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Multi-Tone Millimeter-Wave Frequency Synthesizer for Atmospheric Propagation Studies

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April 2014

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Abstract

This paper presents the design and test results of a multi-tone millimeter-wave frequency synthesizer, based on a solid-state frequency comb generator. The intended application of the synthesizer is in a space-borne transmitter for radio wave atmospheric studies at Q-band (37 to 43 GHz). These studies would enable the design of robust high data rate space-to-ground satellite communication links.

1.0 Introduction

The frequency spectrum allocated and utilized currently for satellite communications uplinks and downlinks are rapidly getting congested due to very heavy usage. The logical choice is to move higher up in frequency into the millimeter-wave (mm-wave) frequency bands, which are sparsely used. The mm-wave bands include frequencies in the Q-band (37 to 42 GHz) and the V/W-band (71 to 76 GHz). Migrating to the mm-wave frequency bands has the added advantages of smaller antenna size and lower mass for a given spacecraft effective isotropic radiated power (EIRP). In addition, in the case of commercial communications satellites, which use multiple beams to increase throughput, the beamwidth for a given antenna aperture size is smaller at the above mm-wave frequencies. The smaller beamwidth results in a smaller spot size on ground, which allows packing greater number of spot beams over a given area and thus enables greater spectral efficiency through frequency reuse. Prior to system planning and system design for deployment in space, it is essential to investigate the effects of Earth's atmosphere on radio wave propagation at the above frequencies. In general, radio waves suffer increasing attenuation, scintillation, depolarization, and group delay due to atmospheric gases, clouds and rain (Ref. 1).

In this paper, we present the design, construction and test results for a multi-tone frequency synthesizer (Ref. 2) based on the discrete frequency spectrum produced by a high frequency solid-state comb generator. Unlike the single frequency beacon source, which flew on NASA's Advanced Communications Technology Satellite (ACTS) (Ref. 3) for Ka-band propagation experiments (Ref. 4), the multi-tone frequency synthesizer is capable of simultaneously delivering coherent multiple frequencies. These multiple frequencies enable characterizing the frequency dependent group delay effects, which are essential for the design of high data rate wide band satellite communications links.

2.0 Multi-Tone Frequency Synthesizer Architecture

2.1 Multi-Tone Frequency Synthesizer Circuit Design, Construction and Mode of Operation

A simplified block schematic of the basic multi-tone frequency synthesizer based beacon transmitter that could fly on a geostationary satellite as a hosted payload for radio wave propagation experiments at mm-wave frequencies is presented in Figure 1. The synthesizer consists of a comb generator, which puts out evenly spaced harmonic frequencies of the input signal, which are coherent and tunable over a wide frequency range. These harmonics are then amplified to the power level needed for radio wave propagation studies.

Harmonics that are amplified are simultaneously transmitted as beacon signals from space to receiving ground stations located at several climate zones within the CONUS. By measuring the signal relative strength and phase at ground sites one can estimate the attenuation and group delay or dispersion due to atmospheric induced effects.

2.2 Rational for a Multi-Band Multi-Tone Frequency Synthesizer Circuit, Design, and Construction

Significant amount of statistical data has been accumulated since the pioneering ACTS experiments of the 1990's and accurate models that predict the impairments to radio waves in the 20/30 GHz bands due to Earth's atmosphere are available. In addition, communications satellite systems are currently operational at these frequencies. It is also well understood that signals at Q-band and V/W-band frequencies would experience much higher attenuation during rain fades than signals in the 20/30 GHz range. The deep fades will result in poor signal-to-noise ratio at the Q-band and V/W-band beacon receivers on ground, which could cause the receivers to lose frequency/phase lock. To overcome this problem it is desirable to include a coherent K-band (18 to 26.5 GHz) beacon source along with the Q-band and V/W-band beacon sources on the payload. Because of higher signal-to-noise ratio at K-band, the beacon receiver on ground can retain lock during deep fades and thus enable high availability attenuation measurements or characterization. This data is valuable and can provide a reference for model development and also provide an understanding of frequency model scaling factors for future system design when Q-band and V/W-band propagation data is unavailable (Ref. 1).

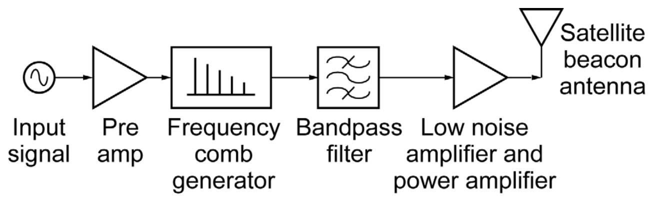

Figure 1.—Schematic block diagram of the basic multi-tone frequency synthesizer based beacon transmitter payload for radio wave propagation experiments.

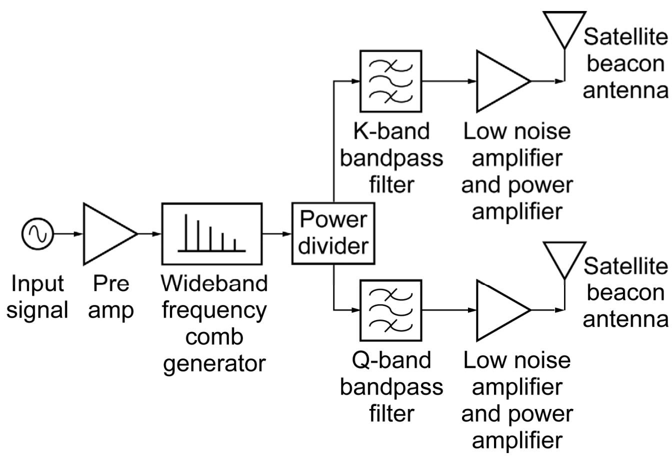

Figure 2.—Schematic block diagram of the multi-band multi-tone frequency synthesizer based beacon transmitter payload for radio wave propagation experiments.

A block schematic of the multi-band multi-tone frequency synthesizer breadboard circuit is presented in Figure 2. The synthesizer consists of a high frequency wideband solid-state comb generator. The K-band and Q-band harmonics are separated by bandpass filters and amplified to the power level required for radio wave propagation studies before transmission.

2.3 Multi-Tone Frequency Synthesizer Characterization and Test Data

A generic test setup for characterizing the K-band and the Q-band multi-tone frequency synthesizer circuits described above is presented in Figure 3. Photographs of the K-band and the Q-band test circuit are shown in Figures 4 and 5, respectively. The bandpass filters and the low noise amplifiers (LNAs) are appropriately selected for the two frequency bands. The measured K-band and Q-band spectrums are presented in Figures 6 and 7, respectively. A chain of MMIC based power amplifiers can further enhance the power levels such that the beacon EIRP is on the order of 30 dBW at the edge of CONUS coverage (Ref. 5). A minimum data collection period of 36 months is recommended and hence the above EIRP is the end of life value (Ref. 1).

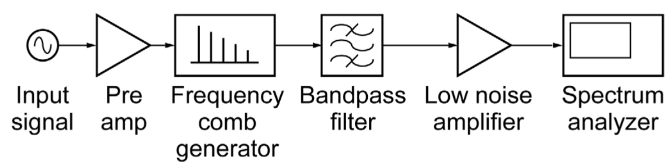

Figure 3.—Test setup for characterizing the multi-tone frequency synthesizer.

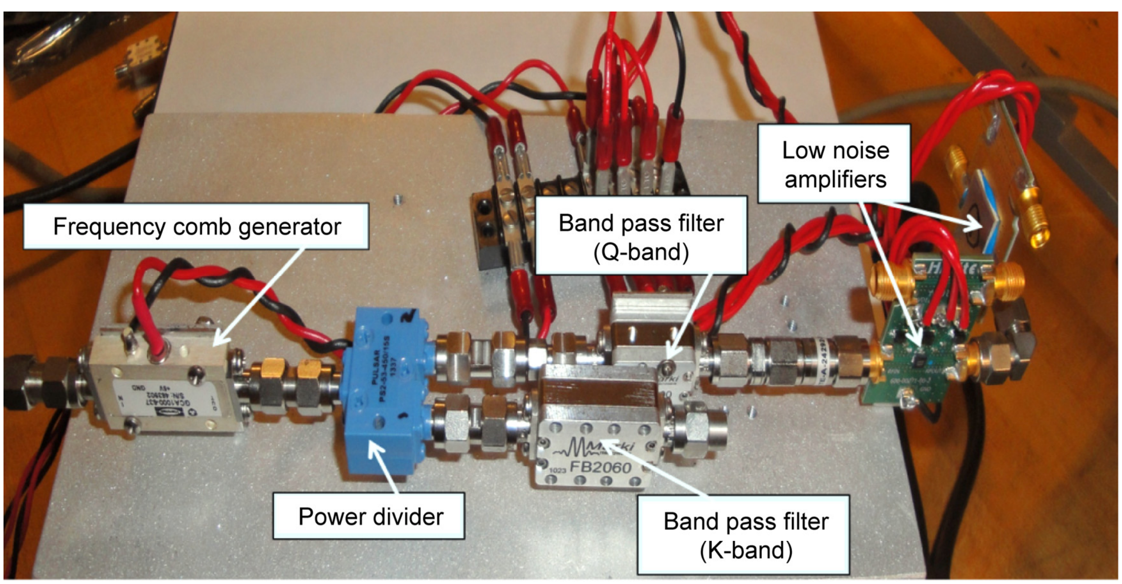

Figure 4.—Test circuit used for measurements at K-band.

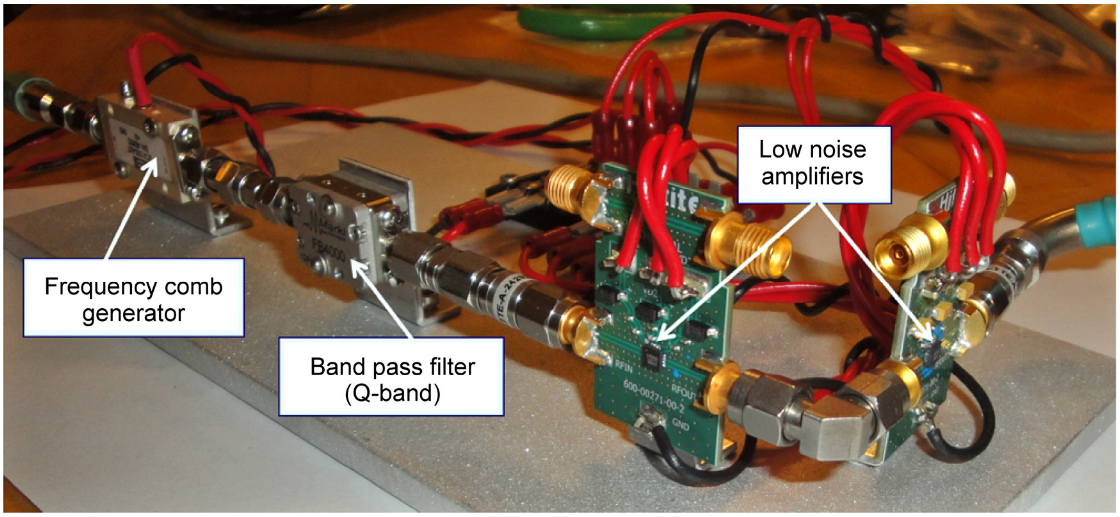

Figure 5.—Test circuit used for measurements at Q-band.

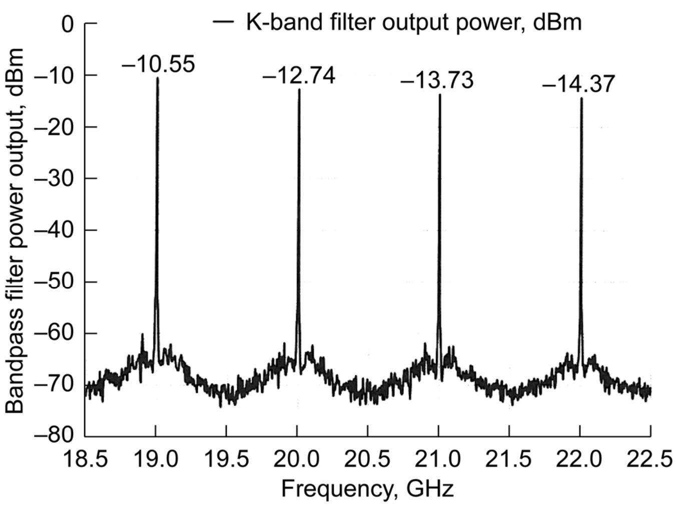

Figure 6.—K-band spectrum as measured at the output of the bandpass filter.

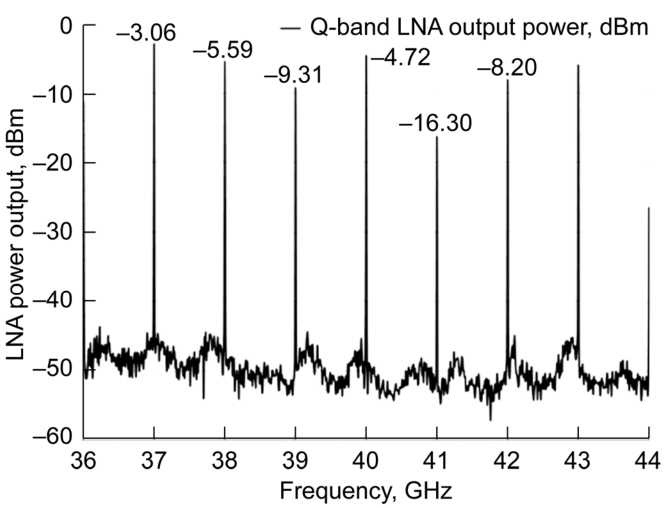

Figure 7.—Q-band spectrum as measured at the output of the low noise amplifier.

3.0 Conclusions

The design, construction and test data for a K-band and a Q-band multi-tone frequency synthesizer for radio wave propagation studies are presented.

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14. ABSTRACT
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