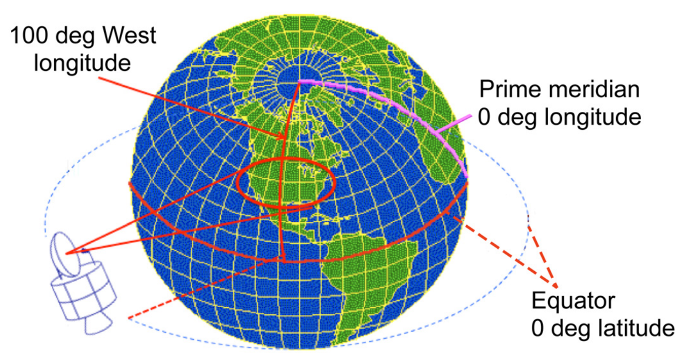

Figure 3.—Schematic illustrating the antenna pattern coverage on Earth.

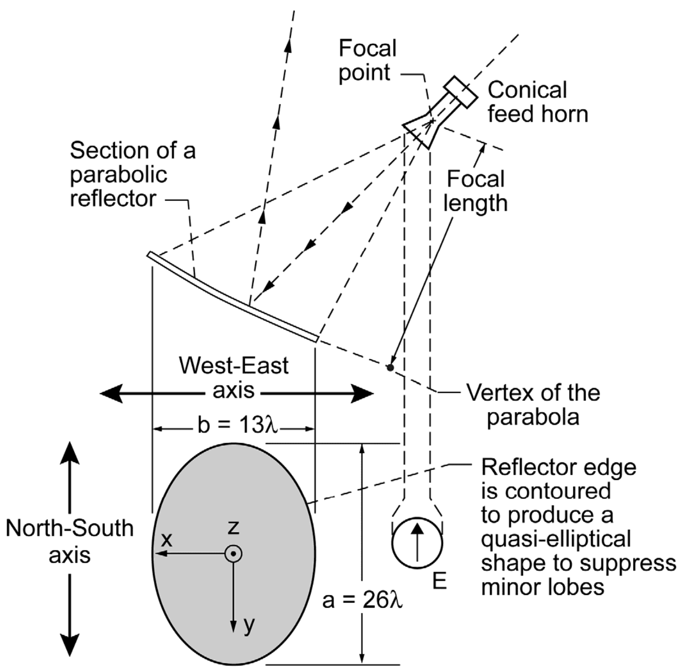

Figure 4.—Schematic illustrating the geometry and layout of the beacon antenna. At 39 GHz, a = 200 mm and b = 100 mm.

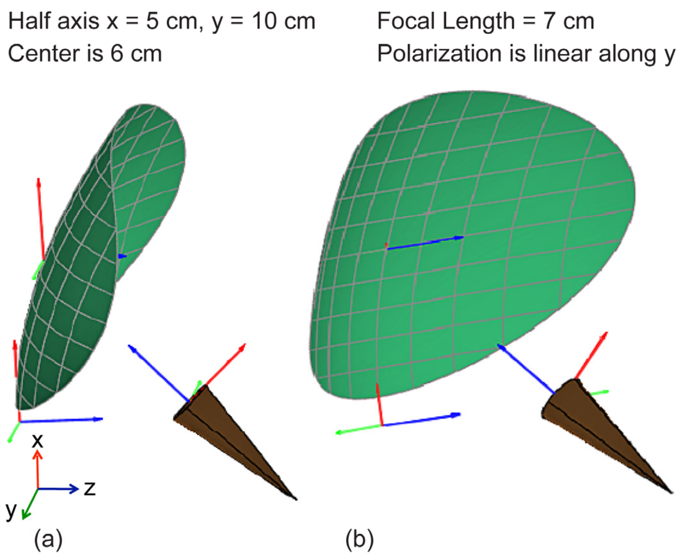

Figure 5.—Offset fed cut parabolic reflector and feed configuration. (a) Side view. (b) Front view.

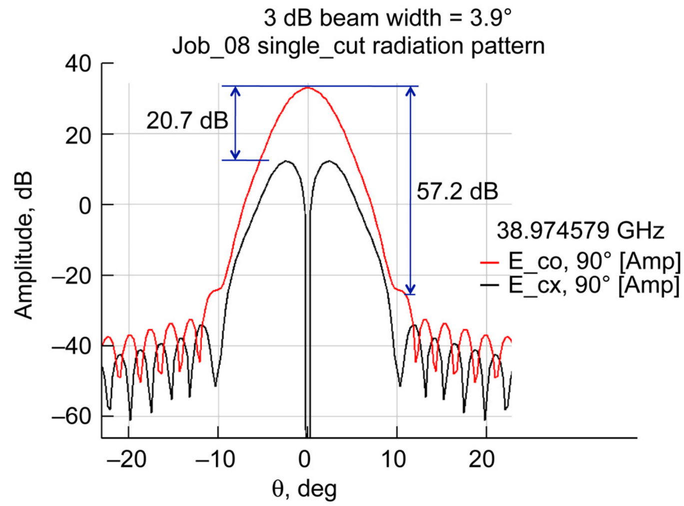

Figure 6.—Computed radiation patterns, y-z plane, ϕ = 90°.

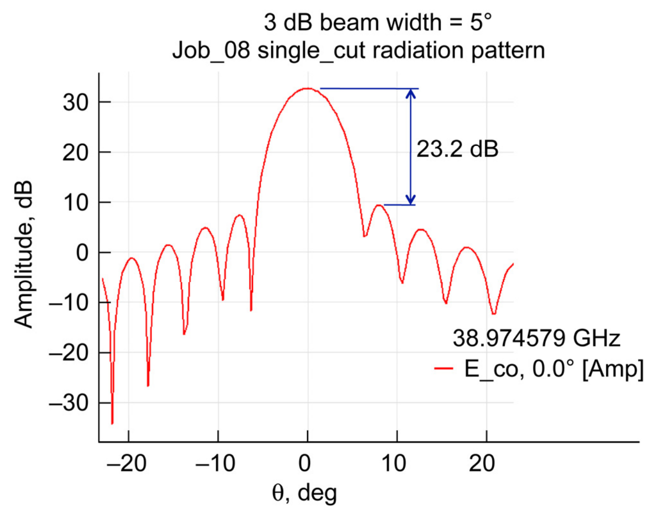

Figure 7.—Computed radiation patterns, x-z plane, ϕ = 0°.

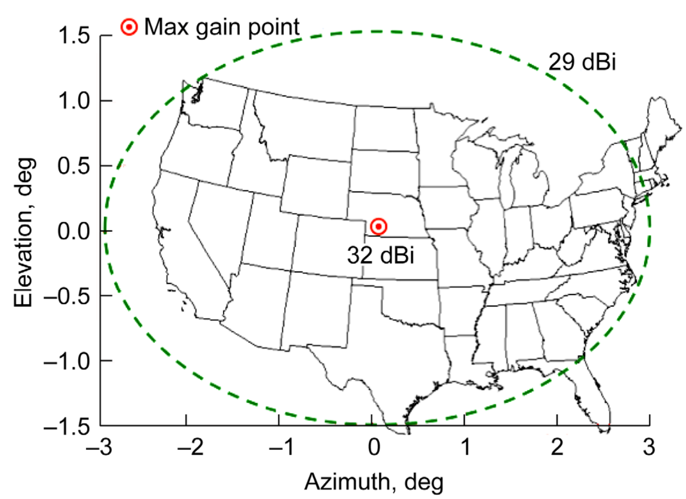

Figure 8.—Satellite beacon antenna notional far-field contoured radiation pattern with gain >29 dBi over the coverage area.

2.3 Earth Station Antenna and Receiver

The ground-receiving terminal will have a 1.2 m diameter reflector antenna with an offset feed. Table II provides the satellite beacon downlink budget in clear air, including the receiver noise characteristics, at the edge of the CONUS coverage.

TABLE II.—Q-BAND GEO SATELLITE BEACON DOWN LINK BUDGET IN CLEAR AIR

Q-band Satellite Beacon Transmitter Parameters	
Beacon saturated output power (end of life)	2 W
Satellite beacon antenna gain, on-axis	32 dB
Signal Frequency and Polarization	
Unmodulated carrier signal frequency, linear	39.0 GHz
Q-band Earth Station Receiver Parameters	
Downlink signal frequency	39.0 GHz
Antenna gain, on-axis, 39 GHz	51.6 dB
Receiver IF bandwidth	10 KHz
Receiving system noise temperature	396.9 K
Downlink Power Budget	
Satellite beacon output power, 2 W (end of life)	3.0 dBW
Satellite beacon antenna gain, on-axis	32.0 dB
Earth station antenna gain	51.6 dB
Free space path loss at 39 GHz	–215.3 dB
Edge of beam loss for beacon antenna	–3.0 dB
Clear air atmospheric loss	–0.8 dB
Polarization loss	–0.2 dB
Earth station antenna pointing loss	–0.5 dB
Received power at Earth station	–133.2 dBW
Downlink Noise Power Budget in Clear Air	
Boltzmann's constant	–228.6 dBW/K/Hz
System noise temperature, 396.9 K	26.0 dBK
Noise bandwidth, 10 KHz	40.0 dBHz
Receiver noise power	–162.6 dBW
Receiver noise power in one Hertz bandwidth	–202.6 dBW per Hz
C/N Ratio in Receiver in Clear Air	
C/N = –132.2 dBW – (–162.6 dBW) = 29.4 dB	
C/N in one Hertz bandwidth = 69.4 dB per Hz	

3.0 Conclusions

The design of a beacon transmitter that will be flown as a hosted payload on a geostationary satellite to enable propagation experiments at Q-band frequencies (39 GHz) is described. In addition, the satellite beacon downlink budget in clear air at the edge of the CONUS coverage is presented.

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