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

Rainee N. Simons and Edwin G. Wintucky

National Aeronautics and Space Administration (NASA)
Glenn Research Center (GRC), MS 54-1, 21000 Brookpark Road,
Cleveland, Ohio 44135

E-mail: Rainee.N.Simons@nasa.gov, Tel: (216)433–3462
E-mail: Edwin.G.Wintucky@nasa.gov, Tel: (216)433–6261

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  - Ka/E-Band MDC Design/Fabrication/Testing
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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

# Introduction – Problem Outline

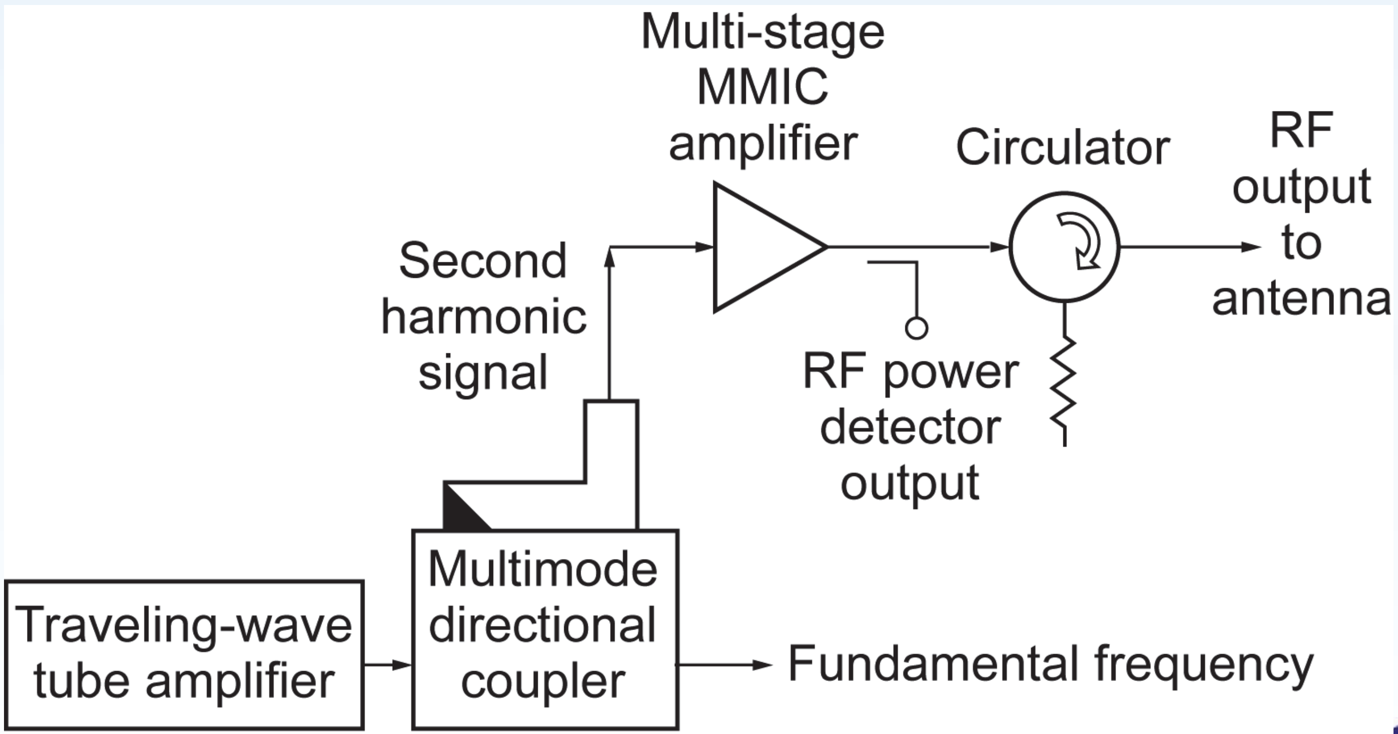
- Lack of rigorous studies to understand the atmospheric effects on radio waves propagation at Q-band & E-band frequencies. These studies are essential for the design of a robust communications system for deployment in space
- To conduct such a study a beacon transmitter at Q-band and E-band frequencies 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 2nd 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

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

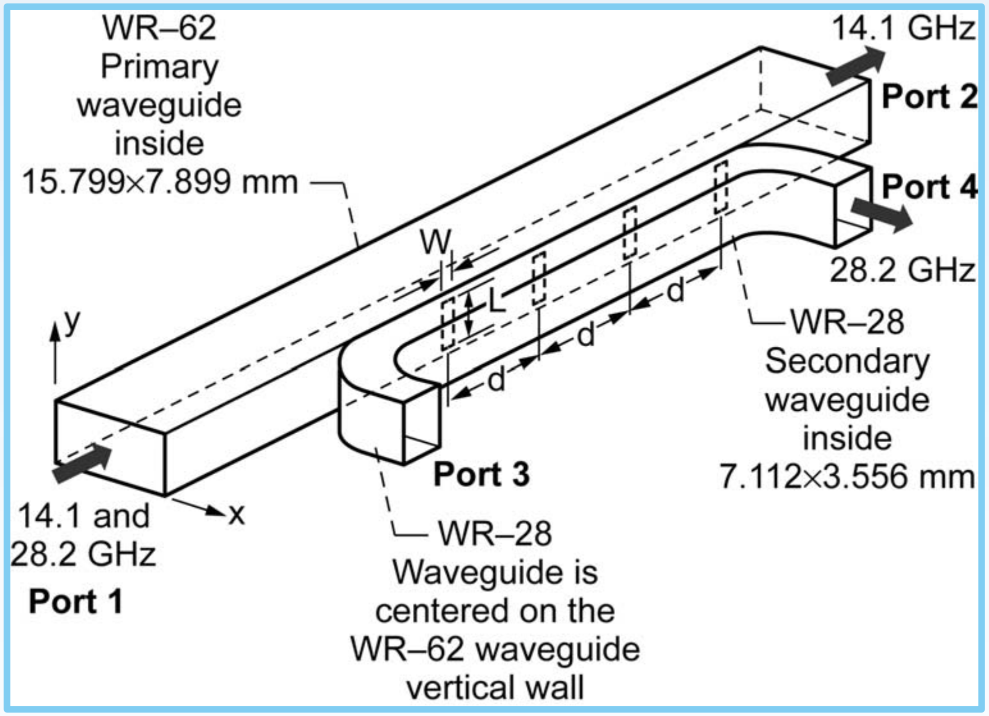
★ **Goal**: Proof-of-Concept demonstration of a MDC at

- ✧ Ku/Ka-band (13.5-15.0 / 27.0-30.0 GHz)
- ✧ Ka/E-band (31-38 GHz / 71.0-76.0 GHz)

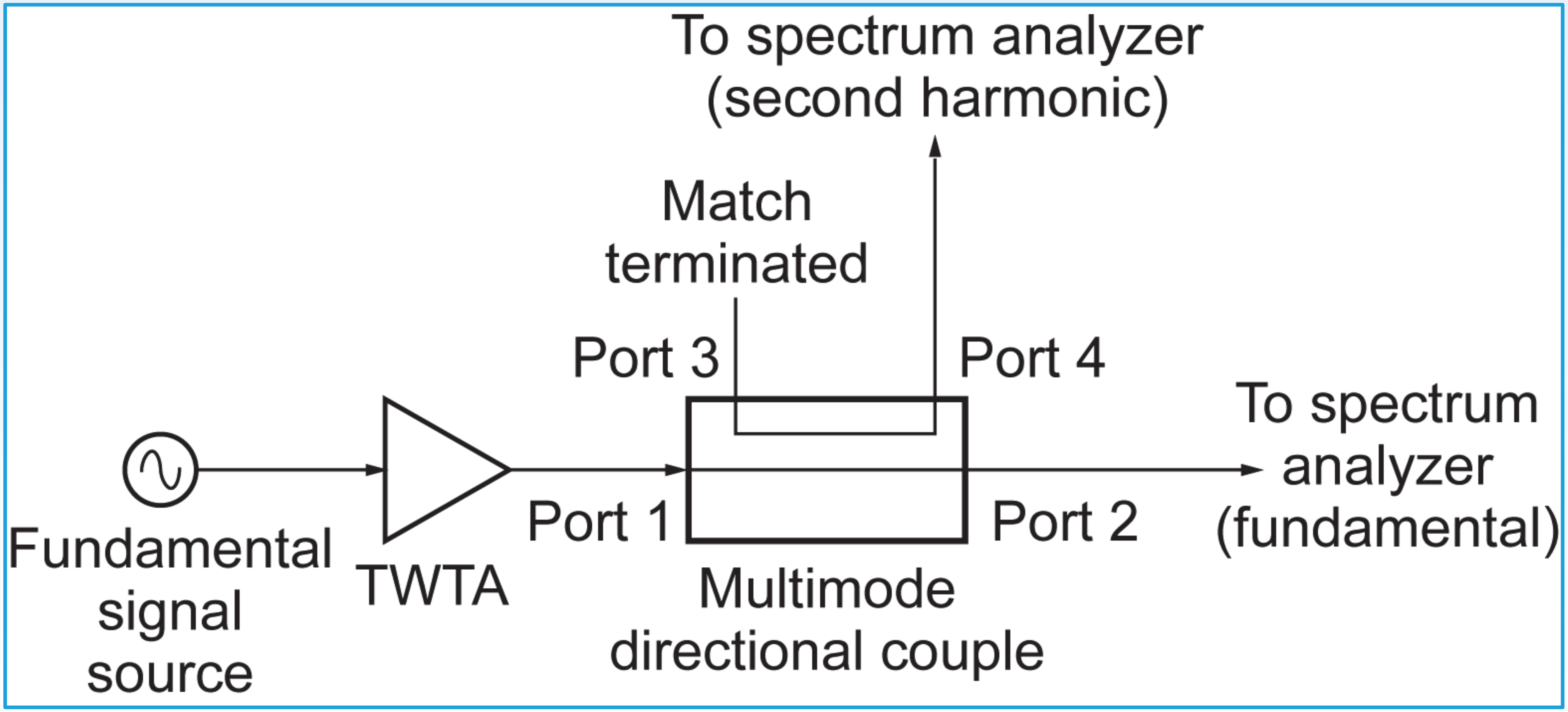
# Ku-Band/Ka-Band Waveguide Multimode Directional Coupler (MDC)

# MDC Concept & Design

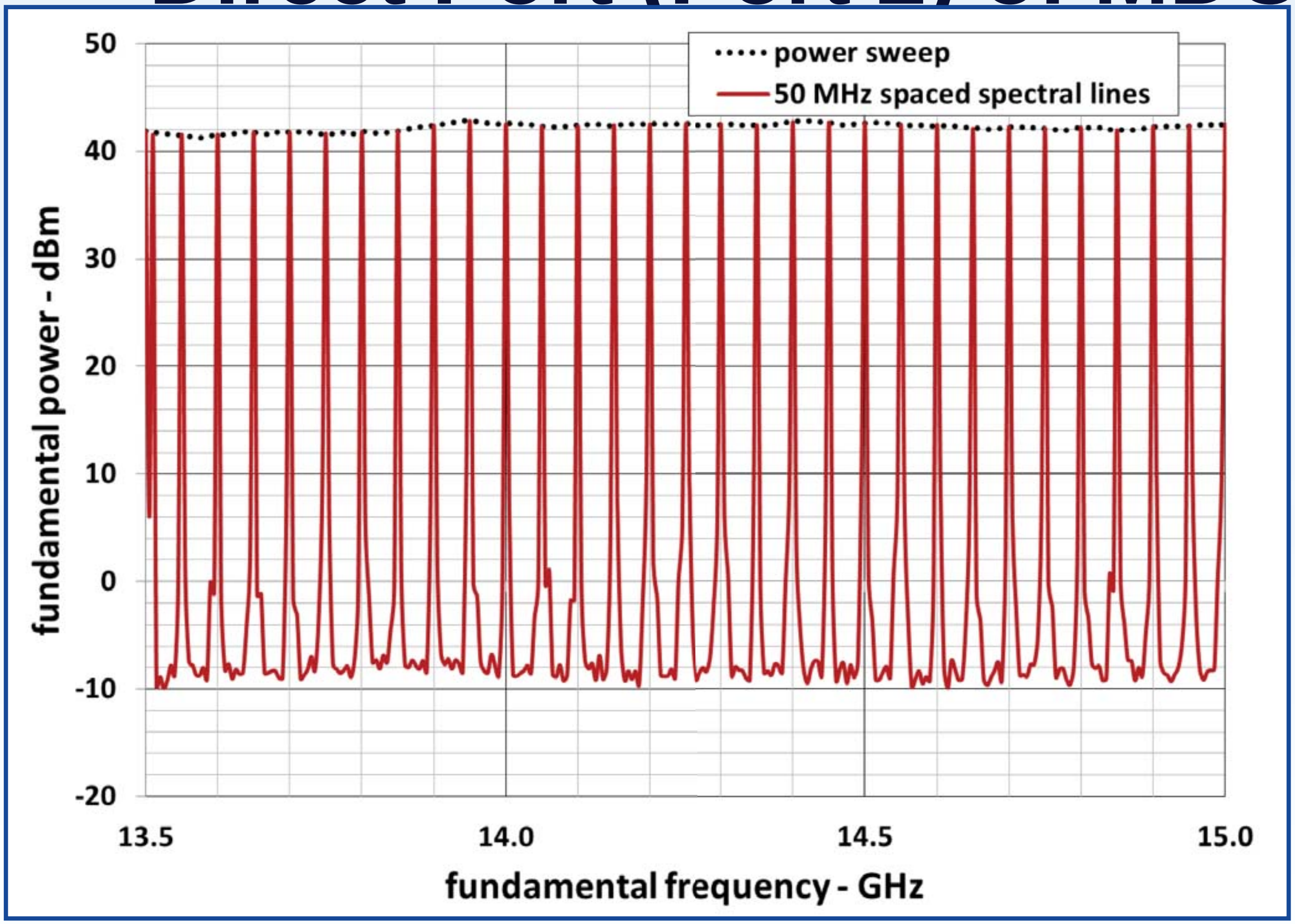
- Two dissimilar waveguides joined together
  - One for fundamental (primary) and one for 2nd harmonic (secondary)
  - Share common wall
- Primary signal propagates in $TE_{01}$ mode, 2nd harmonic propagates in higher order modes, e.g., $TM_{11}$
- Appropriately sized and positioned narrow rectangular 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

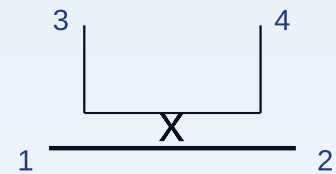


# Schematic of the Ku/Ka-Band Test Setup for Power Measurement at the Output Ports of the MDC

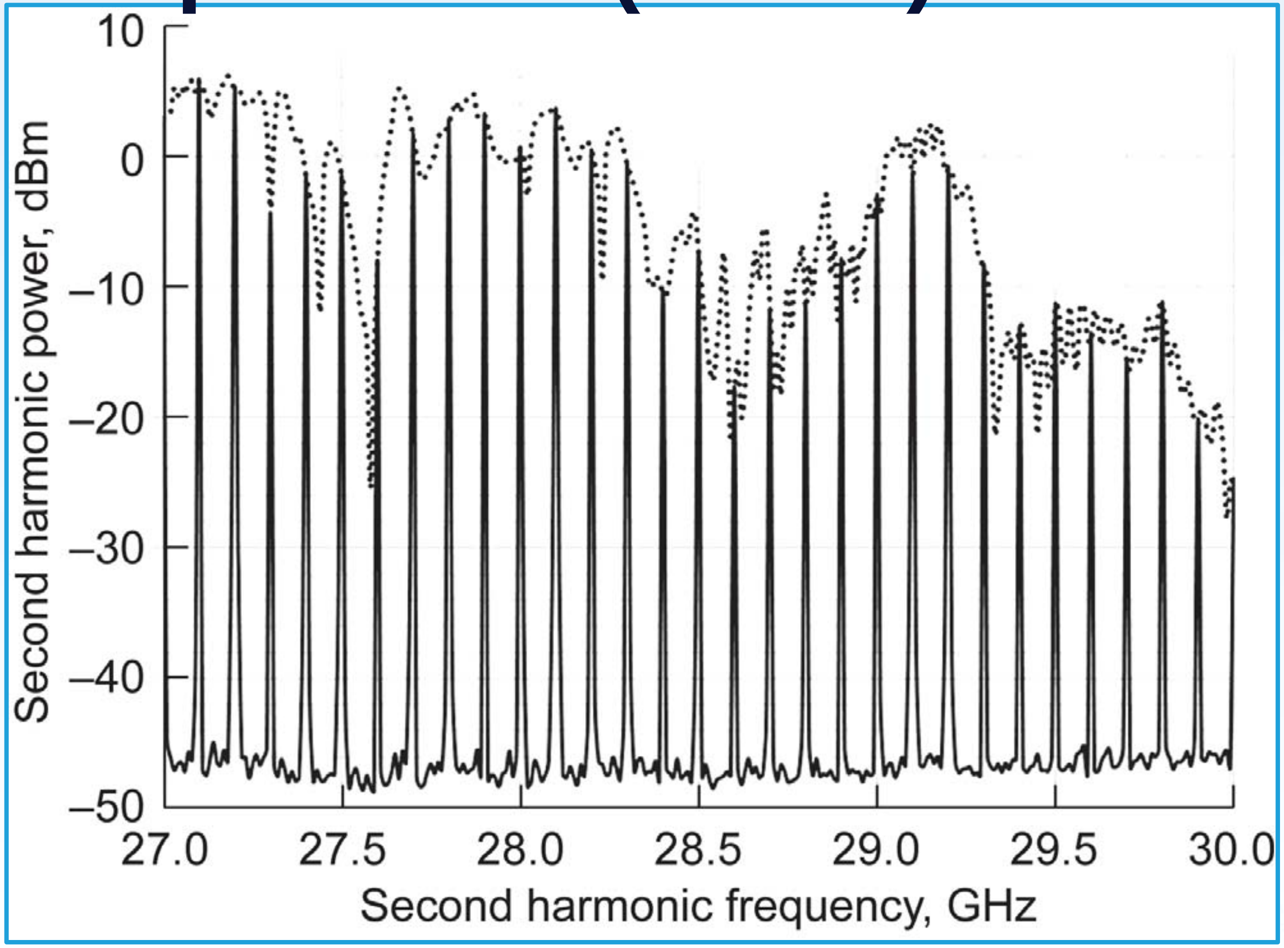


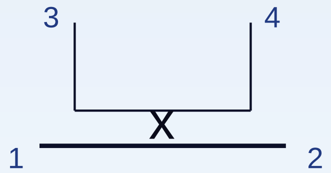
# Measured Ku-Band Fundamental Power at the Direct Port (Port 2) of MDC



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



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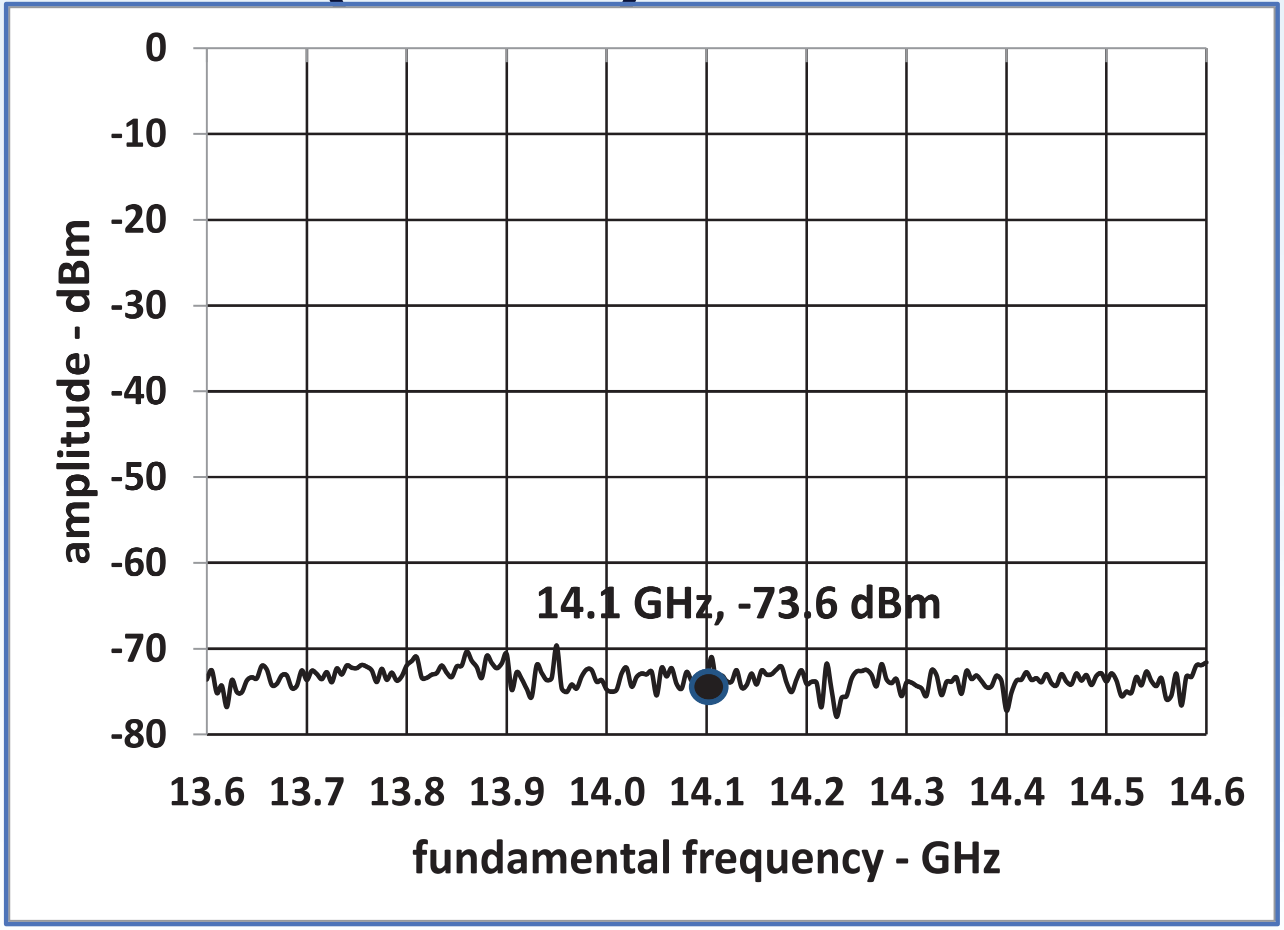
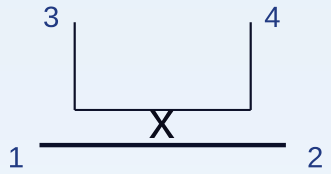
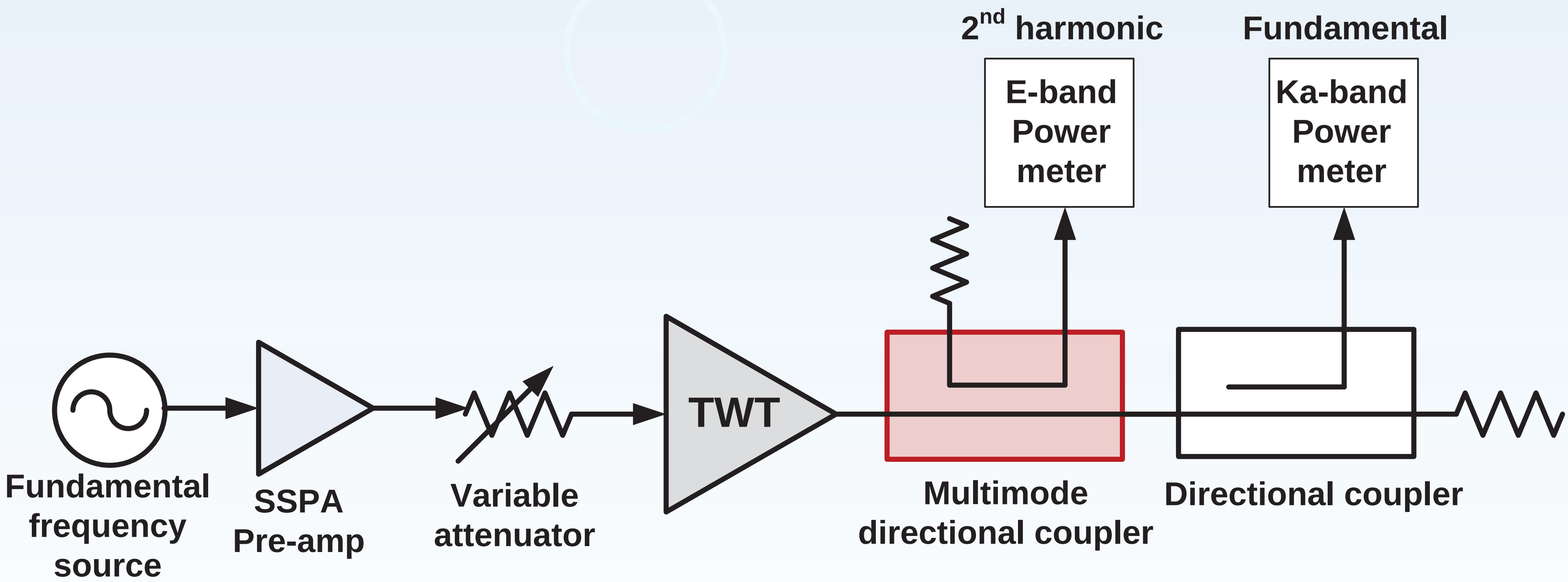


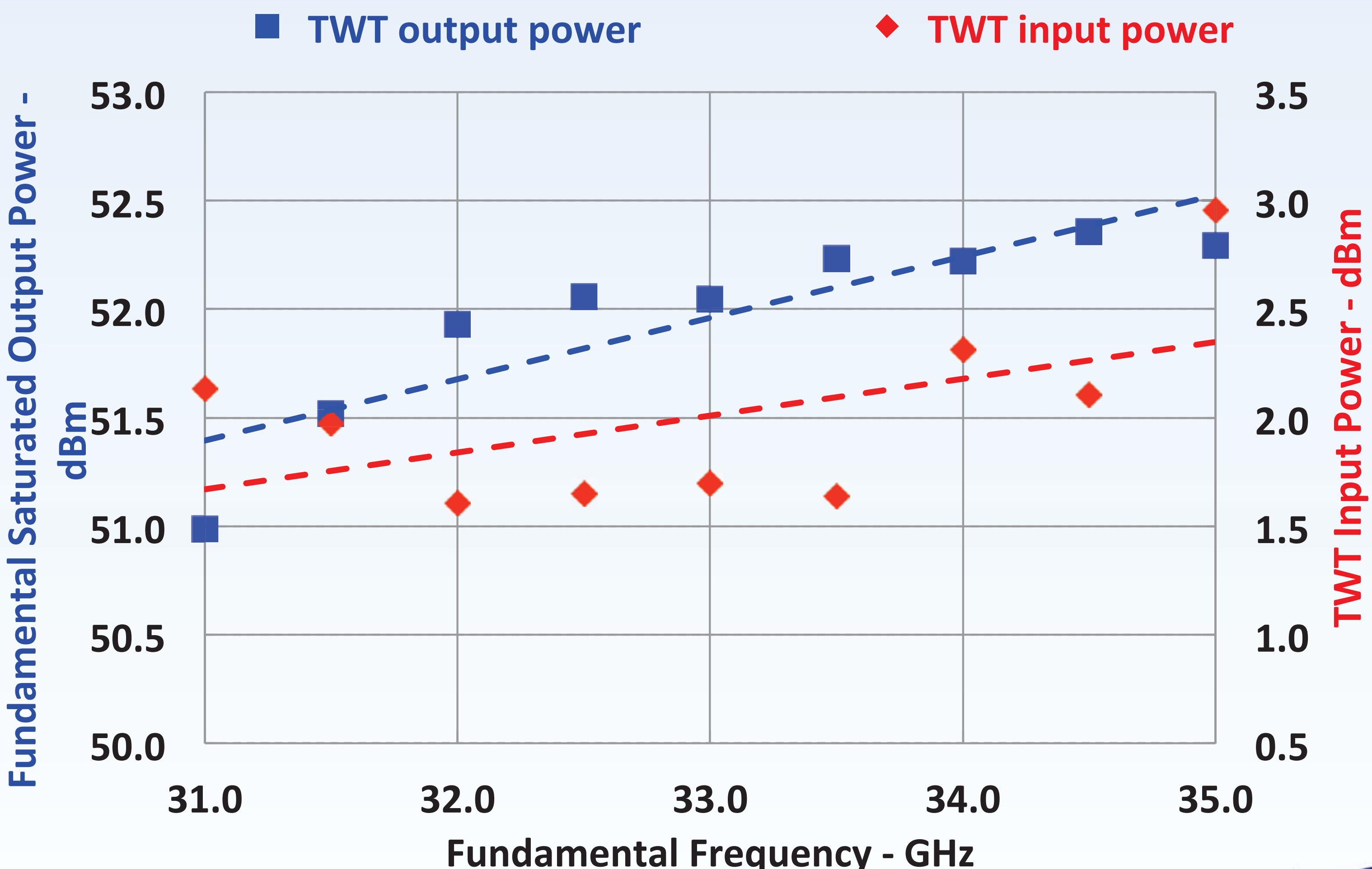



# Ka-Band/E-Band Waveguide Multimode Directional Coupler (MDC)

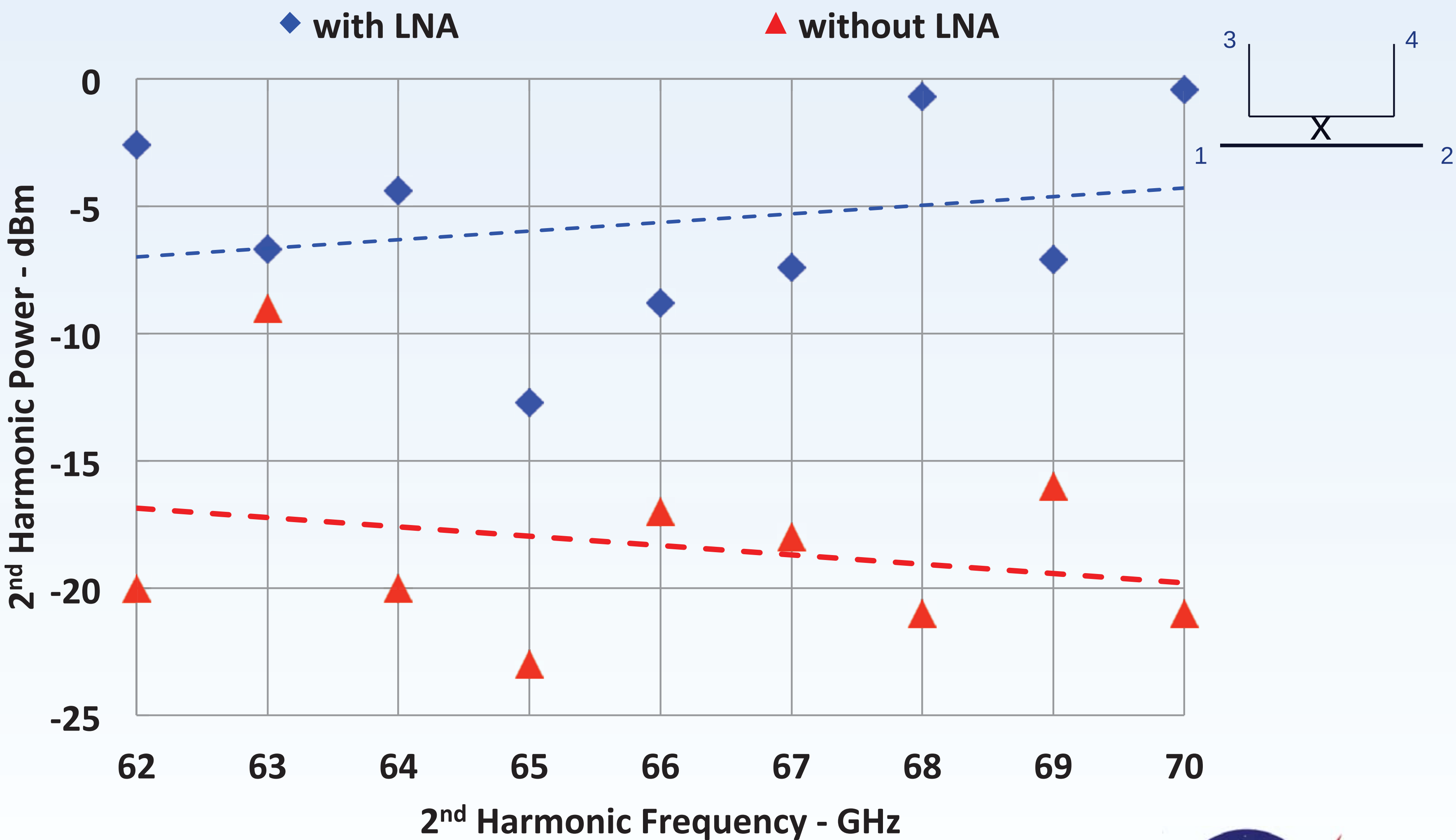
# Schematic of the Ka/E-Band Test Setup for Power Measurement at the Output Ports of the MDC



# Measured TWT Input/Output Powers (Fundamental)



# Measured 2nd Harmonic Power at 62 to 70 GHz at MDC Port 4



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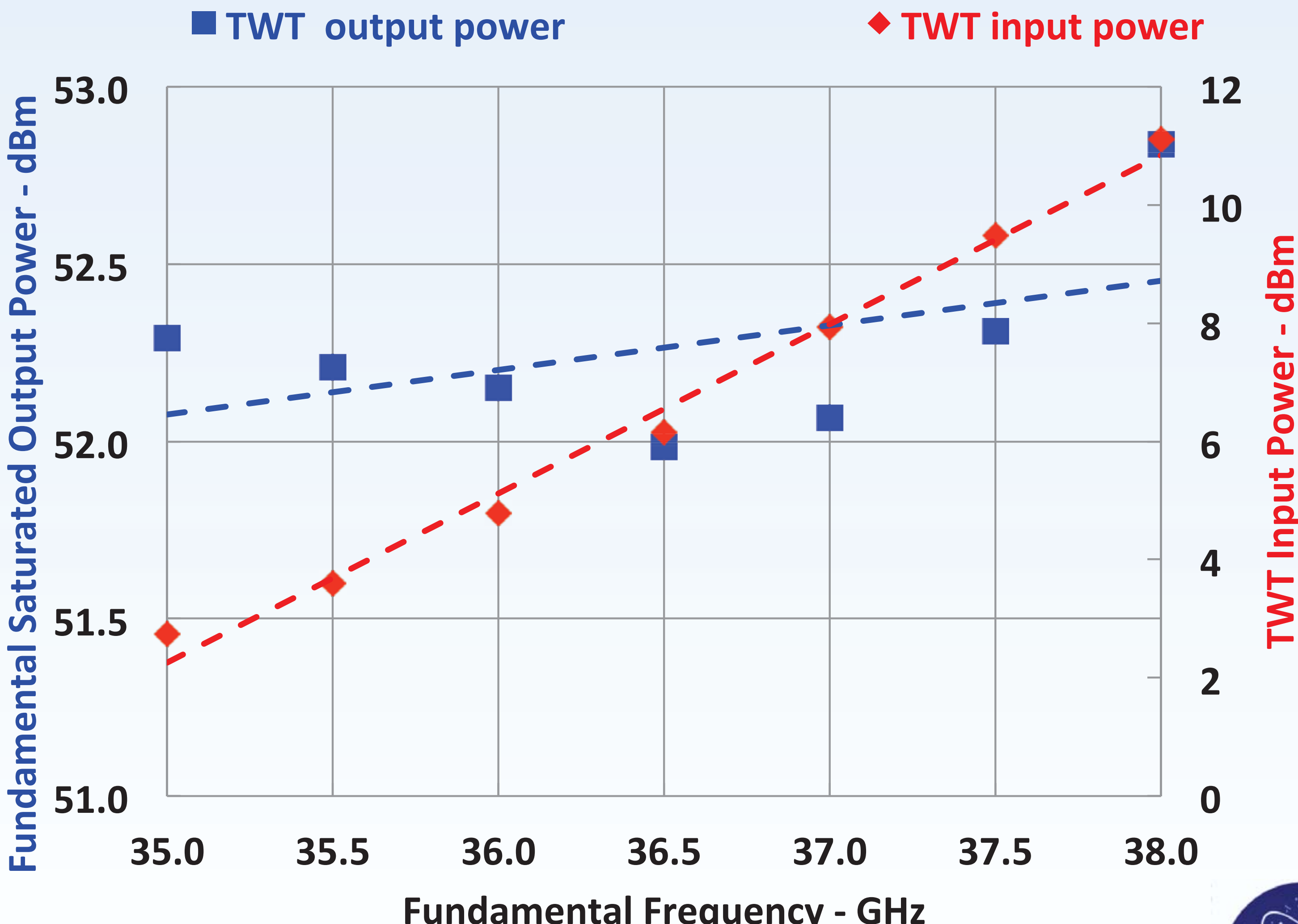
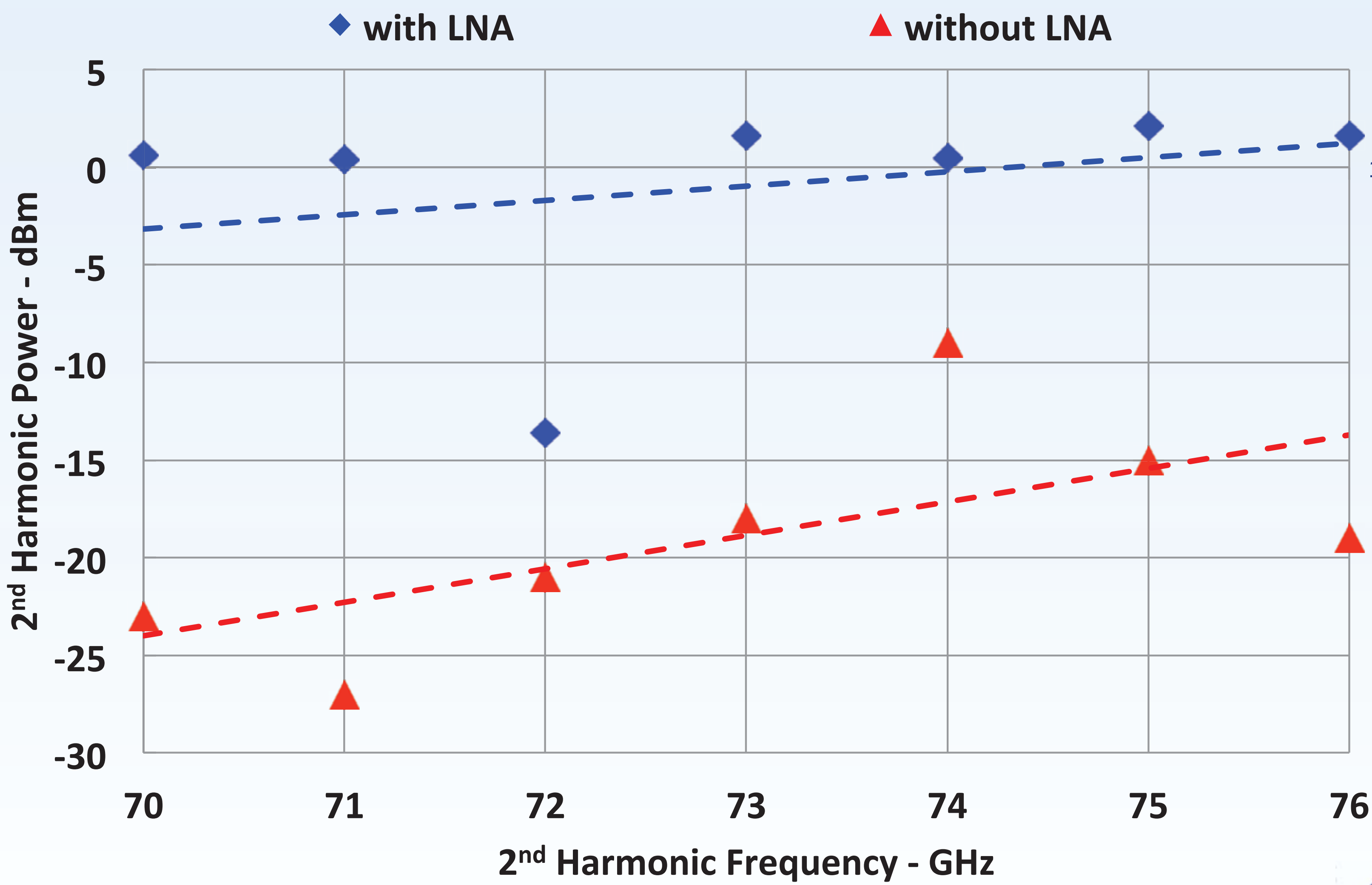
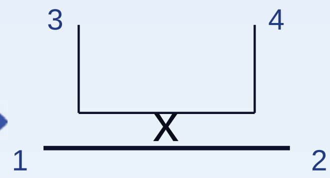


# Measured 2nd Harmonic Power at 70 to 76 GHz at MDC Port 4



# Discussions & Conclusions

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- 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