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

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Introduction
Introduction - Motivation

★ Growing user community has resulted in increased congestion in the traditional Ku, K, and Ka frequency bands designated for space-to-ground data communications

★ The next available bands for satellite downlinks above Ka-band are the Q-band (37-41 GHz) and E-band (71-76 GHz)
Introduction - Advantages

★ Advantages of Q-band & E-band over Ka-band for data transmission

✧ To be competitive with terrestrial fiber optic and wireless services, broadband satellite providers need to reduce the cost per transmitted bit. This can be attained by increasing satellite total throughput. At Q-band and V-band the allocated bandwidth is in excess of 4 GHz, which can enhance satellite throughput by 10X or higher

✧ Narrower beam width and smaller spot size for a given antenna size

✧ Smaller spot size enables greater frequency reuse and spectral efficiency

✧ Other U.S. Government Agencies have interest in the large available bandwidth at E-band

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Introduction – Problem Outline

★ Lack of rigorous studies to understand the atmospheric effects on radio waves propagation at Q-band & E-band frequencies. These studies are essential for the design of a robust communications system for deployment in space.

★ To conduct such a study a beacon transmitter at Q-band and E-band frequencies have to be deployed on a satellite and statistical data on rain attenuation, fading, change in the refractive index, scintillation, de-polarization effects, etc., have to be acquired over 3 to 5 years with ground receivers dispersed over climate zones of interest.
Introduction – Potential Solutions

★ SSPA based Beacon transmitter and antenna system
  ✦ Design of a feasible Q-band beacon transmitter and antenna system was presented at the 2012 IEEE Inter Symp on Antennas & Propagation

★ ALPHASAT – Telecom satellite for technology demonstration
  ✦ Scientific experiment payload: Q-Band Beacon (39.402 GHz, EIRP: 26.6 dBW, Global Horn antenna) and a Ka-Band Beacon (19.701 GHz, EIRP: 19.5 dBW, Global Horn antenna) (3 spot beams) (Launched by ESA July 2013)

★ High power traveling-wave tube amplifiers (TWTAs) are routinely used in satellite transmitters. These tend to generate harmonics particularly when operating in the non-linear saturation region
  ✦ Isolated 2\textsuperscript{nd} harmonic is potentially useful as a beacon source for RF propagation studies at mm-wave frequencies
Introduction – Implementation & Beacon Source Hardware Design
(Simplified Schematic of a Satellite Borne Beacon Source for RF Propagation Studies)
Objective & Goal
Objective & Goal

★ **Objective**: Design a waveguide multimode directional coupler (MDC) to separate out the 2\textsuperscript{nd} harmonic signal from the fundamental signal at the output of a traveling-wave tube amplifier (TWTA)

★ **Goal**: Proof-of-Concept demonstration of a MDC at
- Ku/Ka-band (13.5-15.0 / 27.0-30.0 GHz)
- Ka/E-band (31-38 GHz / 71.0-76.0 GHz)

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Ku-Band/Ka-Band Waveguide Multimode Directional Coupler (MDC)
Two dissimilar waveguides joined together
- One for fundamental (primary) and one for 2nd harmonic (secondary)
- Share common wall

Primary signal propagates in TE$_{01}$ mode, 2nd harmonic propagates in higher order modes, e.g., TM$_{11}$

 Appropriately sized and positioned narrow rectangular slots cut in common wall parallel to y-axis of primary waveguide
- Coupling of TE$_{01}$ mode is negligibly small
- Strong coupling of higher order TM$_{11}$ mode
- 2nd harmonic signal thus selectively coupled to secondary waveguide
Schematic of the Ku/Ka-Band Test Setup for Power Measurement at the Output Ports of the MDC

- Fundamental signal source
- TWTA
- Multimode directional couple
- Port 1
- Port 2
- Port 3
- Port 4
- To spectrum analyzer (second harmonic)
- Match terminated

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Measured Ku-Band Fundamental Power at the Direct Port (Port 2) of MDC
Measured Ka-Band 2nd Harmonic Power at the Coupled Port (Port 4) of MDC
Measured Ku-Band Power at the Coupled Port (Port 4) of MDC

14.1 GHz, -73.6 dBm
Ka-Band/E-Band Waveguide Multimode Directional Coupler (MDC)
Schematic of the Ka/E-Band Test Setup for Power Measurement at the Output Ports of the MDC

- Fundamental frequency source
- SSPA Pre-amp
- Variable attenuator
- TWT
- Multimode directional coupler
- 2nd harmonic
- E-band Power meter
- Fundamental
- Ka-band Power meter
- Directional coupler
Measured TWT Input/Output Powers (Fundamental)
Measured 2\textsuperscript{nd} Harmonic Power at 62 to 70 GHz at MDC Port 4
Measured TWT Input/Output Powers (Fundamental)

- **TWT output power**
- **TWT input power**

![Graph showing the measured TWT input/output powers (fundamental)](image)

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Measured 2nd Harmonic Power at 70 to 76 GHz at MDC Port 4

- with LNA
- without LNA

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Discussions & Conclusions
Conclusions & Discussions

★ Proof of concept and basic design of a MDC successfully demonstrated
-
✧ MDC can be connected directly to RF output port of a TWTA with very minimal loss of fundamental power
✧ No coupling of fundamental signal
✧ 2nd harmonic can be isolated from fundamental
✧ 2nd harmonic can be amplified to potentially useful levels
Conclusions & Discussions (continued)

- Measurement of 2nd harmonic can be important at production facility to quantify and control amount of interference power

- Knowledge of potential interference power can be important for space borne radio science observations

- Knowledge of potential interference power can be considered for improvement in accuracy of navigation systems

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