Over The Air (OTA) Antenna Testing

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Johnstech International

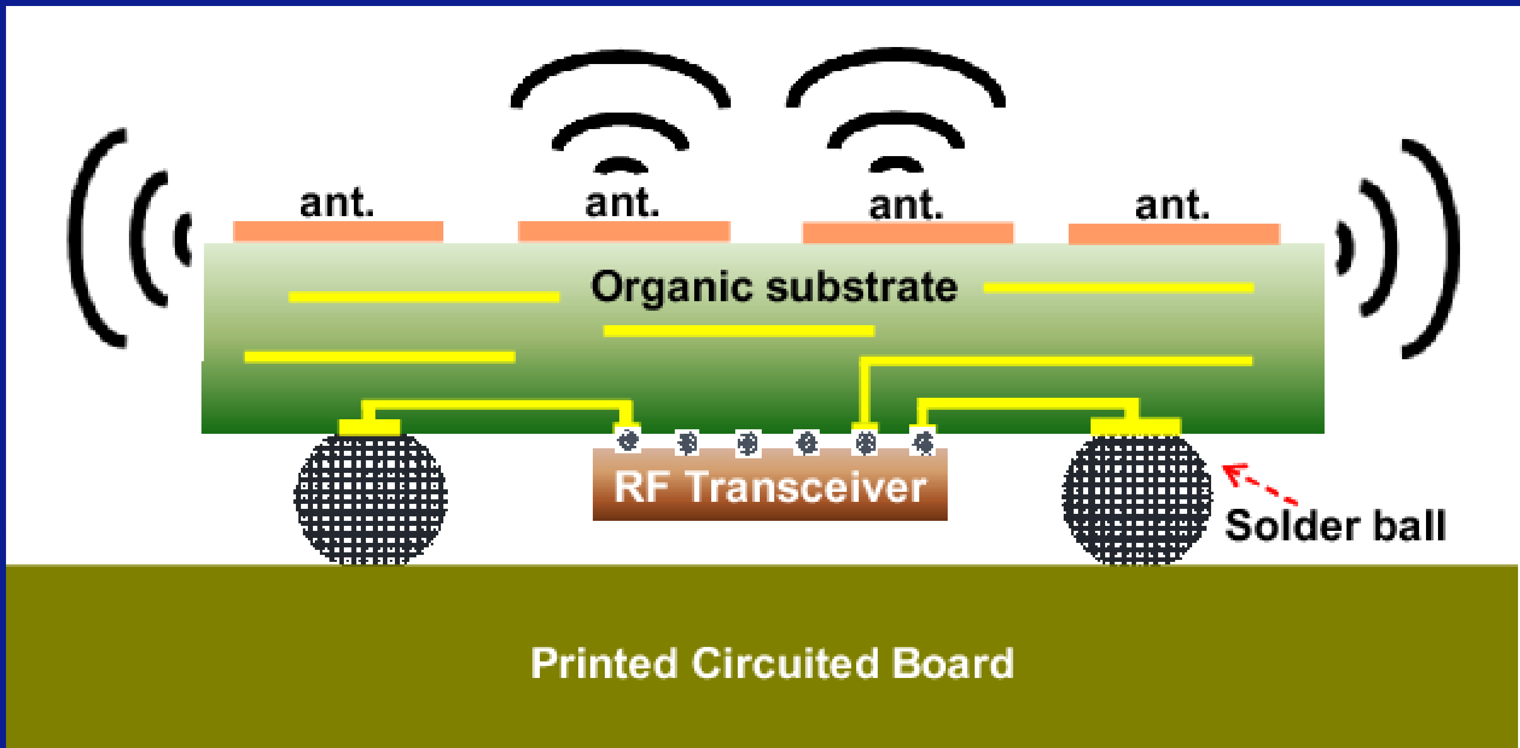
TestConX
Virtual Event ● May 11-13, 2020

Johnstech®

Agenda

- OTA Package, Definitions and OTA System
  - Contactor Types and Measured vs. Modeled Data
- OTA List of Applications and Frequencies
- OTA Frequencies Affect Antenna Size
- OTA Design Effects – Tolerancing and Fixturing
- Types of OTA Tests, Test Equipment and Systems
- Equations to Design Patch Antenna
- OTA Patch Antenna Results
- Conclusion

Typical OTA Device



Definition of OTA and AIP Device

Over-the-Air (OTA) – Method to qualify the RF performance of a Device Under Test (DUT). The DUT will transmit signals to another antenna that is part of a test solution. As RF applications, notably 5G millimeter-wave devices, become more prevalent the higher path loss and shorter wavelengths require OTA to be used as opposed to conducted measurements.

Antenna in Package (AIP) – Integrating the antenna within the Semiconductor package, this reduces the overall footprint of the system. AIP is being implemented in these mmWave applications to reduce complexity of the system and to overcome the signal losses that will exist with conducted measurements.

Typical OTA System

- Contactor
- Alignment Plate / Holding Feature
- Test Equipment / Load Board

- Test Environment
- Antenna (Receive and/or Transmit)

AIP or OTA Specific

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OTA Test System Components

Testing devices with antenna build in packages consists of five parts

- A tester to provide electrical signals and process measured signals - Modified
- A load board to route control and test signals that contactor mounts to and provides signals to Antenna in Package (AIP) device
- Contactor to hold device during testing and a conduit to supply test signals from board to Device Under Test (DUT) - Modified
- A chamber to control radiated signals from DUT - New
- A measuring and/or stimulating Antenna to measure and/or provide a radiated Over-The-Air (OTA) signal from/to DUT - New

New = New to AIP testing, Modified = Needs to be changed for AIP testing

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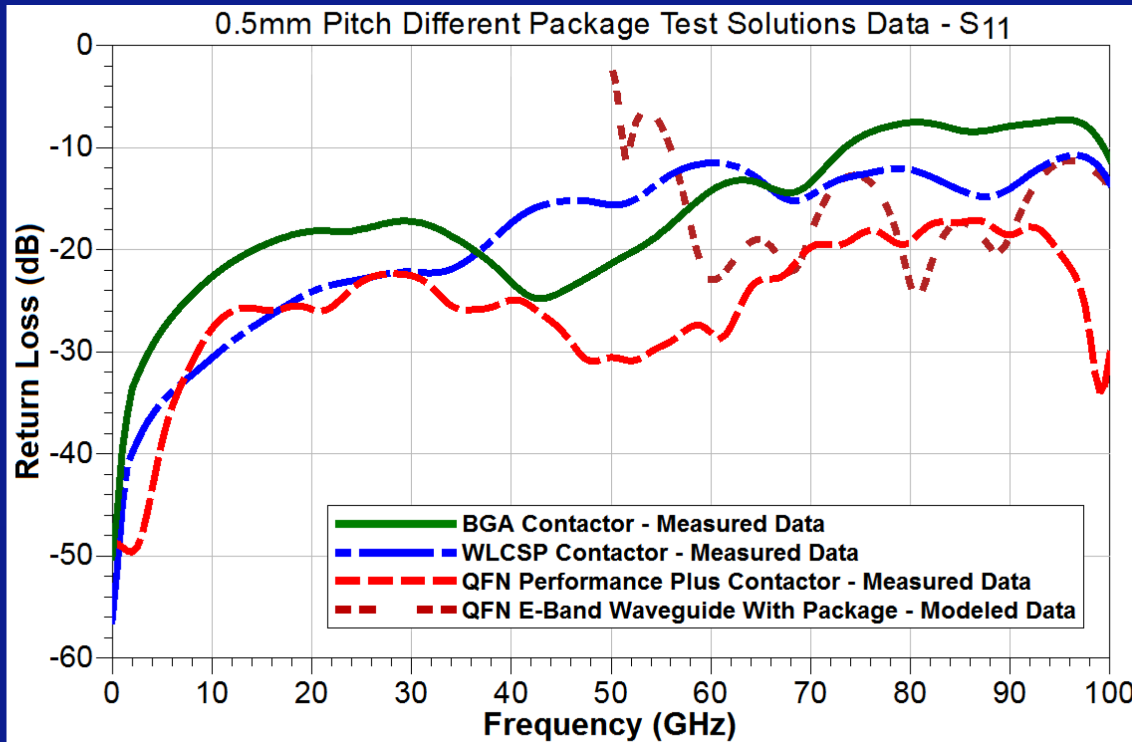
OTA System - Comparison Of Contactors – S_{11}



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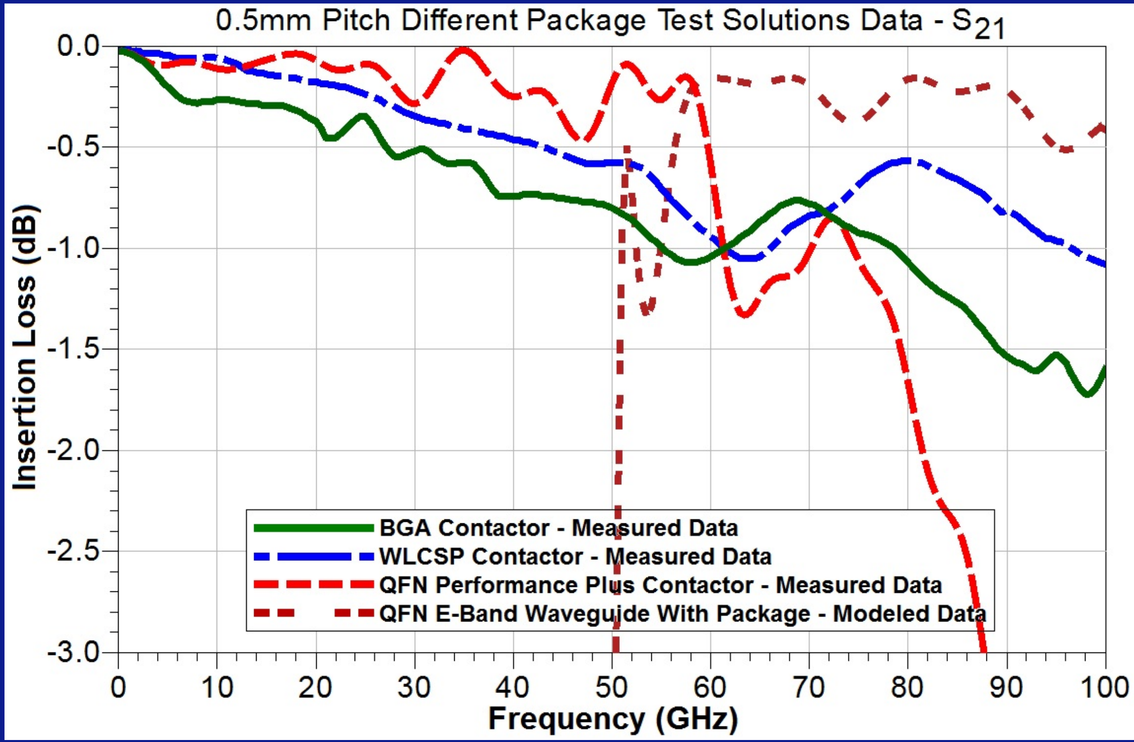
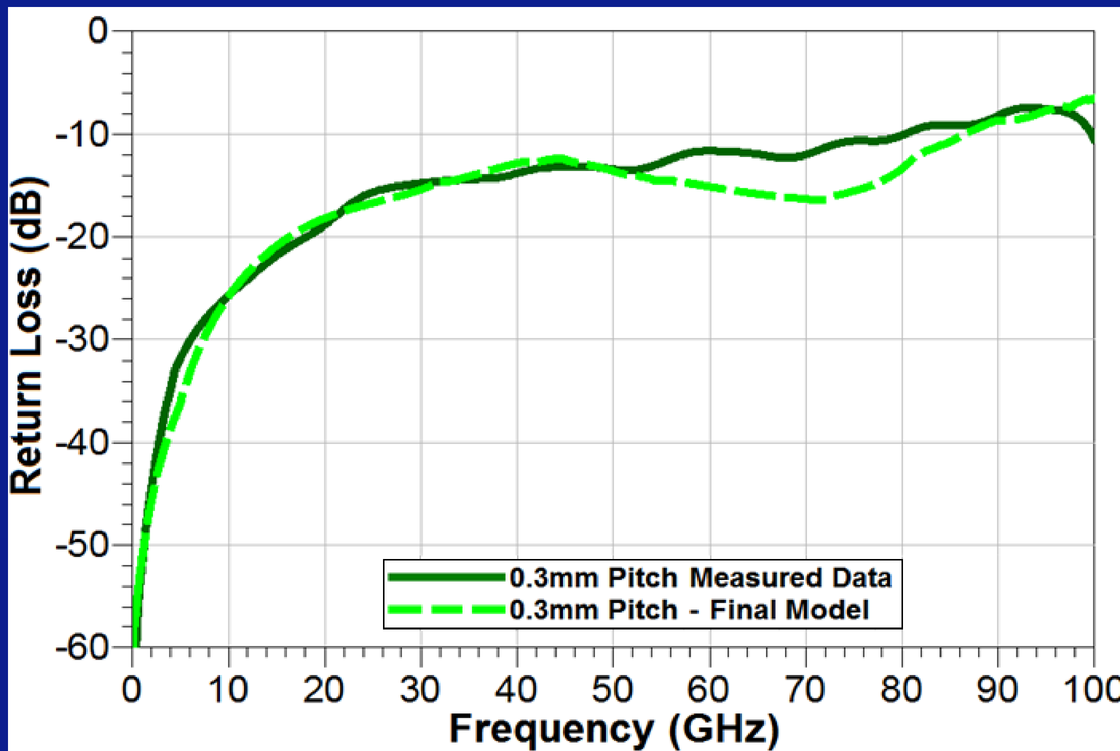
OTA System - Comparison Of Contactors – S_{21}



OTA System – Contactor Measured vs. Modeled Data – S_{11}



From TestConX 2019

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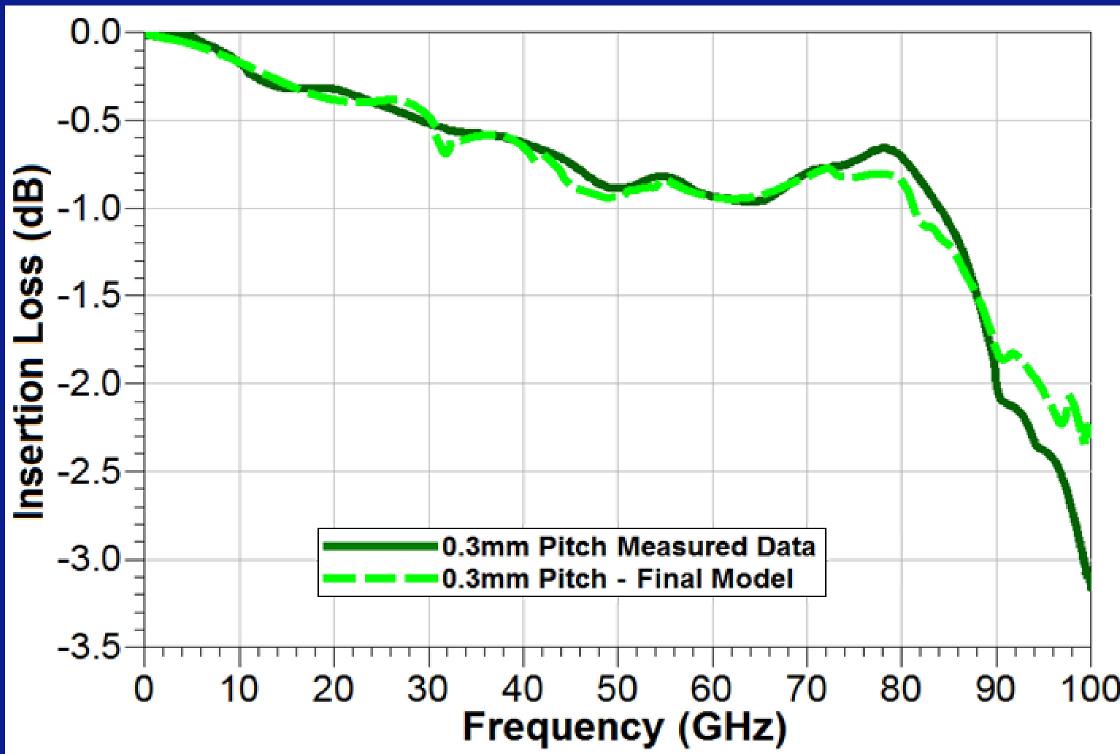
OTA System – Contactor Measured vs. Modeled Data – S_{21}



From TestConX 2019

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OTA Definition of Near and Far Field

FORMULA:

$$\lambda = \frac{\text{Speed of Light}}{\text{Frequency}}$$

$$\text{Far Field} \geq \frac{2D^2}{\lambda}$$

$$\text{Radiating Near Field (Fresnel Region)} \leq \frac{2D^2}{\lambda}$$

$$\text{Reactive Near Field} \leq 0.62 \times \sqrt{\frac{D^3}{\lambda}}$$

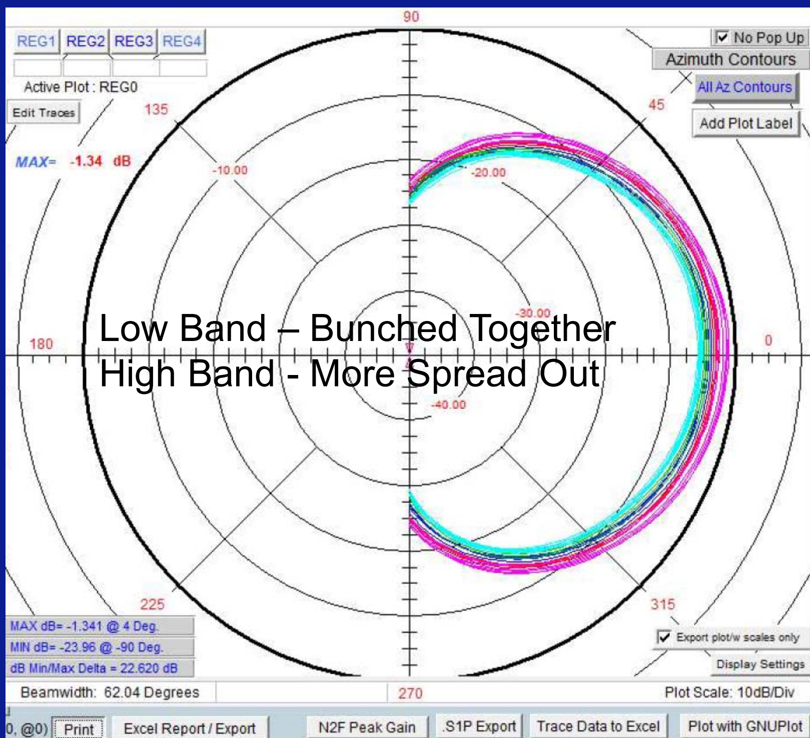
D = Antenna Length or Diameter

Frequency	Antenna Length (mm)	Wavelegth	Far Field	Reactive Near Field
5 GHz	20.7	60.00	14.24	7.52
10 GHz	10.2	30.00	6.94	3.69
28 GHz	3.6	10.71	2.39	1.28
39 GHz	2.5	7.69	1.68	0.90
81 GHz	1.2	3.70	0.73	0.40

Fresnel region is region between near field and far field

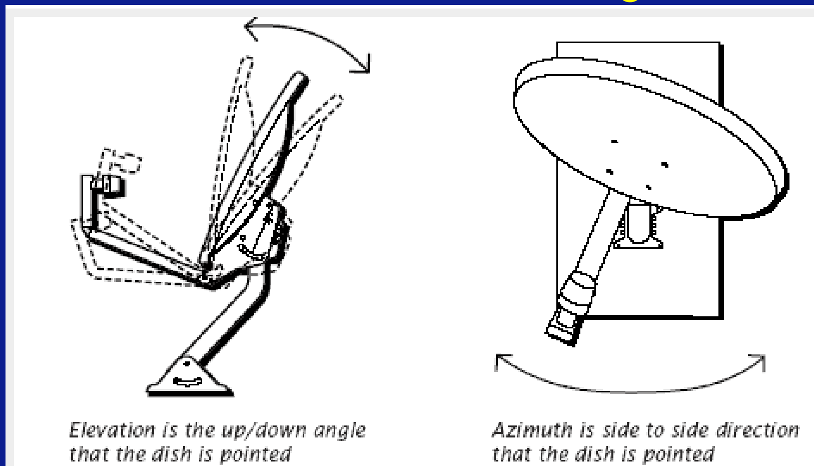
Antenna Patch Length Assuming $\varepsilon_r = 3.0$, 10 mil Substrate

Antenna in Test Chamber – Distance = 75mm



Testing from 27.7 to 28.2 GHz

Azimuth tested -90 to +90 Degrees
Elevation tested -70 to +70 Degrees



Azimuth and elevation infographic via Sat-Sales.com

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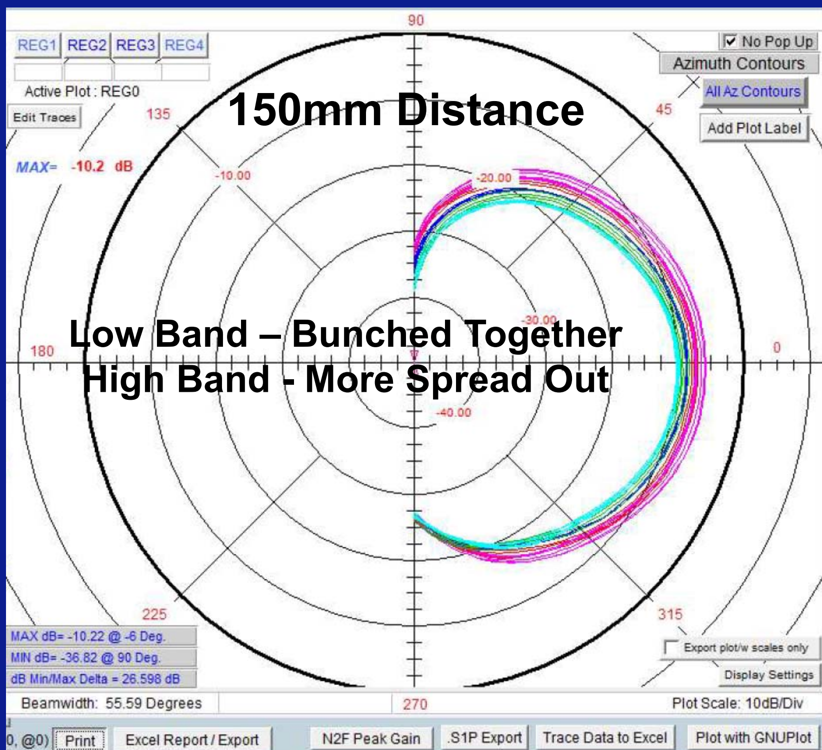
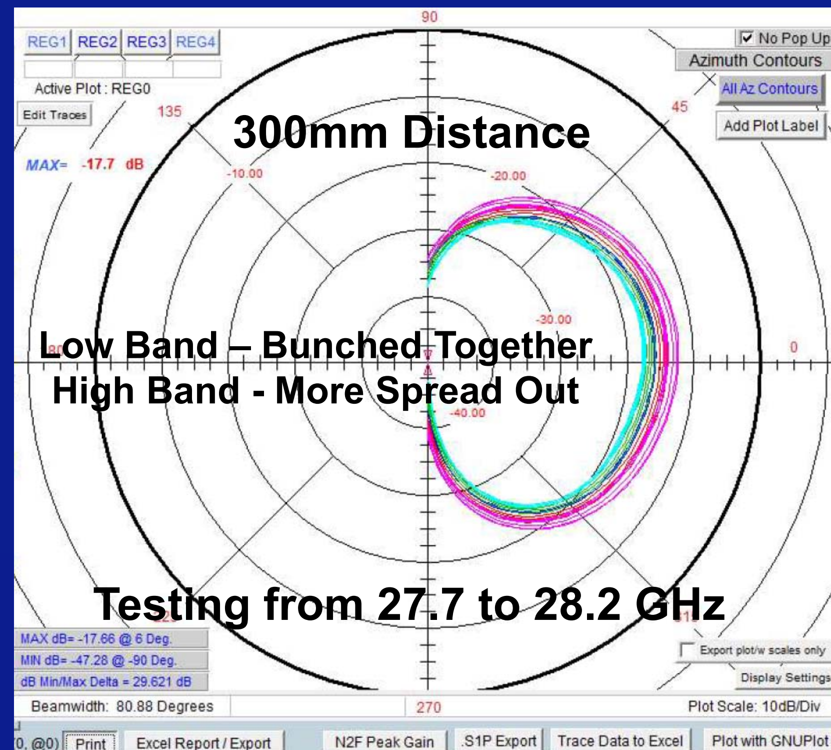
Antenna in Test Chamber – Distance - Azimuth





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List of OTA Applications and Frequencies

- 5G Applications (2, 5,10, 28, 37, 39 and 46 GHz)
- Radios (60 GHz)
- Industrial Robots (2.4, 5, 5.8 GHz)
- Security Cameras
- Drones (2.4, 5.8 GHz)
- Internet of Things (IOT)
- MMW Cellular Devices (30 to 300 GHz)
- Automobiles (77 – 81 GHz)

Higher frequencies means more line of sight applications and shorter distances – Higher Data Rate -> More Data Transfer

OTA Frequencies Affect Antenna Size

- Frequency of operation affects antenna size
- Higher dielectric materials can help shrink antenna size
- Using thinner substrate has minimal affect on antenna size
  - Examples

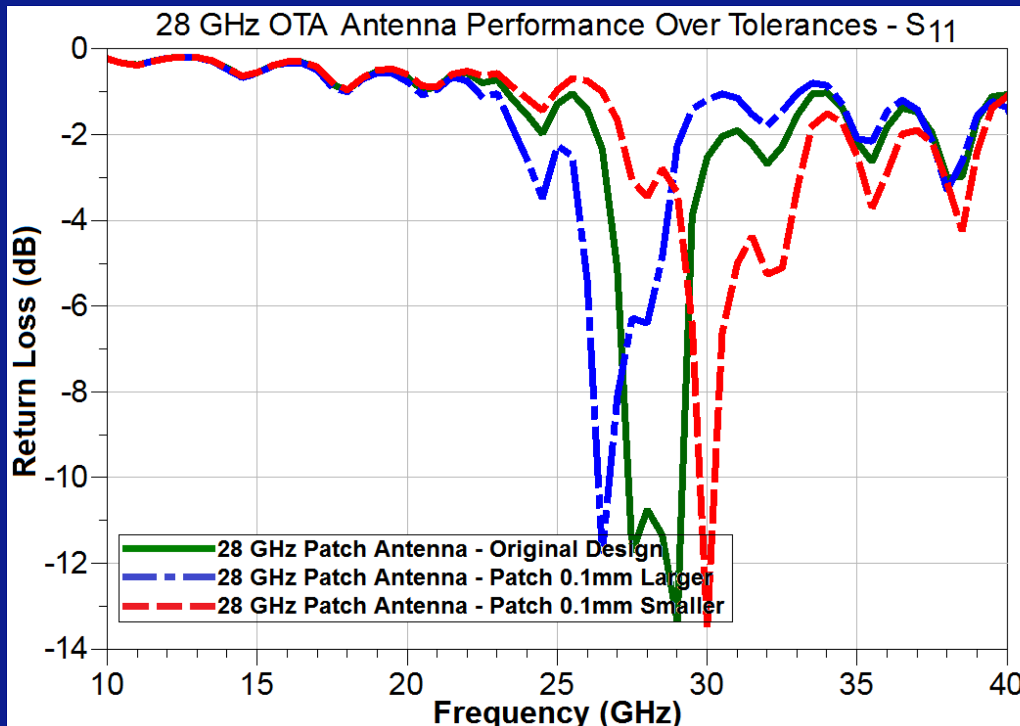
Er = 3.0
Freq. = 5 GHz
Patch = 17x17mm
Sub. Height = 0.254mm

Er = 9.8
Freq = 6 GHz
Patch = 9.3x9.3mm
Sub. Height = 0.254mm

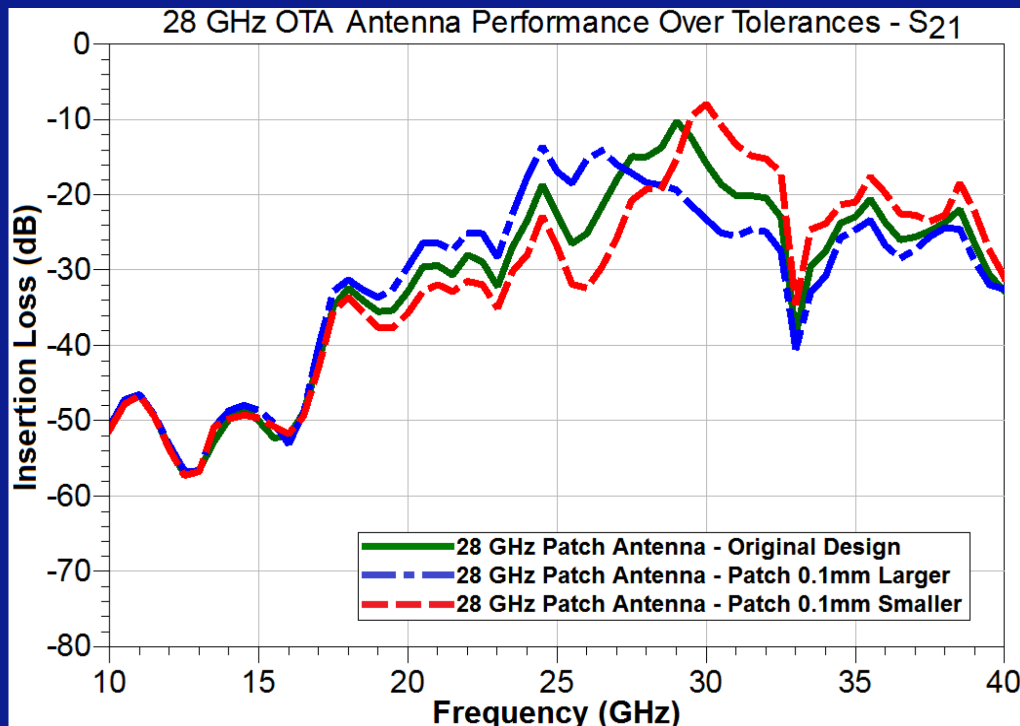
Er = 3.0
Freq = 39 GHz
Patch = 2.06x1.97mm
Sub. Height = 0.254mm

Er = 3.0
Freq = 39.5 GHz
Patch = 2.06x1.97mm
Sub. Height = 0.127mm (Need to adjust trace and feed width to get better results)

OTA Tolerance Effects - Antenna Fabrication (Original Patch vs. +/- 0.1mm Variation) – S_{11}



OTA Tolerance Effects - Antenna Fabrication (Original Patch vs. +/- 0.1mm Variation) – S_{21}



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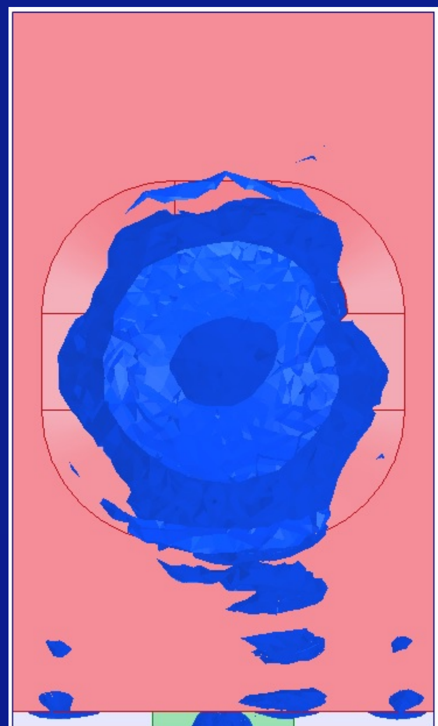
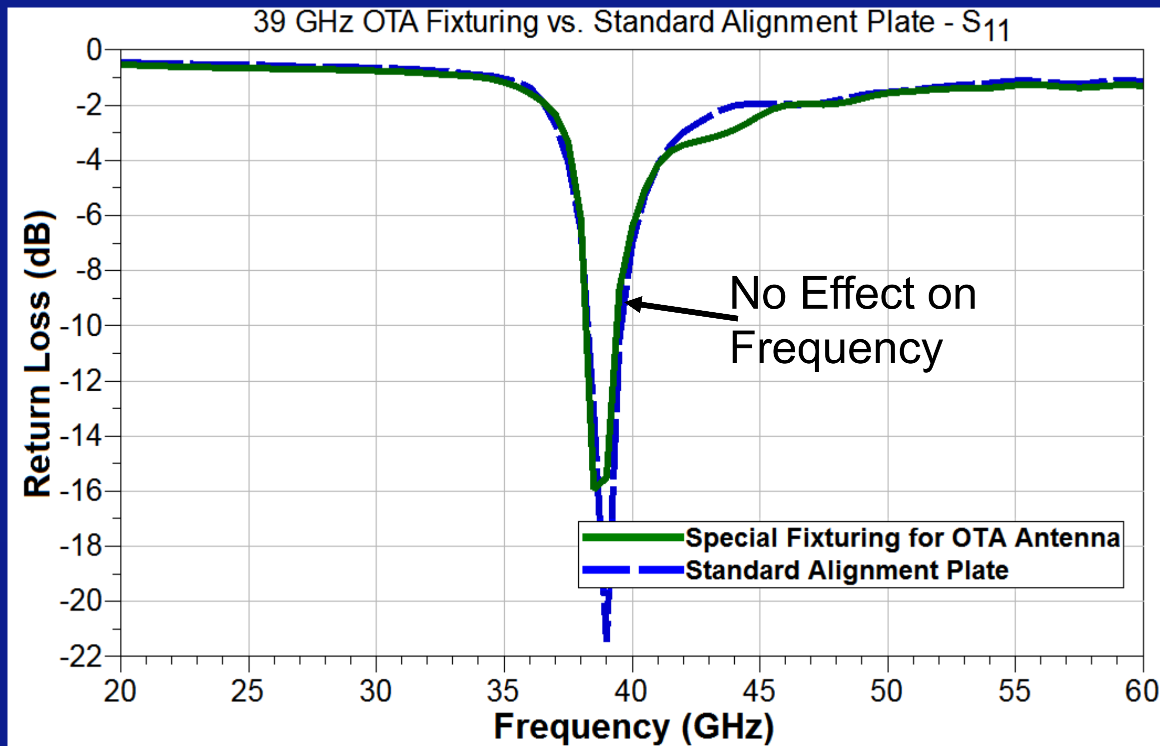
OTA Fixturing Effects - Custom Fixturing – E-Fields



- Device modeled in fixture used single 39 GHz antenna
- System was modeled using HFSS software
- Picture is top view showing E-Field plot of radiated antenna in holding fixture
- Full HFSS model was two identical fixtures facing each other
- Input to antenna in package was 50 ohm trace

OTA Fixturing Effects – S_{11}



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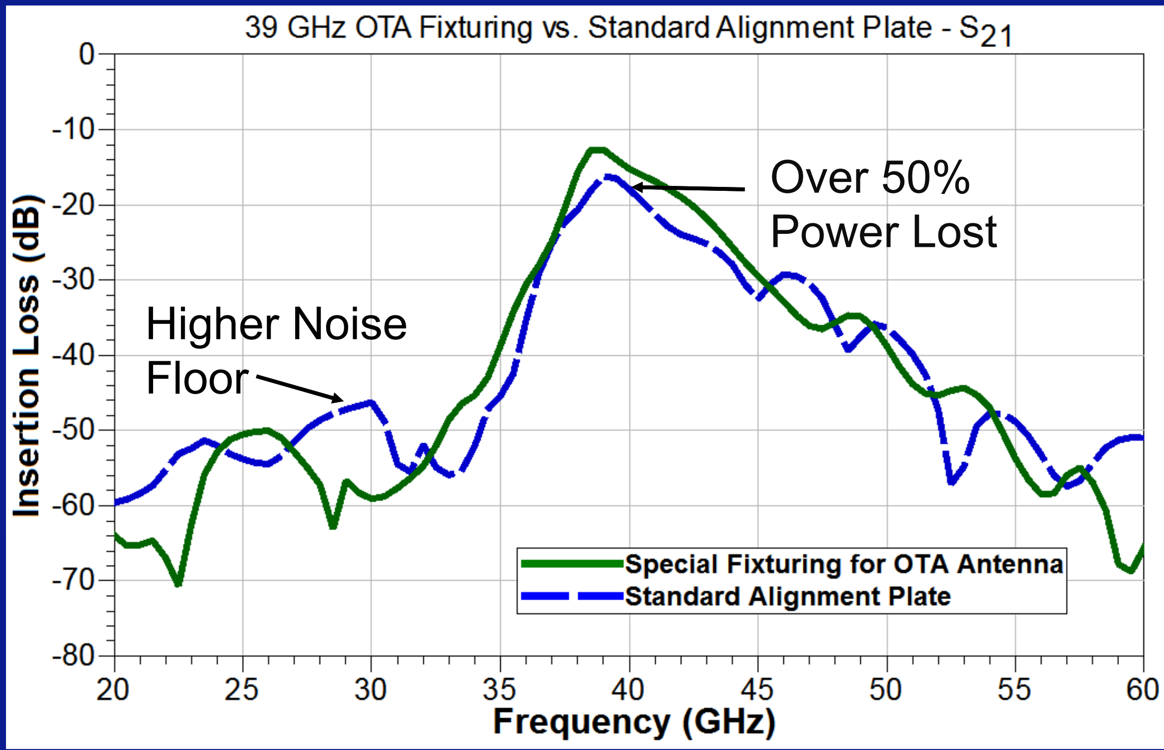

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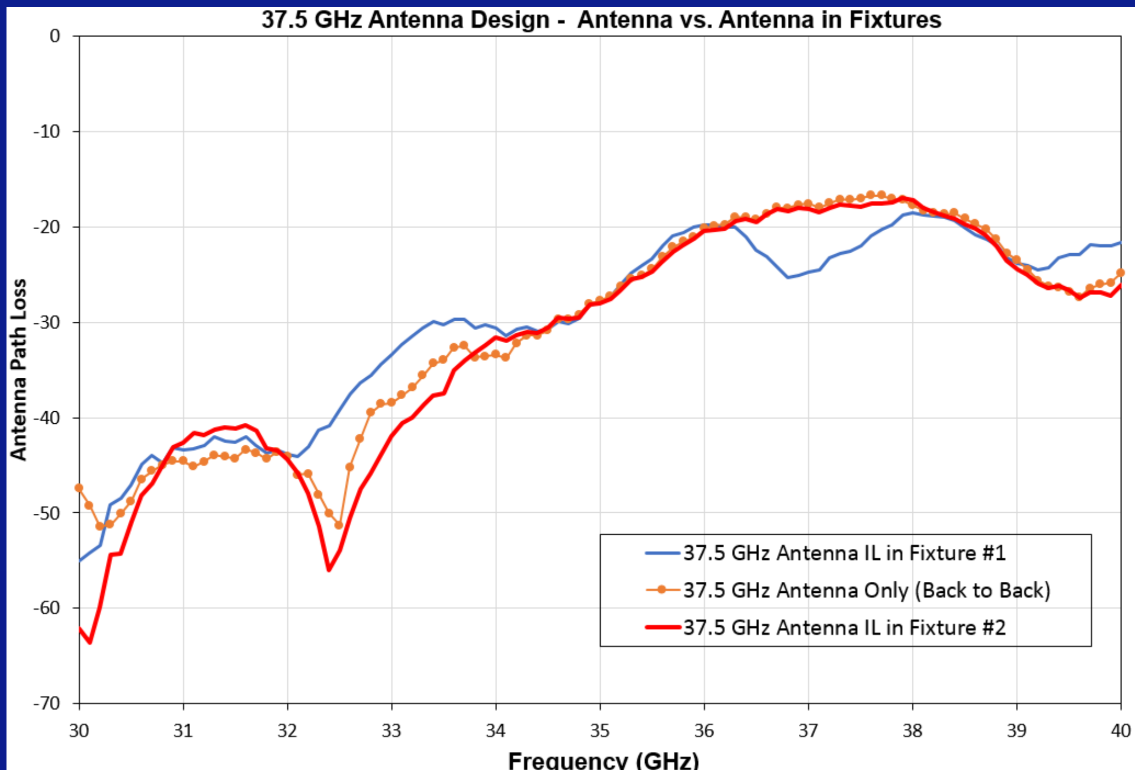
37.5 GHz Antenna vs. Different Antenna Fixturing – S_{21}



- Receive and Transmit Antennae were similar and used for all tests
- Distance between antennae were same
- All cabling calibrated out – Just Fixture and Antennae data
- Antennae tested back-to-back
- All data is measured data with 40 GHz VNA

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Types of OTA Test and Test Equipment

- **Near and Far Field testing**
- **Antenna Beam forming and 3D Antenna Patterns**
- **Antenna Gain, Efficiency, and Directivity**
- **Effective Isotropic Radiated Power (EIRP)**
- **Total Radiated Power (TRP)**
- **Total Isotropic Sensitivity (TIS)**
- **Testing over Temperature**

Test Equipment

- Anechoic Chamber – enclosed for temperature testing
- Network Analyzers – multiple channels

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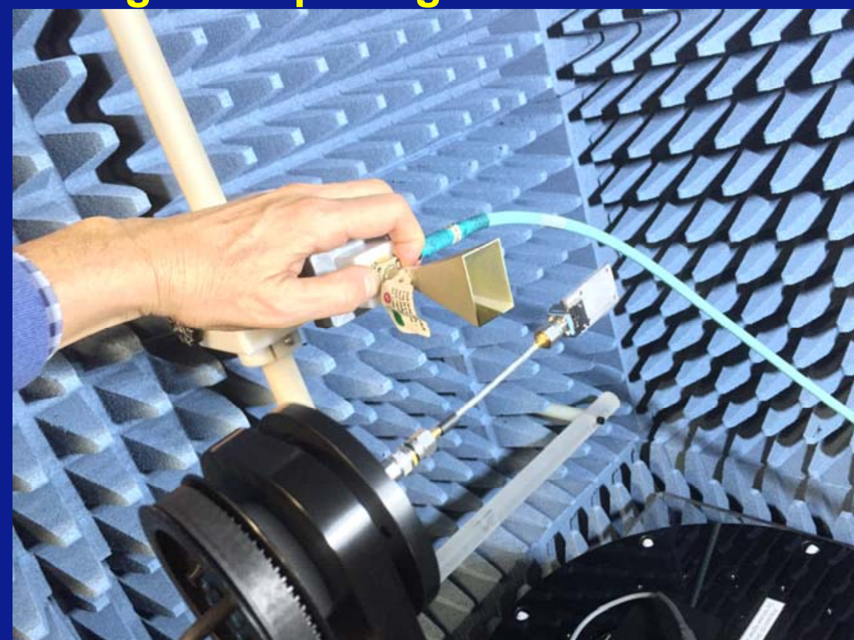
Types of OTA Systems – Broadband

- **Broadband – Waveguide & Horn Antennas**
  - **Bandwidth dependent on Waveguide Opening**
  - **Potentially more noise**
  - **Large in size**
  - **Expensive**



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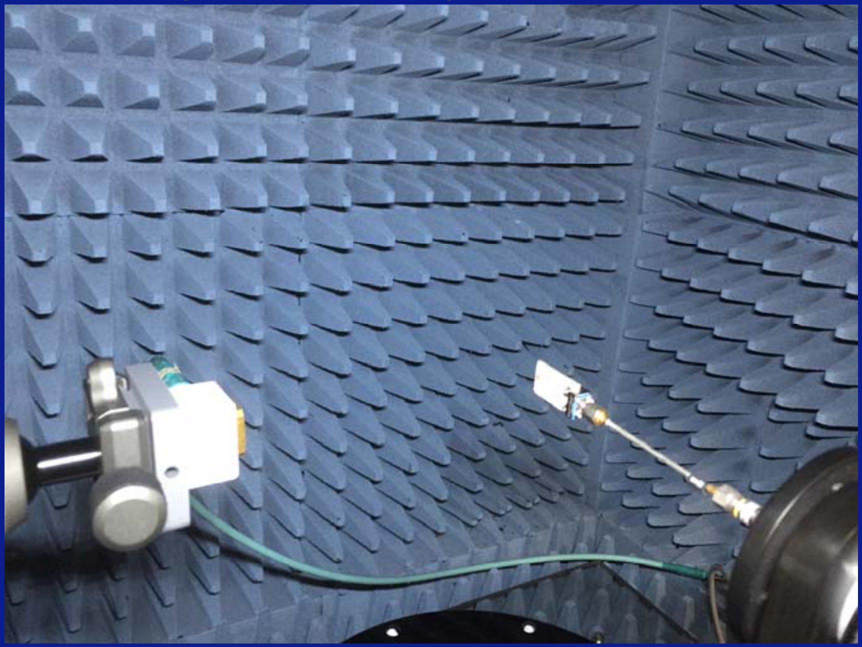
Types of OTA Systems – Narrowband

- **Narrowband – Such as Patch, dipole, etc.**
  - **Very narrow test bandwidth at a single frequency**
  - **Antenna acts as filter**
  - **Potentially small in size**
  - **Inexpensive**



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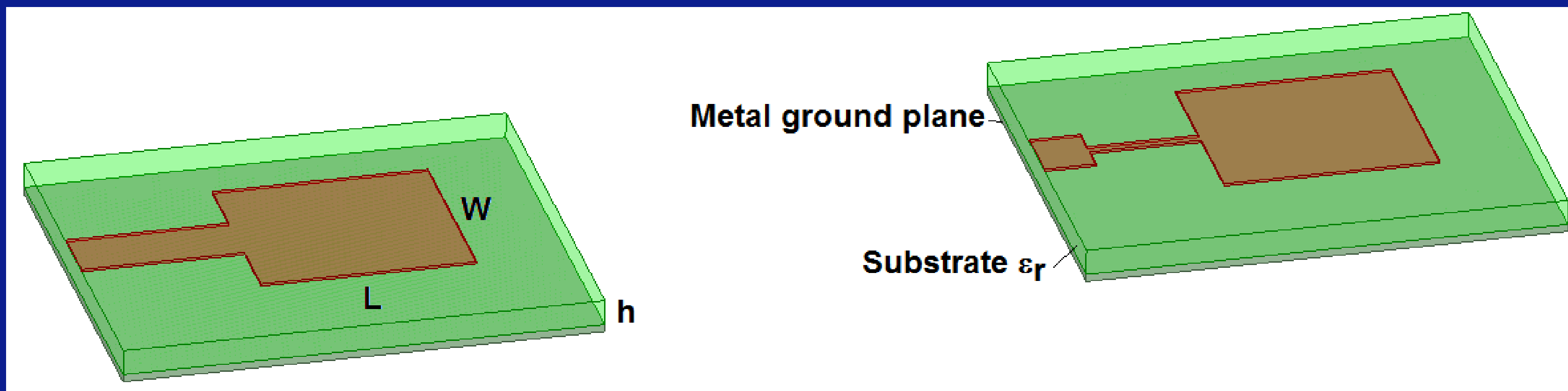
Design Equations For Patch Antenna Design



- Where center Frequency can be approximated by: $f_r = \frac{1}{2L_{eff}\sqrt{\mu_o \varepsilon_o \varepsilon_{reff}}}$
- Where the effective length is defined by: $L_{eff} = L + \Delta L$
- Where L is length of patch and ΔL is:

$$\Delta L = (h)(0.412)\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

Where W is width of patch and h is thickness of substrate

From Practical Antenna Design for Wireless Products by Henry Lau

Design Equations for Effective Dielectric Constant

The following formula can be used to calculate the effective dielectric constant.

If $\frac{w}{h} < 1$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \left(\frac{\varepsilon_r - 1}{2}\right)\left[\frac{1}{\sqrt{\left(1 + \frac{12h}{e}\right)}}\right] + 0.04\left(1 - \frac{w}{h}\right)^2$$

If $\frac{w}{h} >= 1$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \left(\frac{\varepsilon_r - 1}{2}\right)\left[\frac{1}{\sqrt{\left(1 + \frac{12h}{e}\right)}}\right]$$

where,

ε_{eff} = Effective dielectric constant

ε_r = dielectric constant of the material

w = width of the trace

h = separation of the trace from ground plane

e = trace thickness

Trace Thickness = For ½ Oz copper trace thickness is 0.7 mils (0.01778mm) + plating

From Chapter 4 of Signal Integrity for PCB Designers by Vikas Shukla

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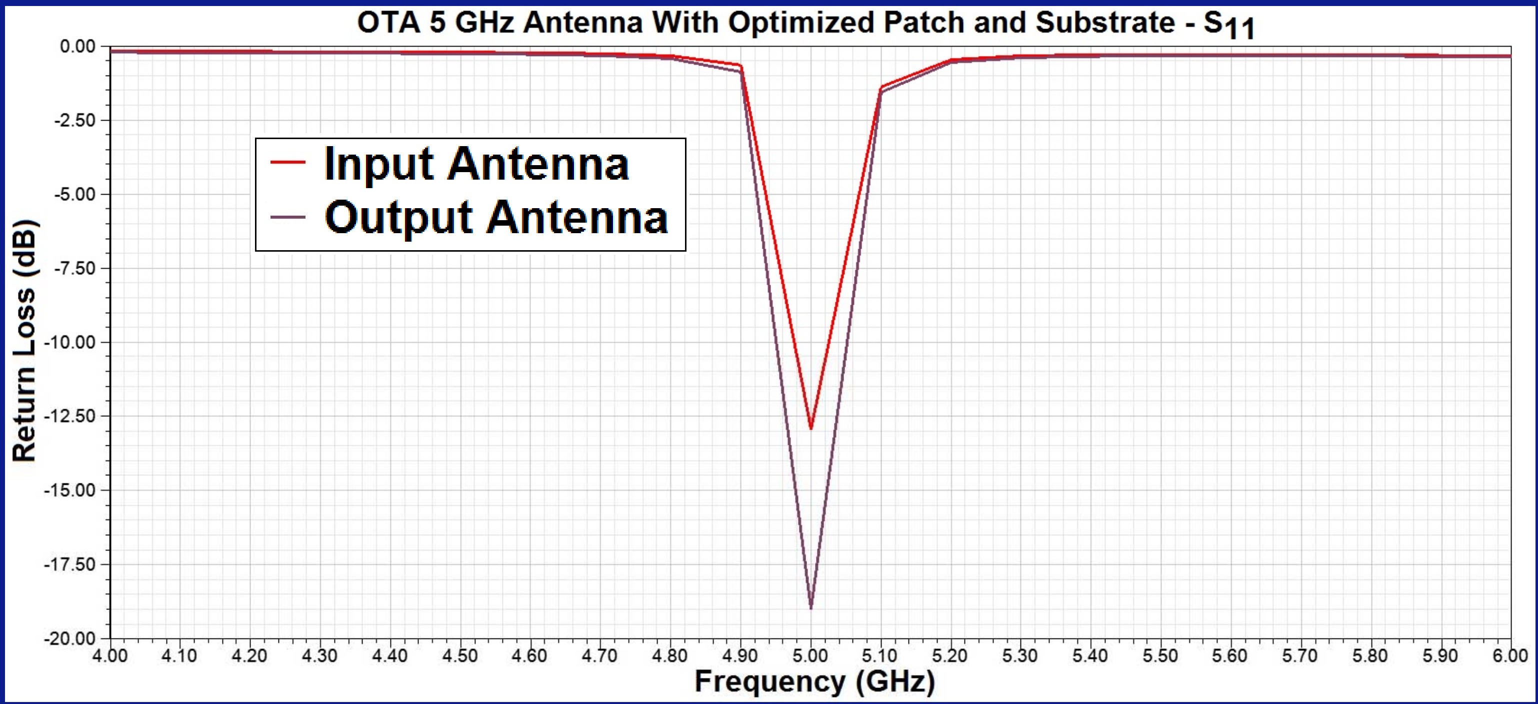
OTA 5 GHz Antenna Modeled and Optimized in HFSS – S_{11}



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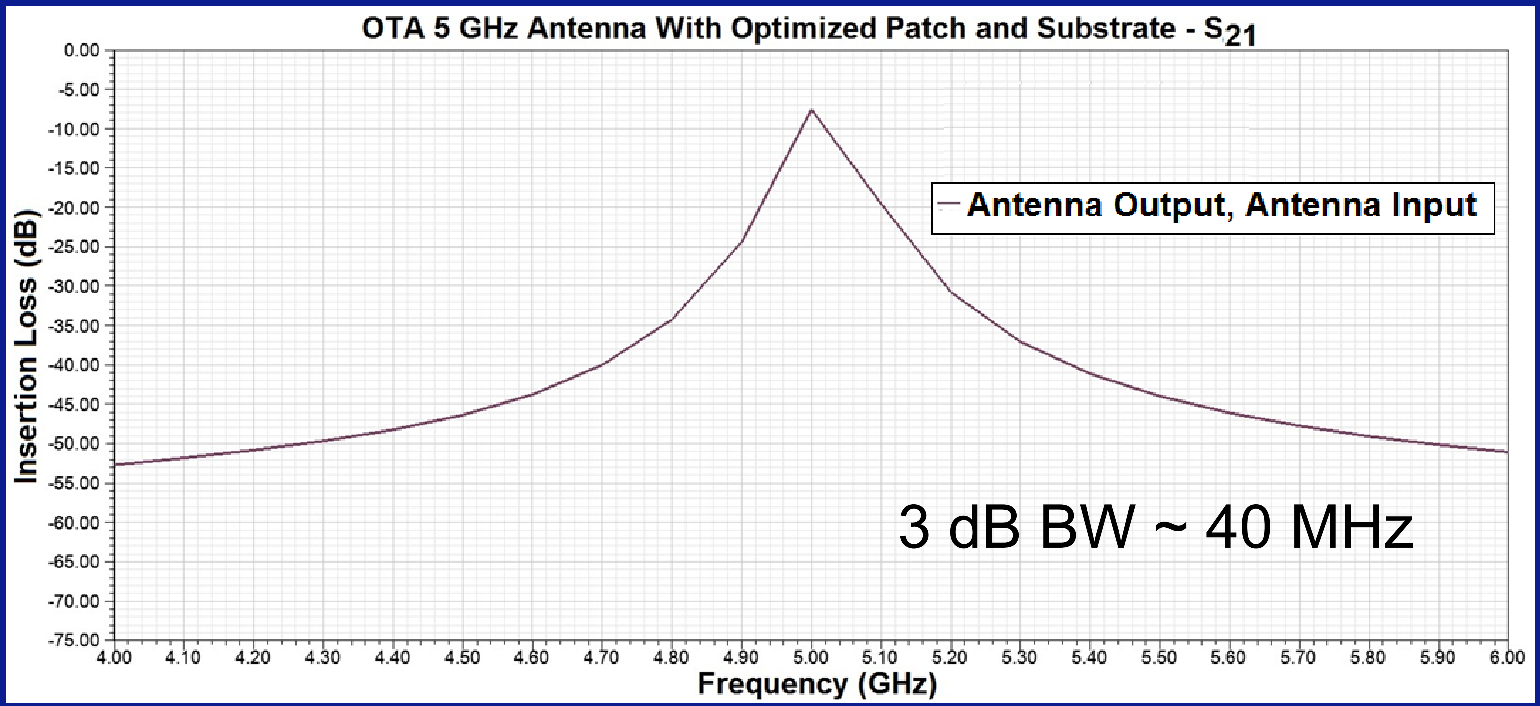
OTA 5 GHz Antenna Modeled and Optimized in HFSS – S_{21}



Conclusions

- OTA devices require more complex contactors and test solutions
- OTA devices run at higher frequencies to reduce size of antenna
- OTA antennas are susceptible to tolerances – leading to more simulation
- Fixturing to hold AIP devices will be custom – leading to more simulation
- There are a lot of applications for OTA devices with more coming
- OTA will require more and different types of testing – potentially leading to longer test times
- Reflections from fixturing add ripple to antenna patterns causing errors
- OTA testing is more complex leading to significant software development