Traveling-Wave Tube Amplifier Second Harmonic as Millimeter-Wave Beacon Source for Atmospheric Propagation Studies

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***Abstract*—This paper presents the design and test results of a CW millimeter-wave satellite beacon source, based on the second harmonic from a traveling-wave tube amplifier and utilizes a novel waveguide multimode directional coupler. A potential application of the beacon source is for investigating the atmospheric effects on Q-band (37-42 GHz) and V/W-band (71-76 GHz) satellite-to-ground signals.**

I. Introduction

Because of increasing congestion in available spectrum at the currently used frequency band (3-30 GHz) for space-to-ground data communications, there is now an effort by NASA, other United States Government agencies and the commercial broadband satellite communications industry to develop the millimeter-wave (mm-wave) frequency band for this purpose. The mm-wave band includes frequencies in the Q-band (37-42 GHz) and the V/W-band (71-76 GHz). Prior to the use of these frequency bands for space communications, it is necessary to first rigorously characterize the many atmospheric effects, including rainfall, cloud coverage and gaseous absorption, on RF signal propagation from a space-based beacon source. For high data rate wide band communications, it will also be necessary to characterize the group delay effects. The design of any operational satellite communication system is intimately tied with the results of the propagation studies.

In the past, NASA Glenn Research Center (GRC) pioneered the development of Ka-band (20-30 GHz) communications by deploying the Advanced Communications Technology Satellite (ACTS) [1], [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 [1].

In this paper, we present the design and test results of a CW satellite beacon source, based on the second harmonic from a space traveling-wave tube amplifier (TWTA). The key-enabling component is a rugged, easily constructed, more efficient waveguide based multimode directional coupler [3] that extracts the second harmonic signal from the RF output of a high power space TWTA [4]. The application of the beacon source is for atmospheric propagation studies at Q-band and V/W-band frequencies leading towards the design of robust space-to-ground satellite communications links. A Q-band space TWTA is presently under development at L-3 Communications Electron Technologies Inc., under a contract from NASA GRC.

II. Beacon Architecture

A simplified schematic of the beacon source is presented in Fig. 1.

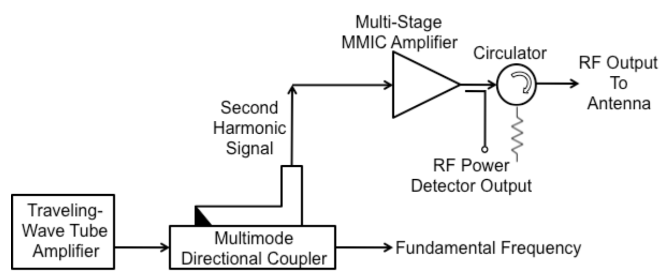

Fig. 1 Simplified schematic of a satellite borne beacon source for RF propagation studies.

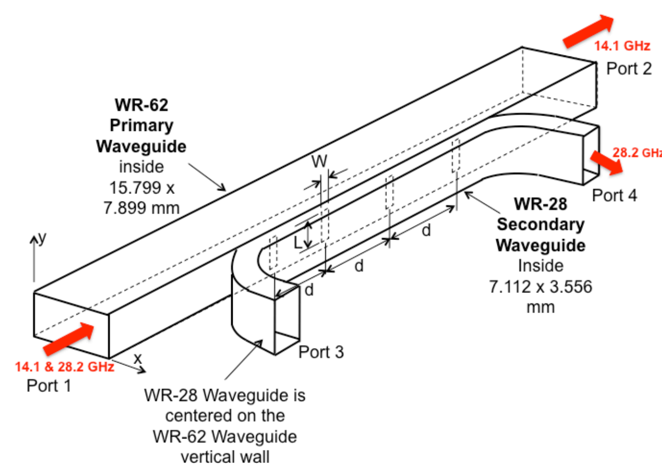

Fig. 2. Schematic of waveguide multimode directional coupler.

A. Waveguide Multimode Directional Coupler Design

The waveguide multimode directional coupler used in the test demonstration is designed and fabricated from two sections of dissimilar waveguides, a primary or larger cross section waveguide for the fundamental frequency and a secondary or smaller cross section waveguide for the second harmonic as illustrated in Fig. 2. The two waveguides are joined together and share a common wall. In the primary waveguide, the signal at the fundamental frequency propagates as the dominant TE_{10} mode. However, the power in the second harmonic signal propagates as higher order modes. If an aperture is cut in the shape of a narrow rectangular slot parallel to the y-axis along the primary waveguide narrow wall the coupling to the TE_{10} mode will be negligibly small. However, the slot aperture will couple strongly to the TM_{11} type higher order mode. Thus the power in the second harmonic signal is selectively coupled to the secondary waveguide and can be amplified to the power level needed for atmospheric propagation studies.

B. Multimode Directional Coupler Fabrication

Fig. 3. Fabricated proof-of-concept Ku-band/Ka-band waveguide multimode directional coupler.

For the initial proof-of-concept (POC) demonstration, the primary and the secondary waveguides were chosen as the WR-62 and WR-28, respectively. Thus, the fundamental frequency is at Ku-band (13.25-18 GHz) and the second harmonic is at Ka-band (26.5-36 GHz). Fig. 3 shows the fabricated POC multimode directional coupler used in the demonstrations.

C. Multimode Directional Coupler Test Data

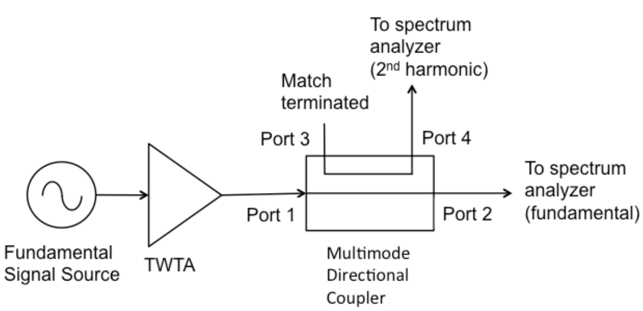

Fig. 4. Test setup for measurement of power at the second harmonic frequencies at port 4 of the multimode directional coupler.

Fig. 4 shows the test setup used for the measurement of power at the second harmonic frequencies at the Ka-band secondary waveguide output port of the multimode directional coupler, when the TWTA is operating at saturation and maximum efficiency. The measured power at the second harmonic frequencies over a broad range extending from 27.0 to 30.0 GHz is shown in Fig. 5. The test data indicates that there is a significant amount of power in the second harmonic. Typically, beacons used in radio wave propagation studies are narrow band sources [1]. Hence, a desired beacon signal frequency can be selected from the above range of frequencies and amplified to the desired EIRP level [5]. It is worth mentioning that the fundamental signal is below the cutoff frequency of the Ka-band secondary waveguide and hence propagates unperturbed in the Ku-band primary waveguide, which is a major advantage over traditional harmonic filters.

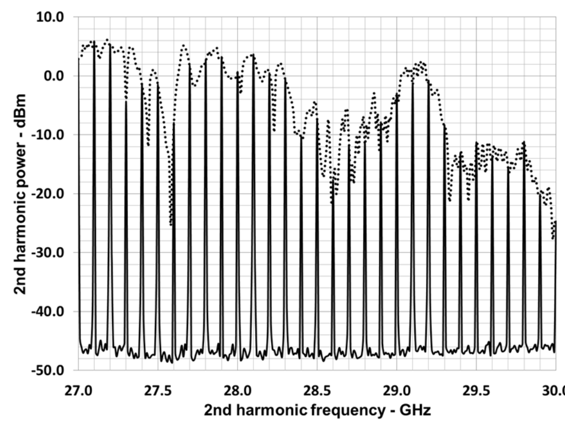

Fig. 5. Measured power at the second harmonic frequencies at port 4 of the multimode directional coupler

III. CONCLUSIONS

The design, fabrication and characterization of a novel waveguide multimode directional coupler is presented. The application of the coupler is in a space borne beacon source for atmospheric propagation studies at millimeter-wave frequencies.

ACKNOWLEDGEMENT

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