TU3D-5

# A 666 GHz Demonstration Crosslink with 9.5 Gbps Data Rate

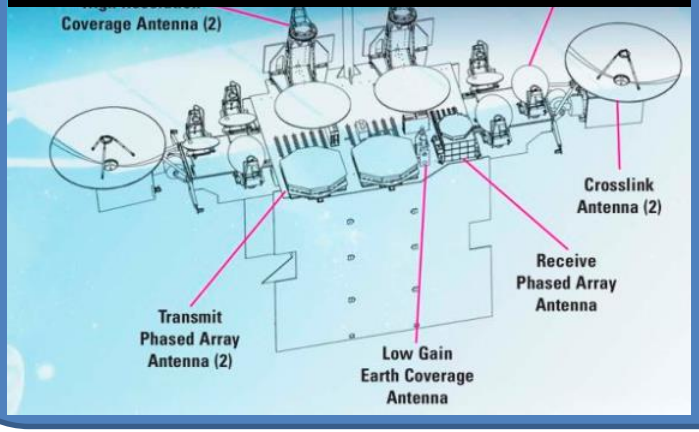
William R. Deal[1], Tyler Foster[1], Mark B. Wong[1], Matthew Dion[1], Kevin Leong1, Xiao Bing Mei[1], Alexis Zamora[1], Gregor Altvater[1], Kevin Kanemori[1], Louis Christen[1], Jack C. Tucek[2], Mark A. Basten[2], Kenneth E. Kreischer[2]
Northrop Grumman Corporation
[1]Redondo Beach, United States
[2]Rolling Meadows, United States

# Outline

- Motivation
- Electronic Capabilities at THz Frequencies
  - Receiver
  - Transmitter
  - Traveling Wave Tube Amplifier
- Link Calculations
  - Cross Link Calculations
  - Terrestrial Calculations
- 100G Modem
- Link Validation
- Conclusions

# Motivation

MM-WAVE Crosslink




MM-Wave Crosslink Benefit:

- Robust, mature microwaves
- Well-understood pointing-and-tracking
- RF Comm infrastructure (backend, mod schemes)

Disadvantage:

- Large Aperture (6 ft for Satcom)
- Limited Bandwidth

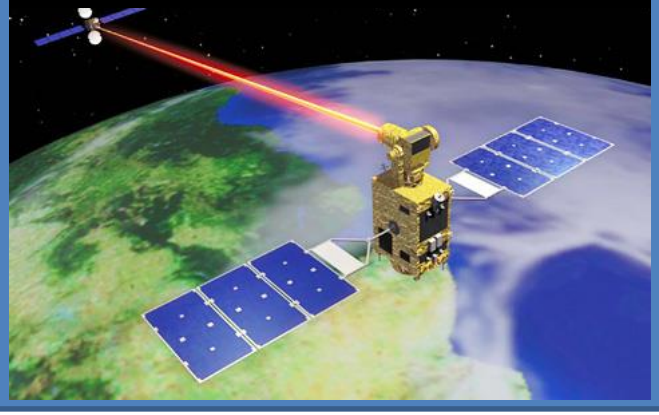
Laser Crosslink Benefit:

- Smaller Aperture (wavelength)
- High instantaneous Bandwidth

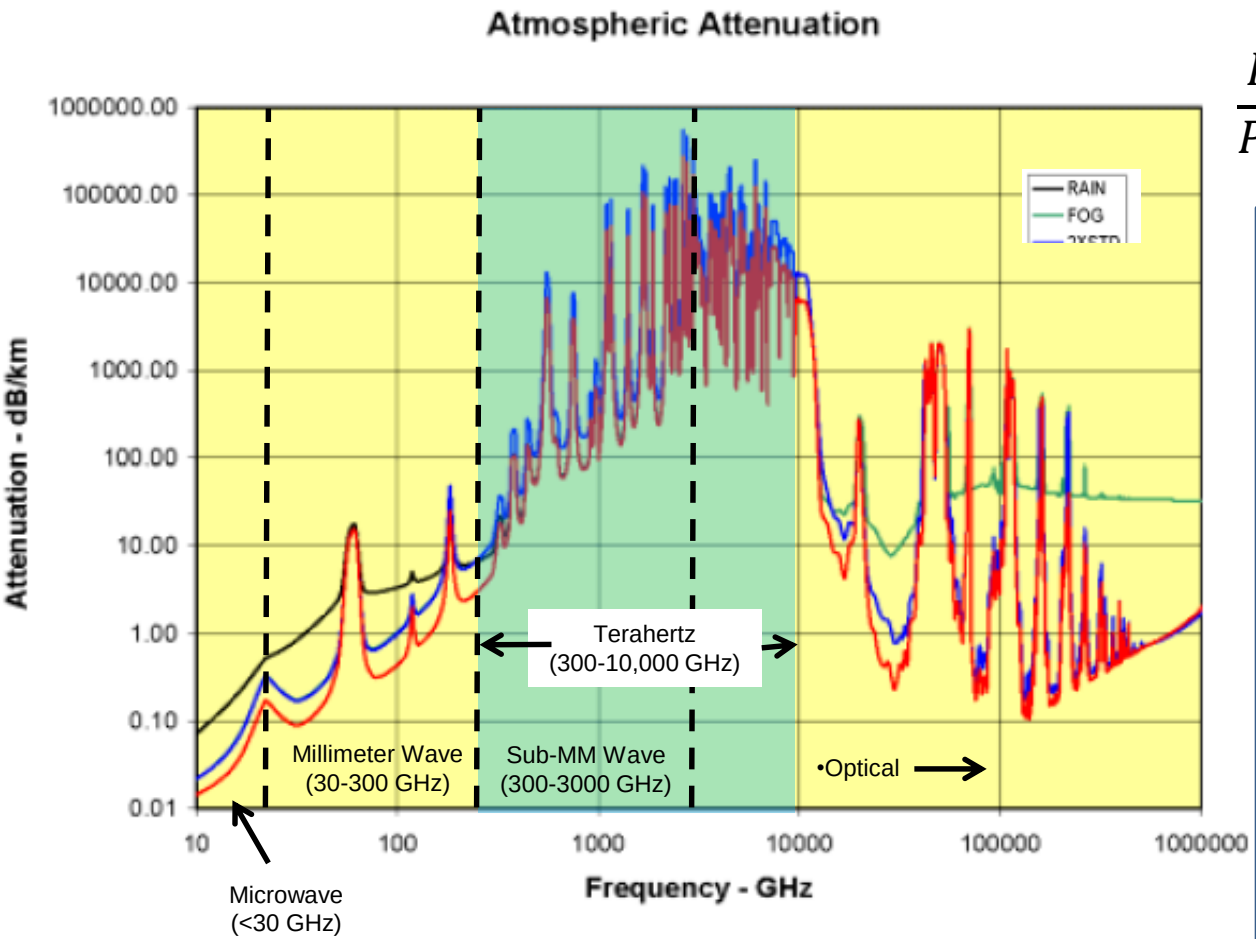
Disadvantage:

- Maturity
- Modulation schemes
- Pointing-and-tracking

Laser Crosslink



# Motivation (continued)




?

$$\frac{P_{rec}}{P_{tran}} = G_{tran} * Grec * (\ \ /4\pi r)^2$$

Increasing frequency:

- Increases bandwidth
- Shrinks aperture
- Limited ground use above 100 GHz (atmospheric attenuation)

Other Facts:

- Output power decreases with frequency (~1/f$^3$)
  - Harder to close link
  - But lower DC power
- Receiver sensitivity degrades (~1/f)

# Motivation (continued)

- Significant RF technology advances over last 10 years
- Transistor-based receivers and transmitters to 850 GHz
- Traveling Wave Tube (TWT) Amplifiers to 1,000 GHz
- Spectrally efficient modems (100G)

$$\frac{P_{rec}}{P_{tran}} = G_{tran} * Grec * (\quad /4\pi r)^2$$

Friis Transmission Formula

$$G \propto \left(\frac{d}{\lambda}\right)^2$$

Small Aperture!

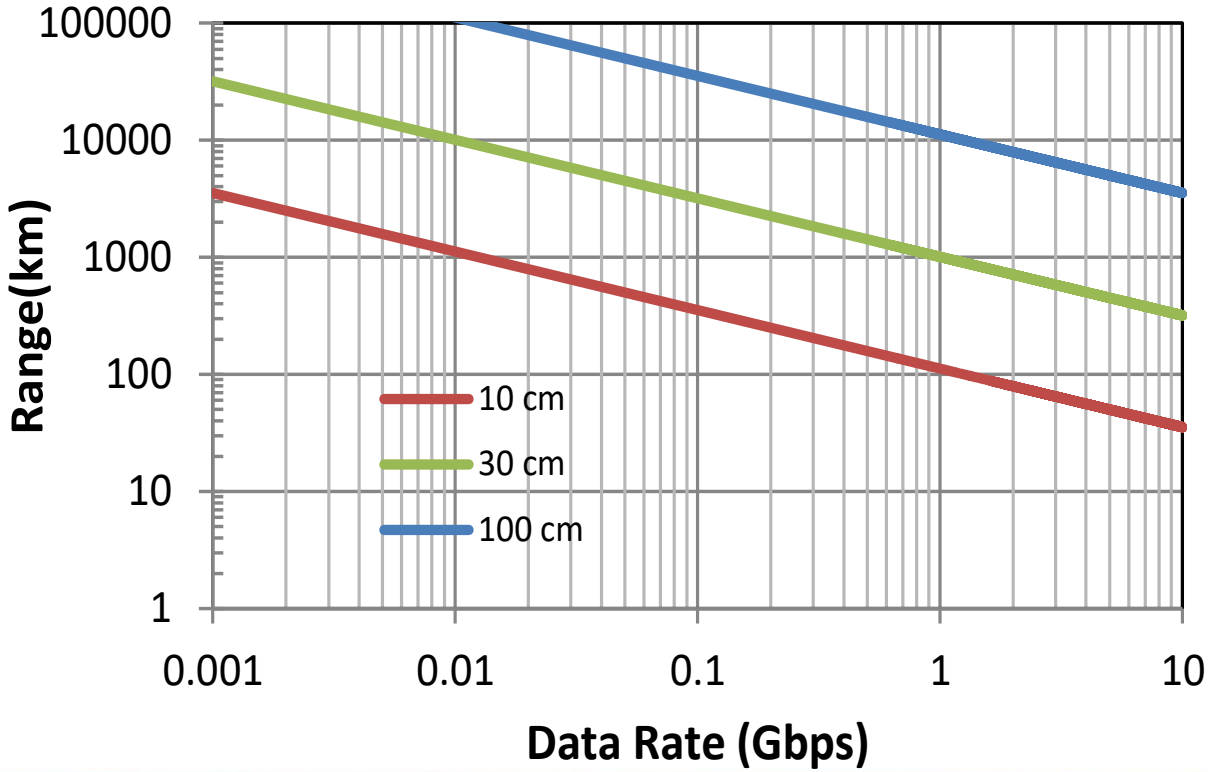
$T_{rec}$ 1/f Sensitivity Degrades

$P_{trans}$ $(1/f)^3$ Power Drops Quickly

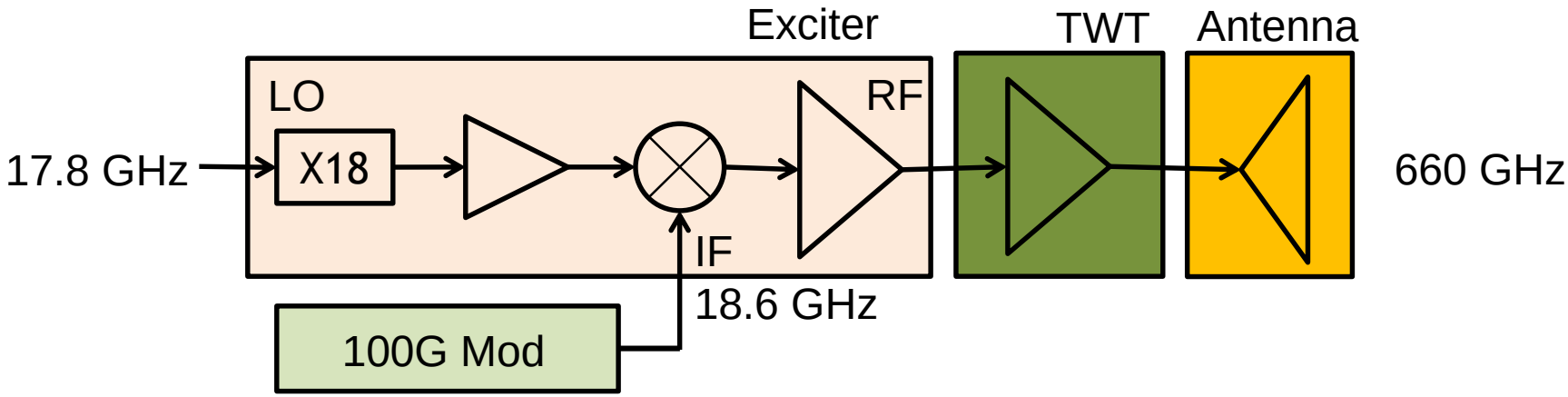
**What would it take to do a 670 GHz Link?**

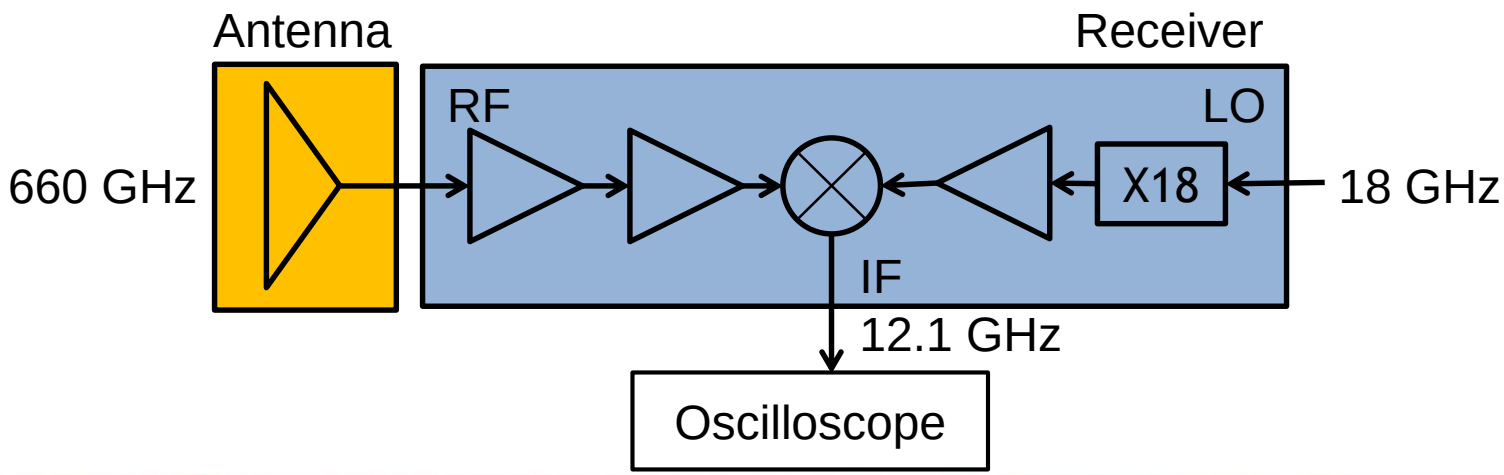
# Link Calculations

- Terahertz high data rate communications now proven at short range in atmosphere
- Satellite crosslinks may be ideal application for this technology
  - Low probability of intercept
  - Supports high level modulation rates
  - Supports LEO-LEO links with 30 cm aperture



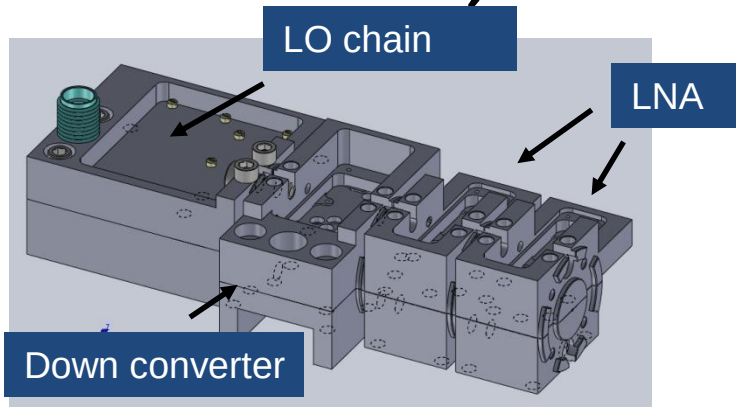
# Link Components

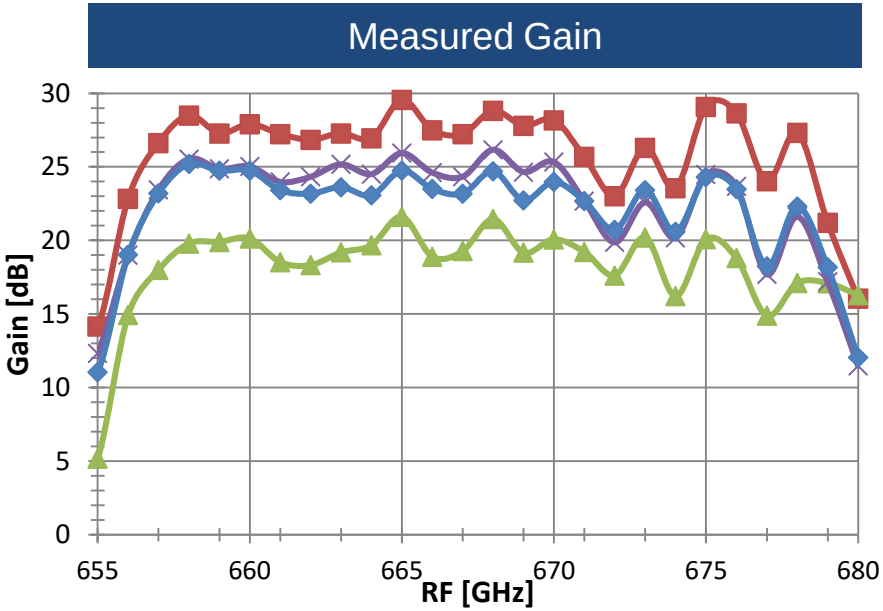


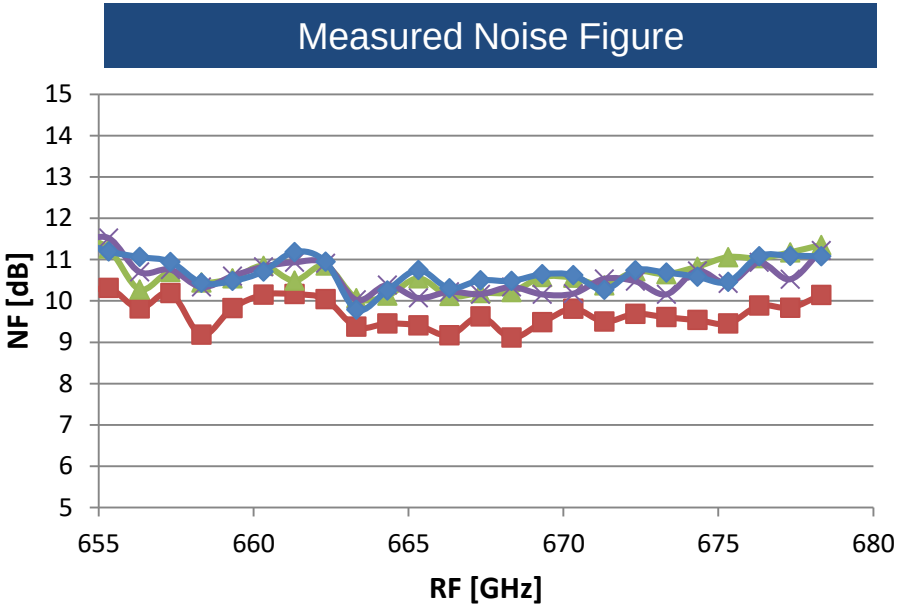



# Receiver (NGAS, Redondo Beach)

- ~25 dB Gain and 10 dB NF
- Bandwidth ~ 20 GHz
- Limited by IF mixer bandwidth

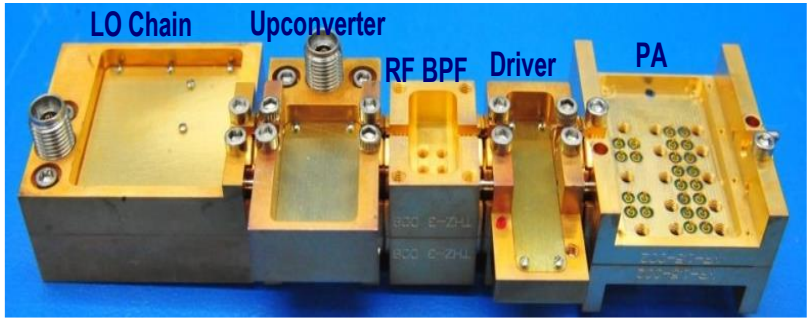


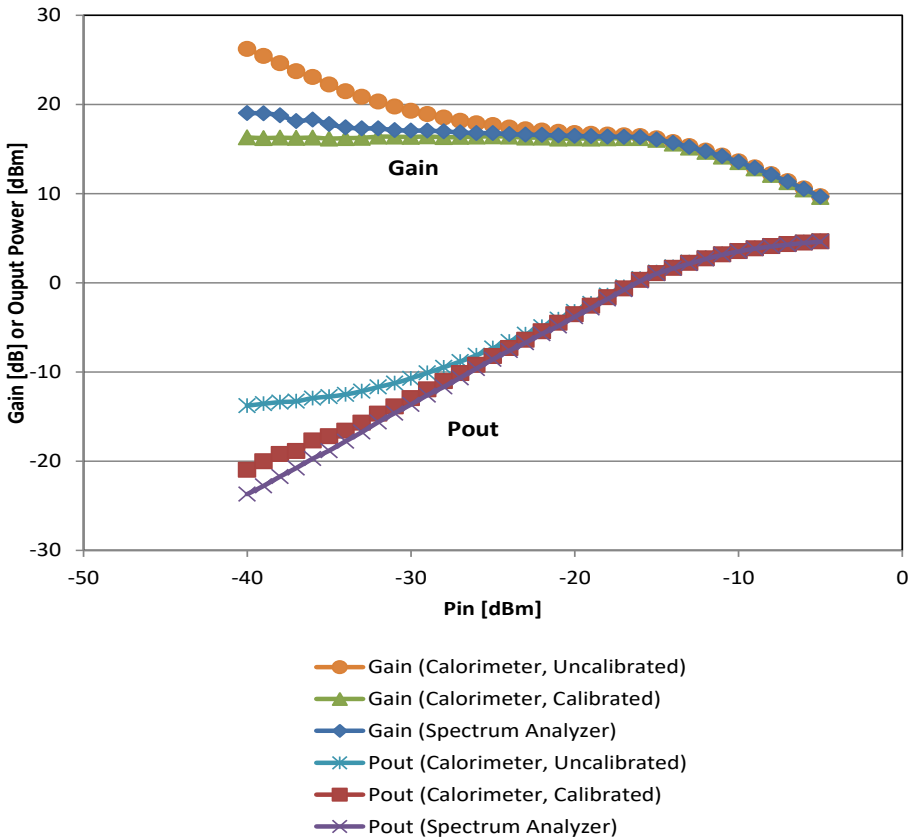



# Exciter (NGAS, Redondo Beach)

- Heterodyne up-converter
- 16 dB small signal gain
- 6 dBm saturated output power

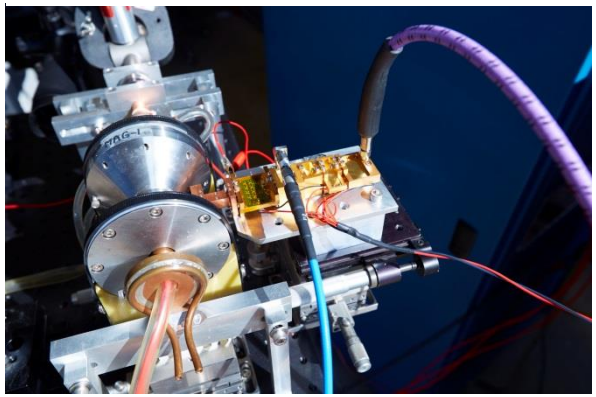


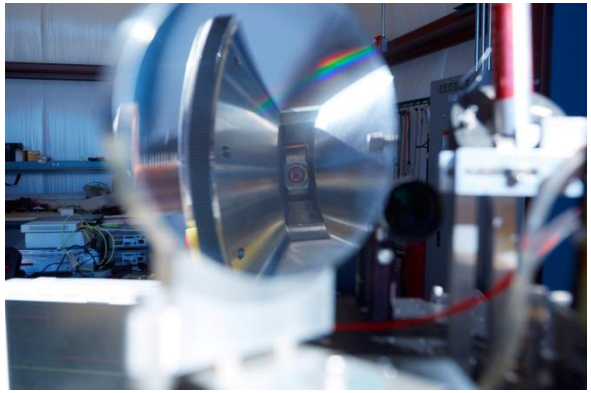
# TWT (NGMS, Rolling Meadows)

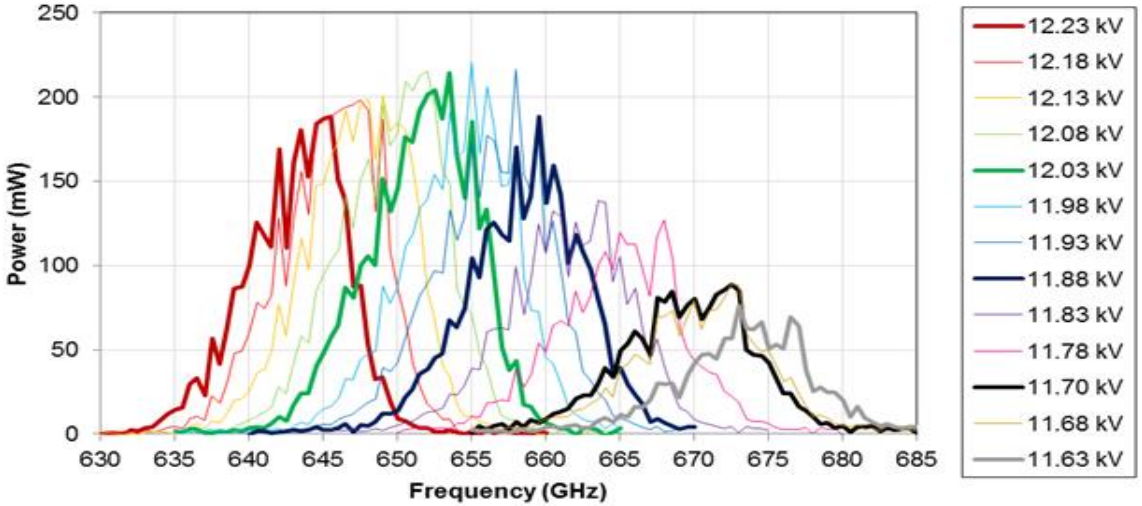
- Peak power of 200 mW
- >100 mW available at demo frequency (666 GHz)
- Tuneable with voltage
- Integrated with frequency converter (exciter and SSPA) and 10 cm reflector

TWT with exciter



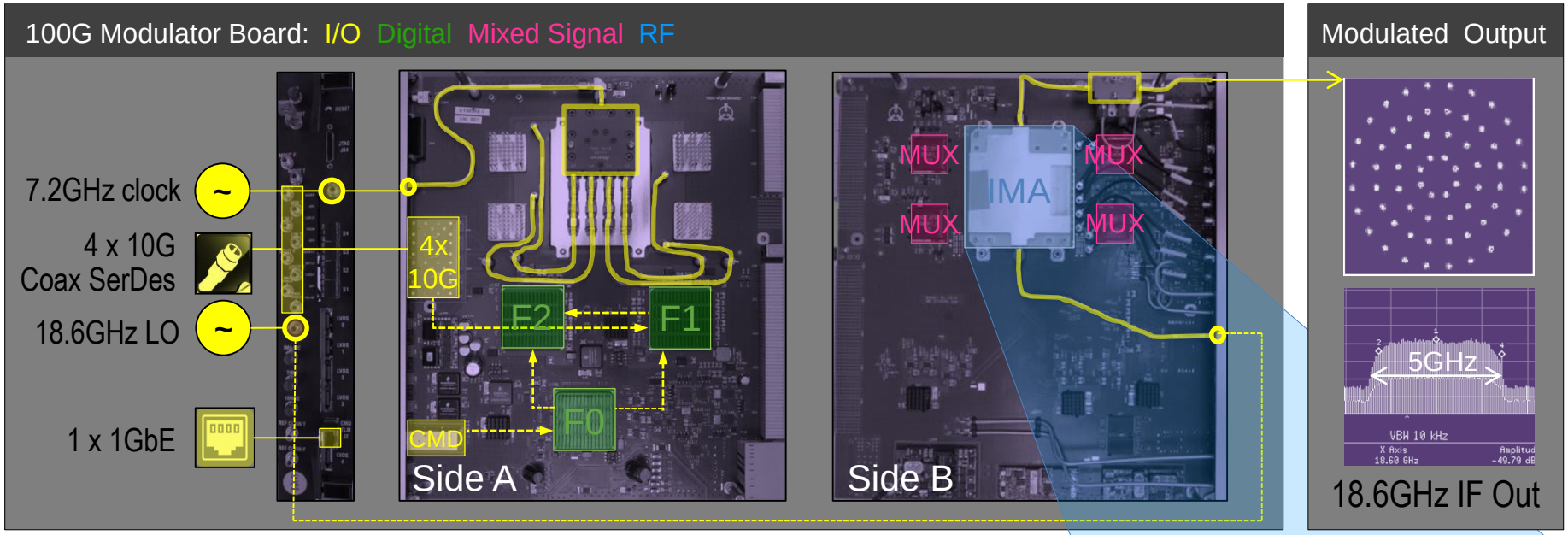
Reflector and Window



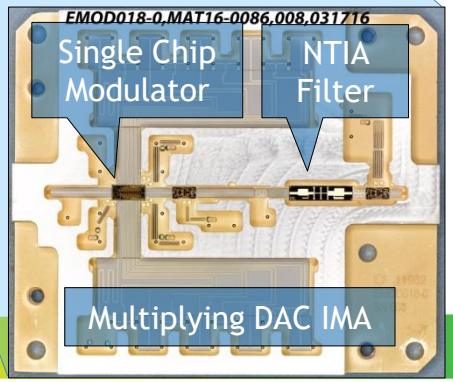


# 100G Modulator

The 25Gbps ATCA form factor 100G modulator board processes internally generated PN11 payload data over a 5GHz wide bandwidth directly at 18.6GHz IF




- Custom DSP on two Virtex 7 FPGAs performs encoding, framing and pulse shaping (4.77Gsym/s upconverted to 7.2Gsamp/s)
- Parallel (low speed) to serial (high speed) 64:4 mux operation on custom designed SiGe mixed-signal ICs
- Direct modulation at 18.6GHz IF with 8bit I, 8 bit Q InP multiplying DAC IMA (Integrated Module Assembly)

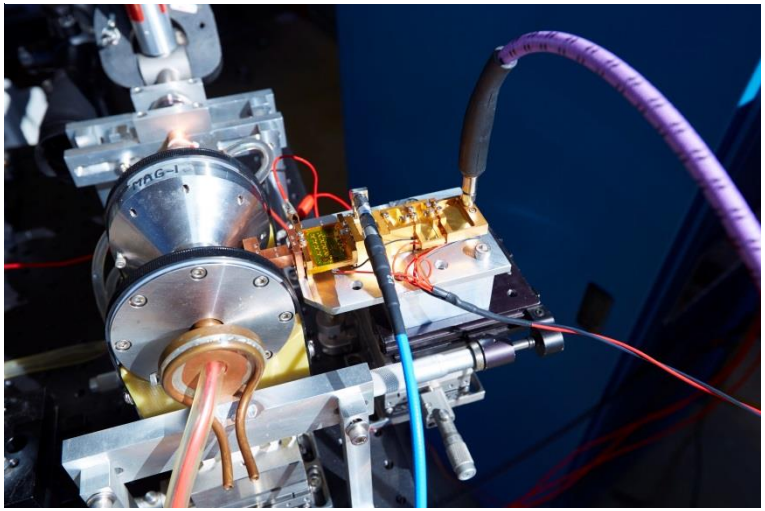


# THz Data Link Overview

- Demo took place in Rolling Meadows, Illinois
- Week of March 33rd 2017
- Two Demos:
  - "Short Range": 250 M
  - "Long Range": 600 M

100 G Modulator


THz Electronics TX (with TWT)



RX with Reflector

# Ground Based Link Predictions

| Parameter | | Unit | Notes |
|---|---|---|---|
| Transmit Frequency | 666 | GHz | |
| Modulation & Coding | 16-APSK r=7/8 | | |
| Data Rate | 25 | Gb/s | |
| Net Transmit Power | 20 | dBm | |
| Backoff | -1.8 | dB | |
| Losses | -1 | dB | |
| Net Transmit Gain | 55.9 | dBi | |
| Aperture Diameter | 10.00 | cm | |
| Pointing Loss | -0.5 | dB | |
| **EIRP** | **75.6** | **dBmi** | |
| Path Loss | -144.5 | dB | |
| Range | 600.0 | m | Long range test |
| Atm Loss | -5.8 | dB | 15% humidity |
| Total Channel Losses | -150 | dB | |
| **RSSI** | **-74.6** | **dBmi** | |
| Net Receive Gain | 54.9 | dBi | |
| Aperture Diameter | 10.00 | cm | |
| Pointing Loss | -0.5 | dB | |
| Circuit Loss | -1 | dB | |
| Received Signal Power | -20.2 | dBm | |
| Noise Temperature | 3238.3 | K | |
| LNA NF | 10.5 | dB | |
| Earth+Sky Contribution | 191.0 | K | |
| LNA+Backend Rx | 2975.7 | K | |
| **Net G/T** | **19.8** | **dB/K** | |
| **Available Eb/No** | **41.3** | **dB** | |
| **Net Req'd Eb/No** | **11.4** | **dB** | |
| Ideal Reqd Avg Eb/No | 6.4 | dB | |
| Implementation Loss | -5 | dB | |
| **Link Margin** | **30.0** | dB | |

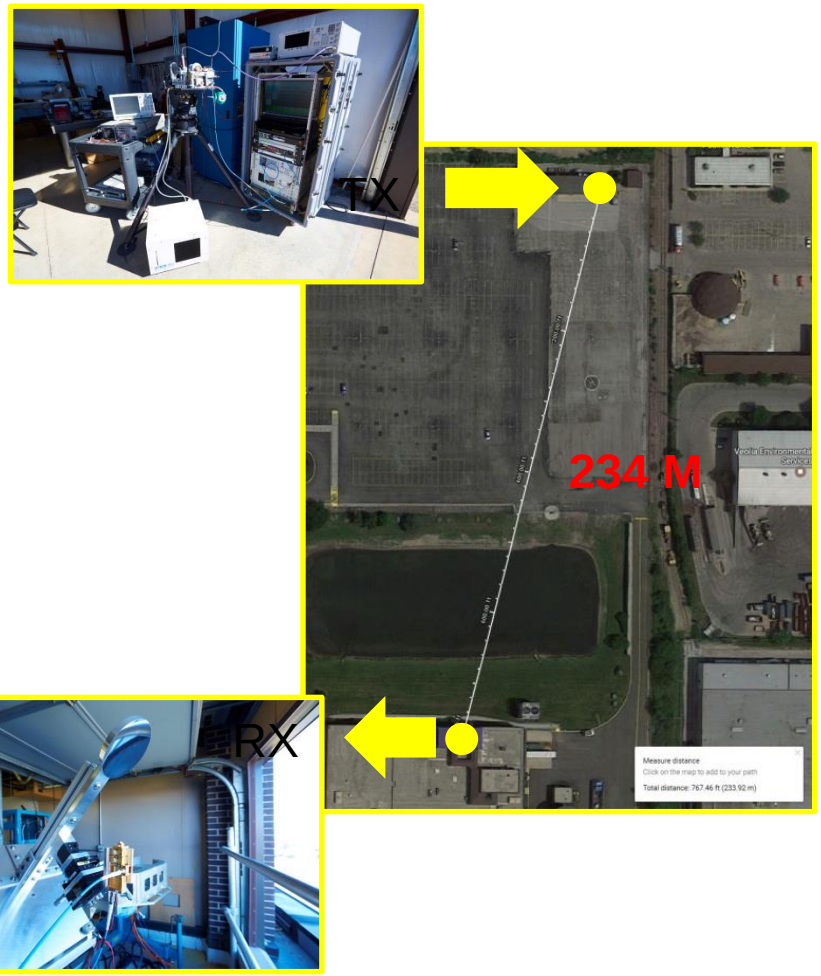
- **Original link budget booked -61 dB/km for gaseous atmospheric losses based on ITU reference standard atmosphere**
- **Weather measurements taken during testing predicted a loss of -9.6 dB/km due to favorably low humidity**
  - **22% during demo, 15% during long range testing**

Weather Station

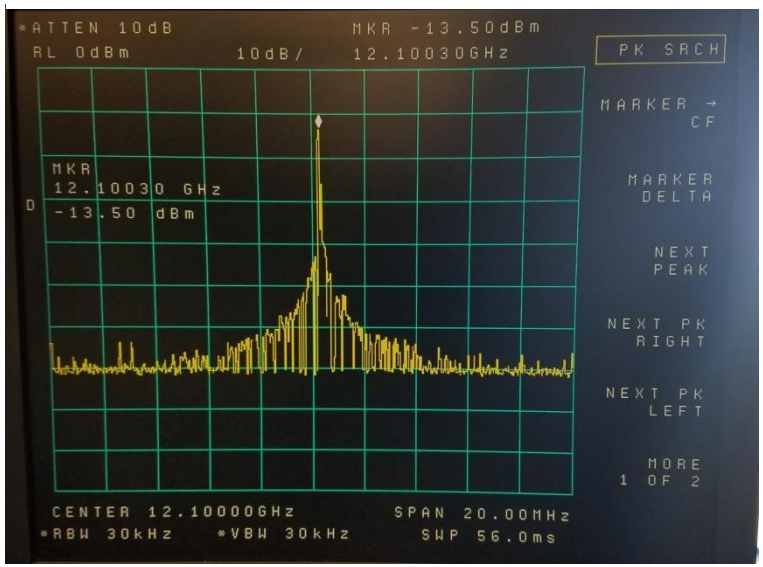
# Demo Overview: Short Range

**Link Details:**

- **234 M Range**
- **Receiver initially saturated**
- **Rotated receive horn by 90 degrees to receive Cross-Polarization and reduce receive power**




CW Mode Receiver Output*

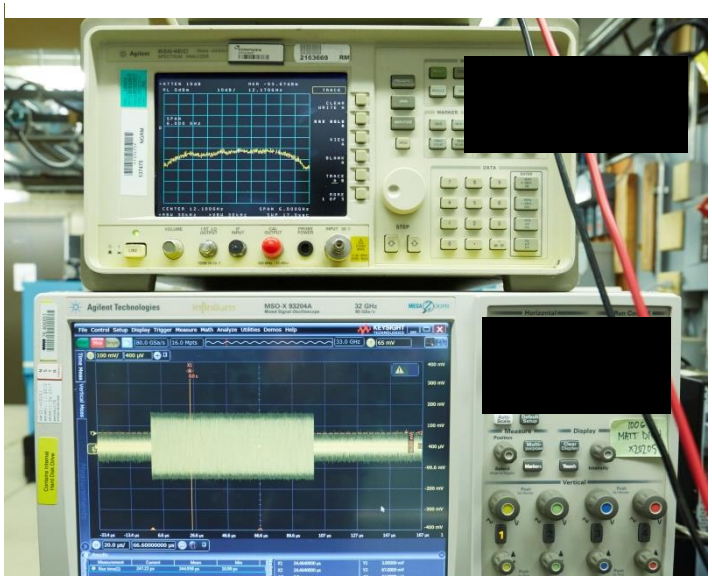



***Note that TWT is operated in pulsed mode**

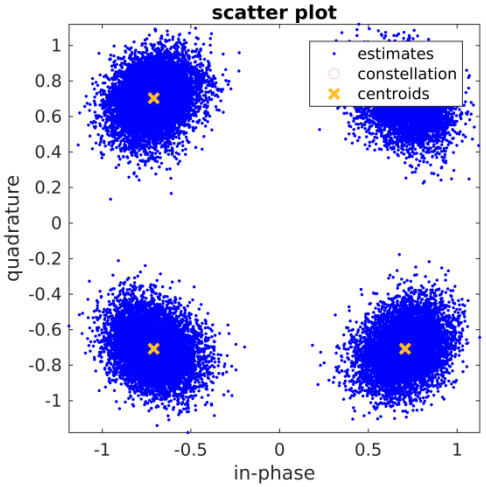
# Results: Short Range

- Successfully received and demodulated QPSK and 16-APSK

Received Waveform




QPSK

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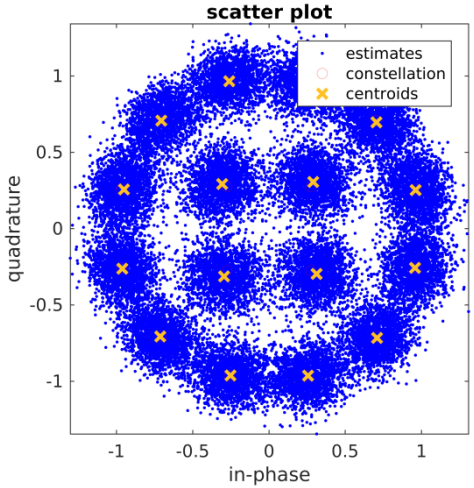
16-APSK

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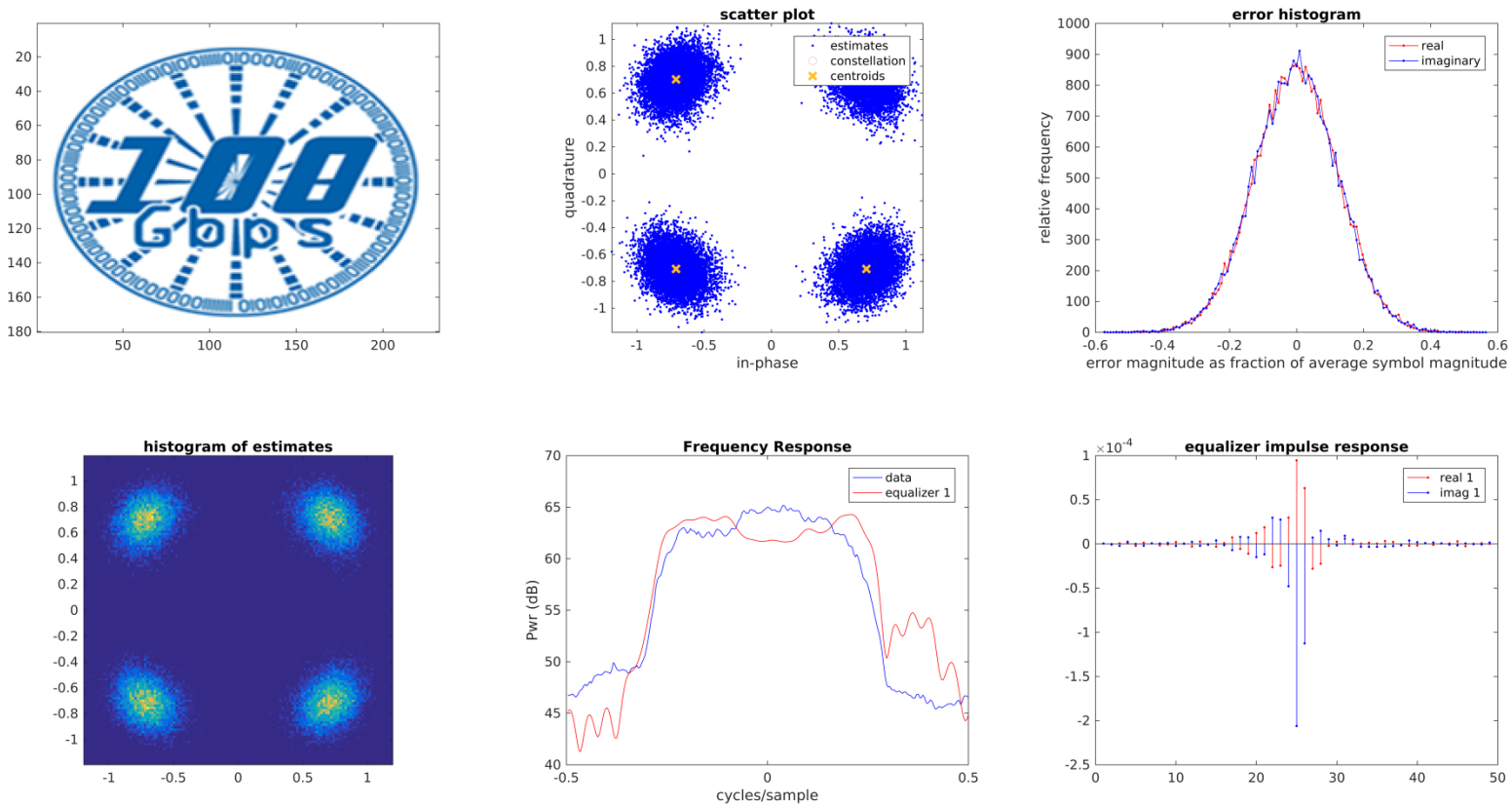
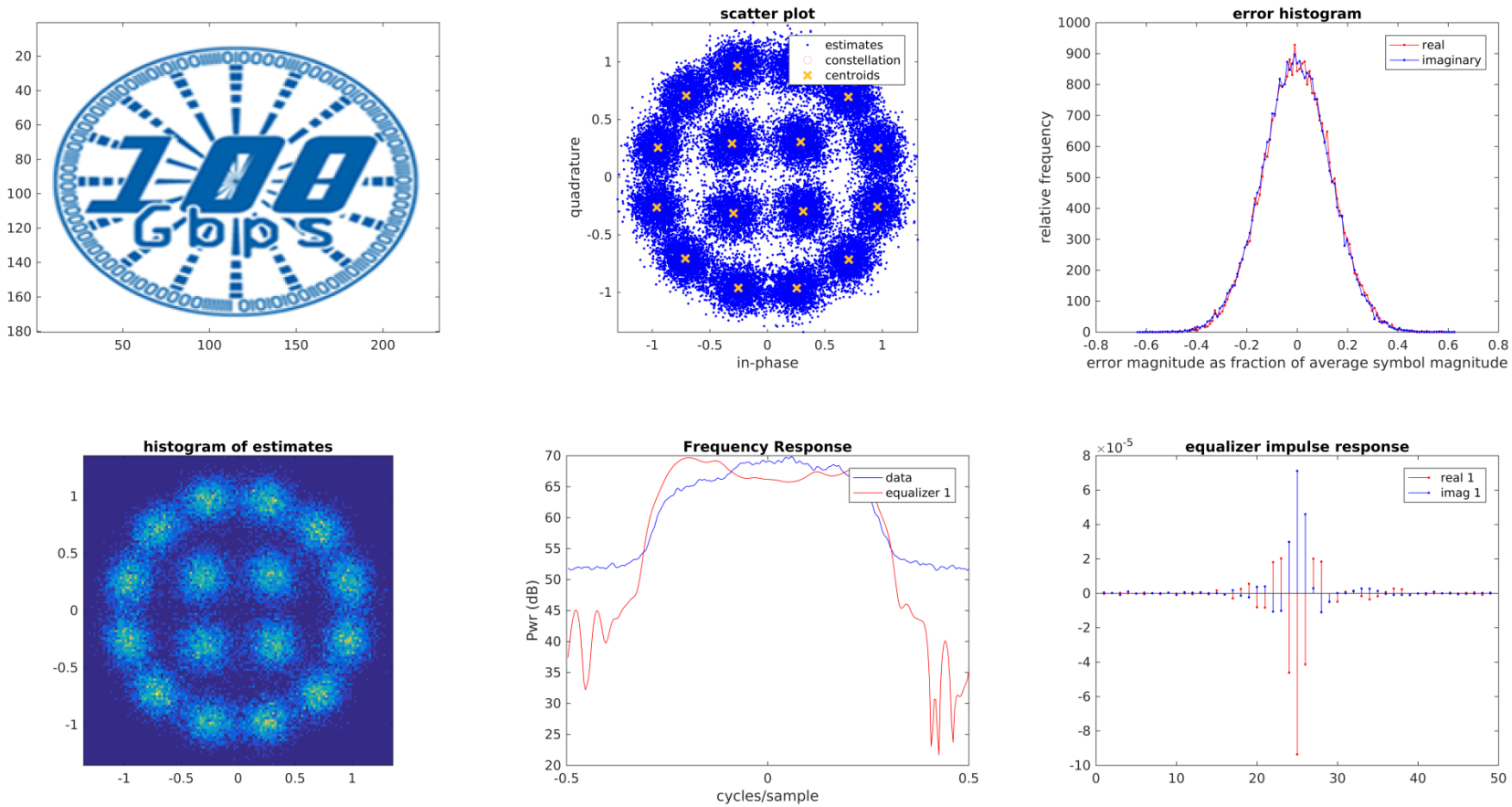
# Results: Short Range

Const. # 2: 29789 sym $EVM_{RMS/RMS}$=17.6%



# Results: Short Range

Const. # 2: 29789 sym $EVM_{RMS/RMS}$=19.1%

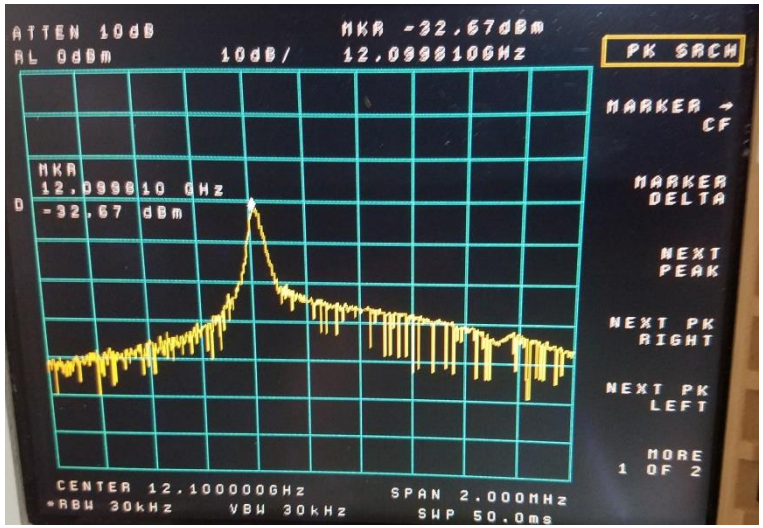


# Results: Long Range

**Link Details:**

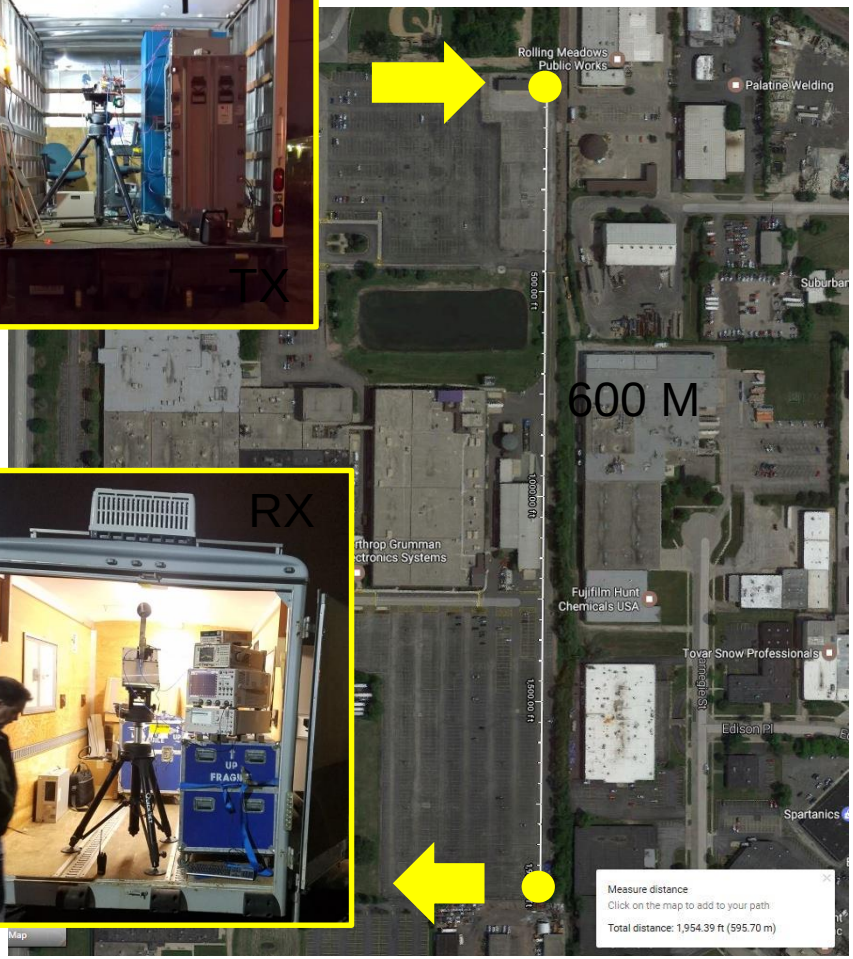
- 600 M Range
- Receive and Transmit each deployed in a trailer
- Received power ~ 20 dB lower after flipping polarization of horn to Co-Polarization
- Note transmit mixer was swapped after power outage due to component failure

CW Mode Receiver Output*




*Note that TWT is operated in pulsed mode

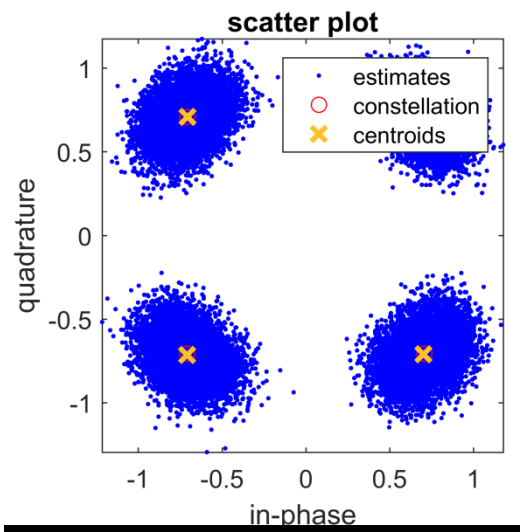




# Results: Long Range

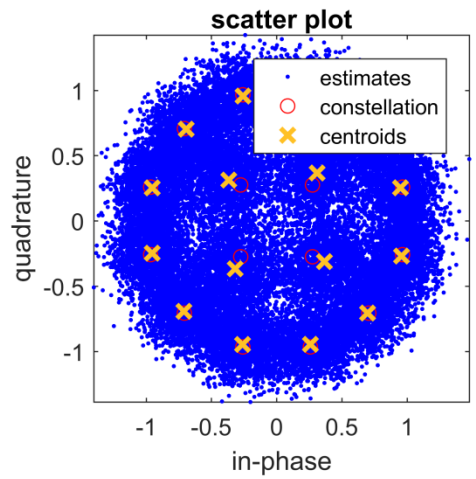
- Successfully received and demodulated QPSK
- Error rate on 16-APSK is higher
- May be at least partially attributed to swapped mixer with higher LO leakage in band

QPSK




EVM: 19%

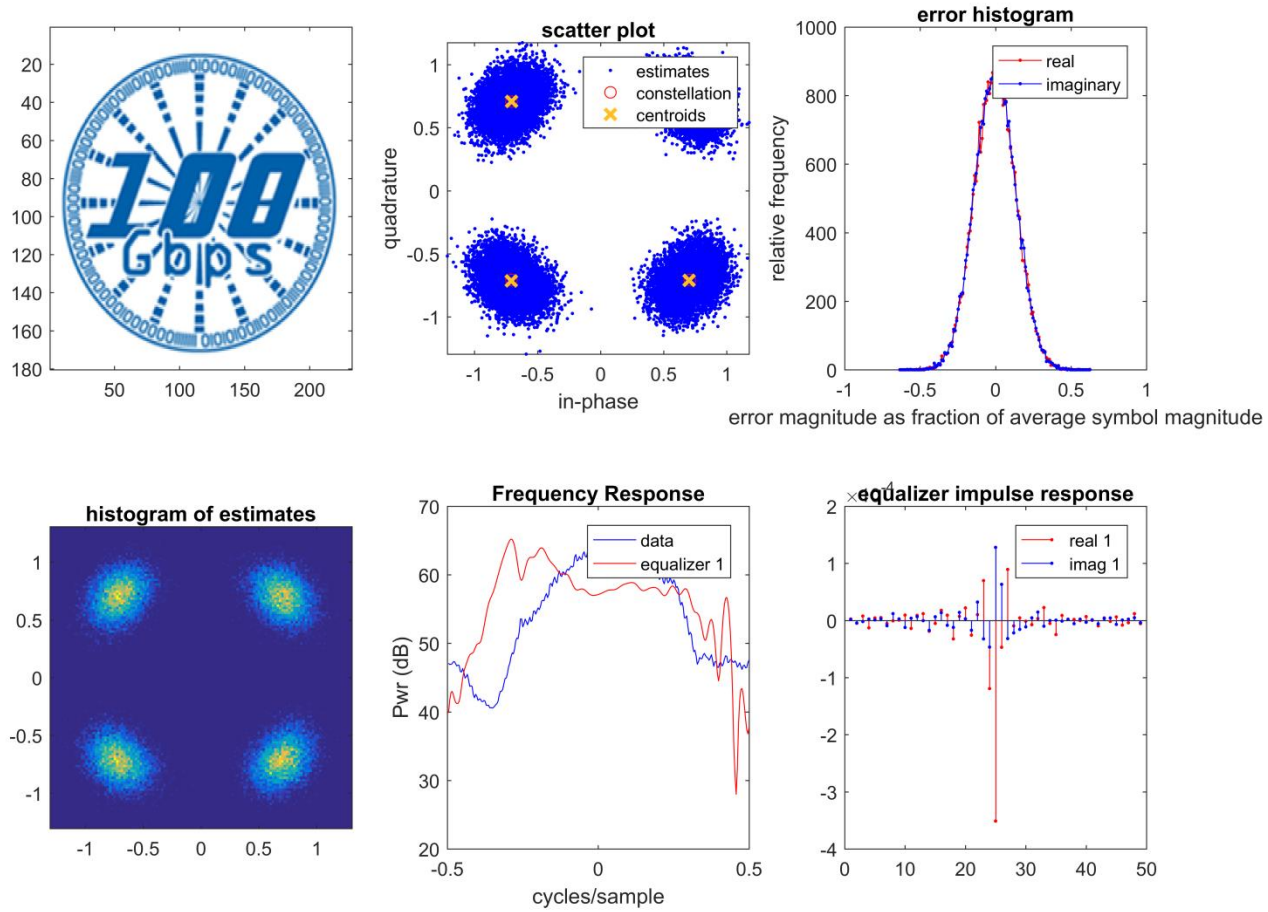
16-APSK




EVM: 26.6%

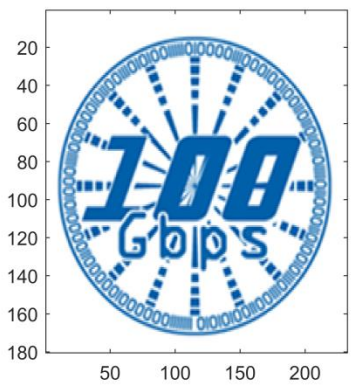
# Results: Long Range

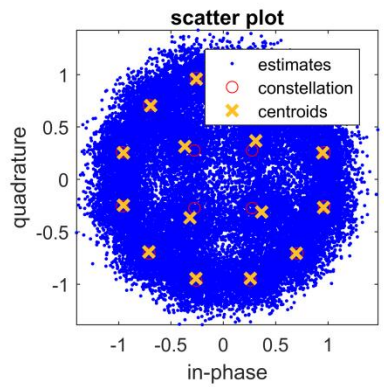
Const. # 2: 29789 sym $EVM_{RMS/RMS}$=19.0%

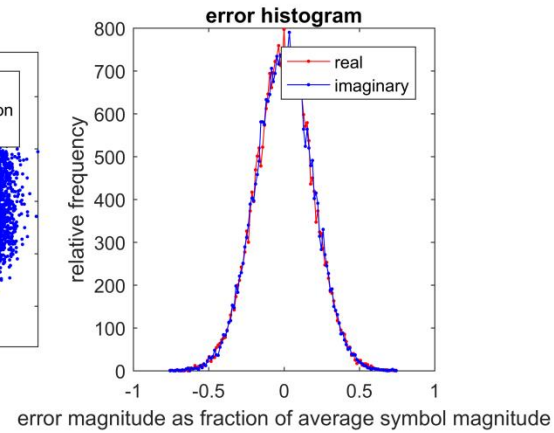


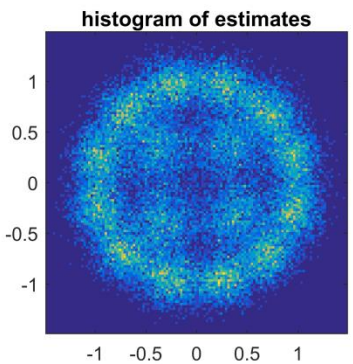
# Results: Long Range

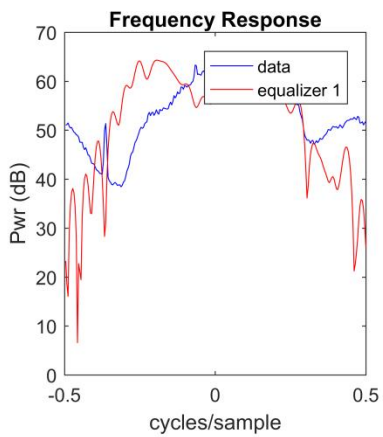
Const. # 2: 29789 sym $EVM_{RMS/RMS}$=26.6%

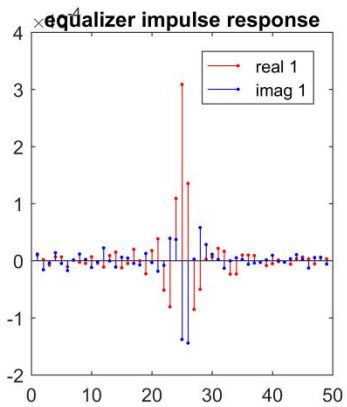


# Outcomes and Insights

- Data passed over-the-air at 666 GHz and 600 M range with good link margin in atmosphere
- Both QPSK and 16-APSK transmitted and demodulated
- Careful Size, Weight and Power (SWaP) trades may show THz links are a viable alternate to millimeter and optical cross links

# Ongoing Northrop Grumman "THz" Activities

- First Air-to-Air THz Demo currently being prepared at Northrop Grumman
- CloudSat Radar at 239 GHz in development (NASA)
- "Optically Thin" Contrail Cumulus Cloud demonstration in development (NASA)
- "THz" Technology wafer fabrication now offered as a foundry service.

# Acknowledgement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