5G mmWave Materials

White Paper

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Applications,Materials and Characterization

Paul Dixon

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5G

Introduction

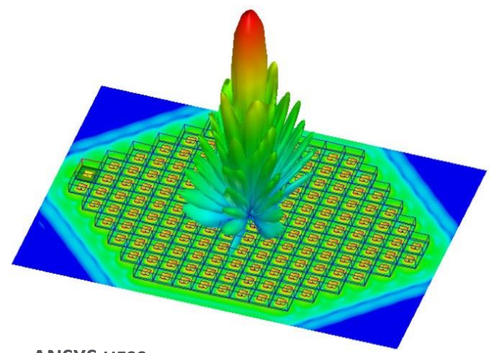
In order to deliver the large increase in wireless data transfer needed for the new 5G wireless standard, spectrum in the millimeter wave range will be needed. There is simply not enough available spectrum in the sub 6GHz range. The millimeter wave range is largely unregulated with wide chunks of available bandwidth making it ideal for data transfer applications.

As in lower frequency applications in the RF/microwave bands, control of electromagnetic interference (EMI) is critical in the mmWave bands. Traditional shielding techniques are less effective due to smaller wavelengths. A gap in a shield that is negligible at 3 GHz becomes large in terms of a wavelength at 30 GHz. While higher tolerance manufacturing techniques can mitigate this somewhat, the use of absorbers for EMI control in the mmWave range is critical.

What can absorbers do at mmWave?

Antenna isolation

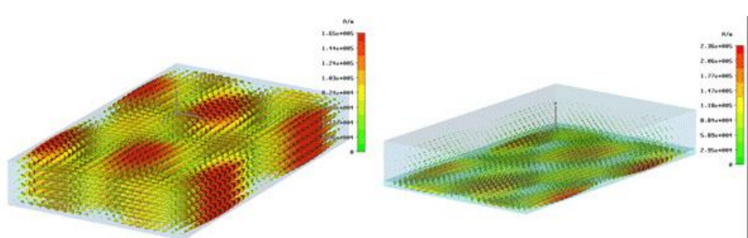
Some 5G systems will use massive MIMO techniques to enable high gain antenna beams and to increase spatial multiplexing. These antennas will consist of arrays of anywhere from 16 to 128 antenna elements that will act as a phased array to steer antenna beams. Since each antenna element will act as both a transmitter and receiver, it is critical to isolate the elements from each other to prevent the (relatively high power) transmitted signal from one element to leak into the receive portion of an adjacent element. This is difficult to do effectively with shielding alone. An absorber material with the correct properties would be ideal to reduce this cross talk and also to eliminate reflections from other parts of the device which could interfere with the desired signal.



ANSYS HFSS

Board Level Shield Cavity Resonance

Board level shields will still be a key part of an EMI mitigation plan at mmWave. However, care must be taken reduce the impact of cavity resonance. Cavity resonance occurs when a conductive enclosure is larger than half a wavelength. Energy can then oscillate (or resonate) inside the cavity, potentially affecting circuit operation inside the cavity and increasing shielding leakage at the cavity resonance frequencies. The existence of a cavity resonance depends on both the frequency and the size of the cavity. At 2 GHz, the shield would need to have a dimension of 7.5cm (half a wavelength) to exhibit a resonance. This is rather large for a shield hence cavity resonance is rarely an issue at these low frequencies. At 30 GHz, however, a shield as small as 5mm could exhibit a resonance.



To maintain the shielding effectiveness of a board level shield that exhibits a cavity resonance, a thin layer of absorber material could be applied inside the shield. The electromagnetic parameters (permittivity, permeability) of absorber material are related to energy storage of the electric and magnetic fields. When added inside a cavity, solving the field equations shows that the energy tends to reside in the high permittivity/permeability material. The energy will resonate inside the absorber where it will be absorbed.

Millimeter wave reflection reduction

In free space, once the mmWave signal has radiated, objects near the antenna can reflect signal which will interfere with the desired transmitted signal. Absorbers can be used to reduce or eliminate these reflections.

Laird millimeter wave materials

Introduction

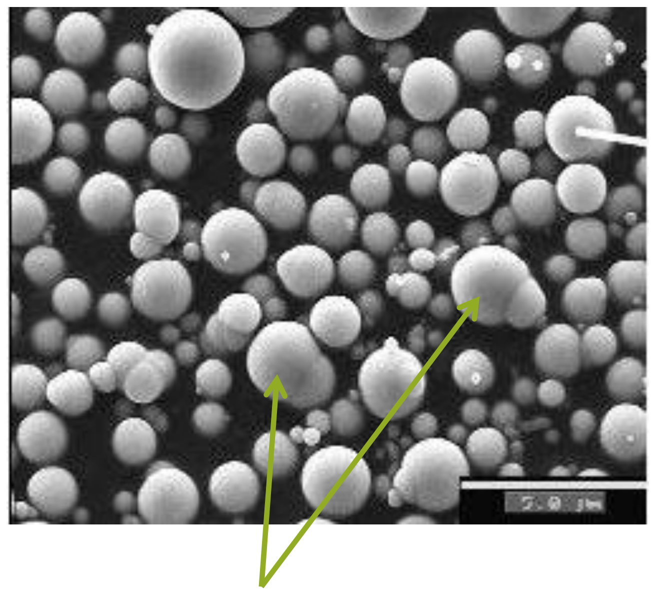
Laird offers a range of absorber materials effective in the mmWave spectrum. Absorbers are available in various forms including polyurethane foams, silicone or urethane elastomers and in a range of thermoset forms intended for injection molding.

Absorbers

Absorbers consist of two general parts, the container material and the filler material. The key to electromagnetic absorption of a material lies almost entirely in the filler material. The container material serves to suspend and hold the filler in place in order to absorb the energy. Absorptive fillers come in two categories, dielectric and magnetic. A dielectric filler absorbs primarily the electric field energy in an electromagnetic wave while a magnetic filler absorbs primarily the magnetic field. The electric field and magnetic field are coupled so that a reduction in one will result in a reduction of the other. The choice of which filler type to use comes down to what type of energy dominates at the absorber's location.

For many applications a magnetically loaded absorber may be desirable. Unfortunately magnetically active filler materials tend to lose their effectiveness above 40 GHz so dielectric fillers are recommended for that frequency range.

The container material is chosen based on its physical properties or the desired size/shape of the final product. A polyurethane foam may be chosen based on cost or low weight. An elastomer may be chosen for material toughness or other environmental properties are desired. A thermoset material may be chosen for a complex shaped part which is best made using injection molding techniques.



Filler particles

Laird mmWave materials

ECCOSORB 5G MeF 1

5G MeF 1 is a magnetically loaded silicone elastomer. It is very tough and has a high service temperature (165C). It is recommended for all mmWave applications below 40 GHz. It has a UL94 V-0 rating. It is available in a range of thicknesses 0.25mm, 0.5mm and 1.0mm. It can be made with an integral pressure sensitive adhesive.

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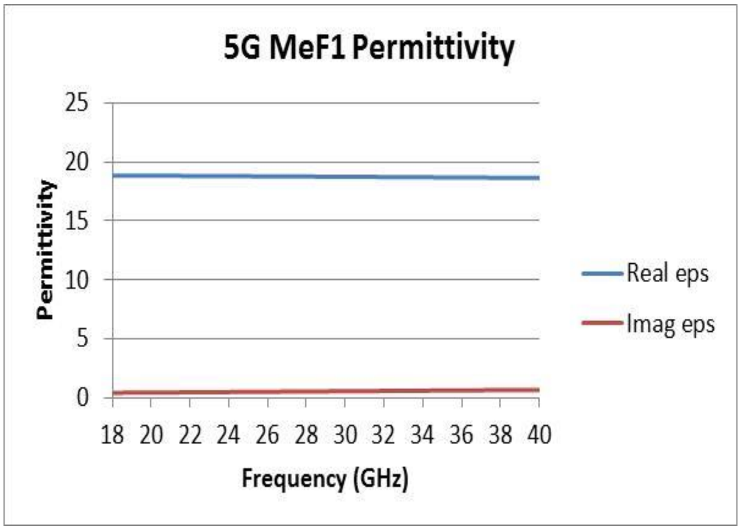
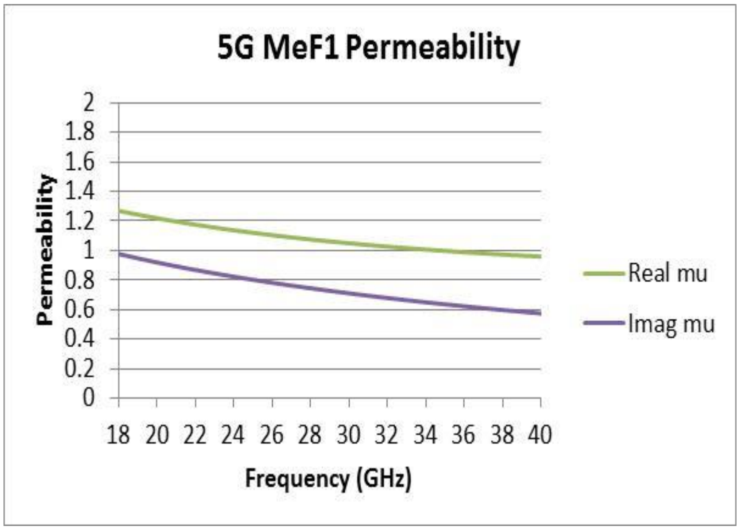
SPECIFICATIONS

TYPICAL PROPERTIES	FEATURES	
Color	Dark grey	
Density	4.4	
Service temperature	-55 + 165°c	
Frequency Range	18-40GHz	
Attenuation		
18 Ghz	60 dB/cm	
32 Ghz	82 dB/cm	
40 Ghz	97 dB/cm	
Tensile Strenght	>4.5 Mpa	
Hardness	65 shores A	
Outgassing	TML 0.48%/0.29CVCM%	ASTM E595-07
Flammability rating	UL 94 V0	

Data for design engineer guidance only. Observed performance varies in application.

Engineers are reminded to test the material in application.





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ECCOSORB 5G HiF 1

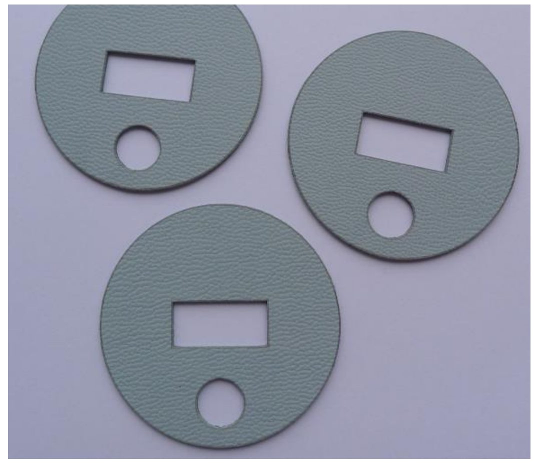
ECCOSORB 5G HiF1 is a dielectrically loaded elastomer with excellent absorption properties in the mmWave range. It is flexible with a high service temperature (165C). It has a UL94 V-0 fire retardancy rating.

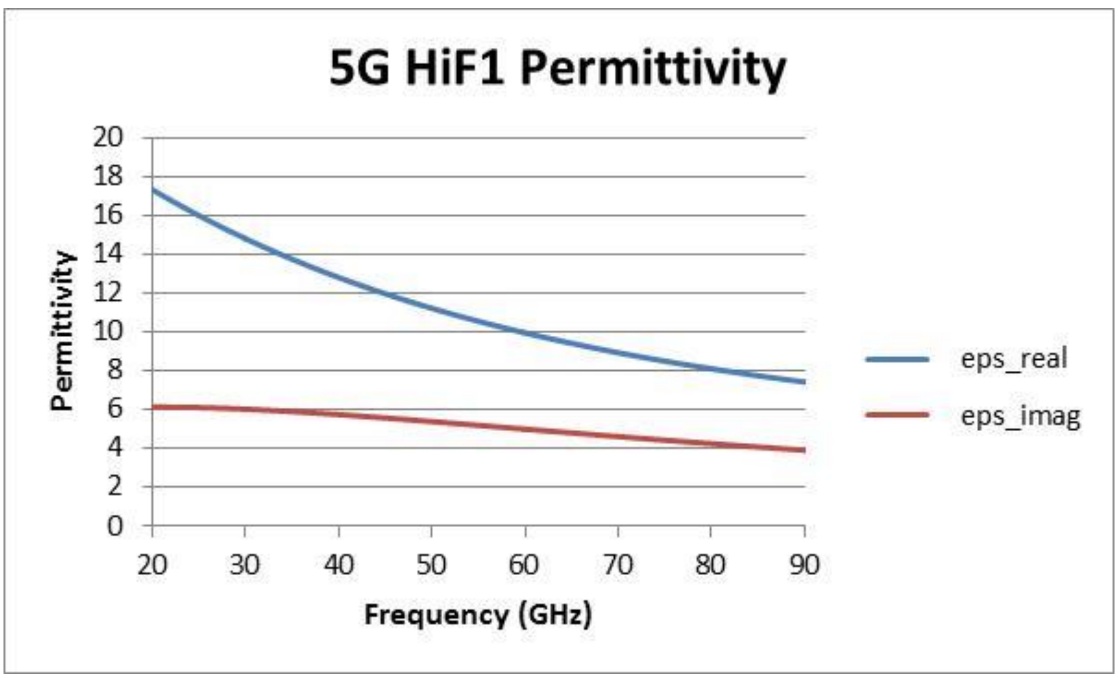
SPECIFICATIONS

TYPICAL PROPERTIES	FEATURES	
Color	Light grey	
Density	1 Kg/m2	0.5 mm
Service temperature	-55 + 165°c	
Frequency Range	>40Ghz	
Attenuation		
40 Ghz	55 dB/cm	
60 Ghz	75 dB/cm	
80 Ghz	90 dB/cm	
Tensile Strenght	>4 Mpa	
Hardness	70 shores A	
Flammability rating	UL V0 pending	

Data for design engineer guidance only. Observed performance varies in application.

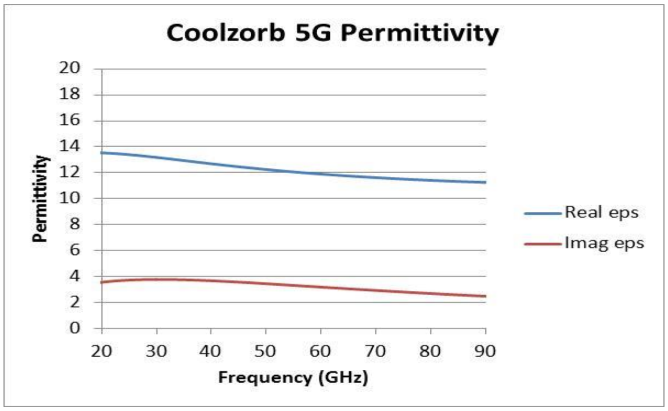
Engineers are reminded to test the material in application.

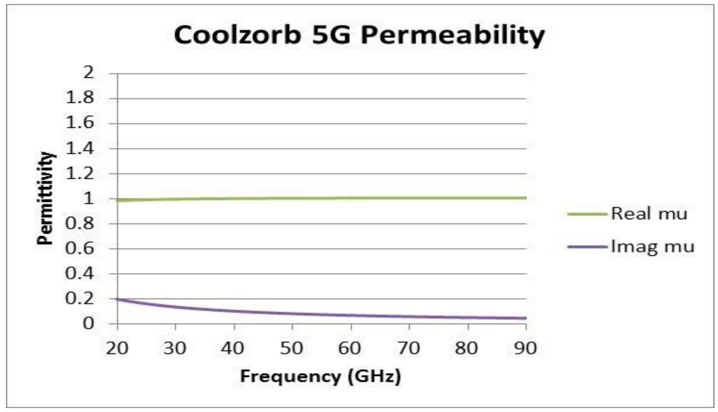




CoolZorb 5G

CoolZorb 5G is a hybrid material exhibiting both excellent thermal conductivity characteristics and electromagnetically absorbent properties in the mmWave spectrum.





FlexK-LoK 5G

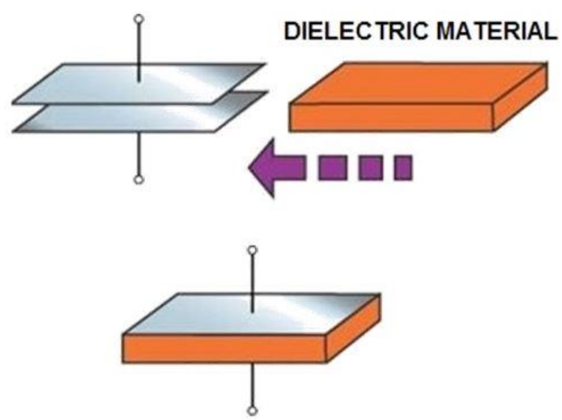
In many circuit designs, the best result is seen when components can be spaced a prescribed distance from each other. Ideally the interposer material would be air but often inclusion of posts to keep the components separate is not feasible. In these cases a thin sheet of material can be employed. This sheet would provide mechanical support and have a minimal effect on electromagnetic performance. Ideally the dielectric constant would be equal to 1. Many foam materials can approach a dk of 1 but it is often difficult to manufacture foam at the thicknesses needed in designs. Also, foam can often not handle the high temperatures seen in some electronic designs.

In addition, if the spacer material is between two conductive planes, the inclusion of a dielectric will increase the capacitance of those planes, often resulting in unacceptable coupling or other effects. The capacitance is directly proportional to the dielectric constant.

$$C = \epsilon_r \frac{A}{4\pi d}$$

Where A is the area of the capacitor, d is the separation and ϵ_r is the permittivity (or dielectric constant). A high dielectric constant will increase the capacitance and the coupling between the two conductors.

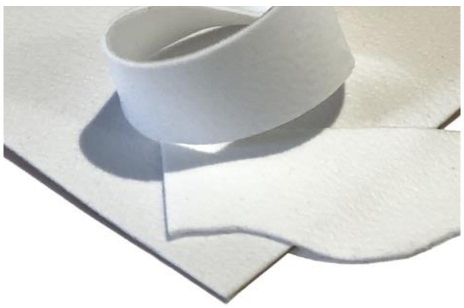
The drive towards miniaturization and complexity in today's systems is pushing elements ever closer together, potentially exacerbating capacitive coupling.



FlexK-LoK 5G is a soft (Shore A=45) flexible silicone material with a low dielectric constant (dk=1.7). Its dielectric constant is significantly lower than comparable soft materials on the market.

FlexK-LoK 5G is available in thin sheets with an integral pressure sensitive adhesive for easy application.

FlexK-LoK 5G – Flexible Dielectric Solution



- Low Loss and Low K Dielectrics
- Soft and Flexible
- Easily die cut
- Optional pressure sensitive adhesive

Material	Dielectric Constant κ
Air (dry)	1.000 59
Bakelite	4.9
Fused quartz	3.78
Neoprene rubber	6.7
Nylon	3.4
Paper	3.7
Polystyrene	2.56
Polyvinyl chloride	3.4
Porcelain	6
Pyrex glass	5.6
Silicone oil	2.5
Strontium titanate	233
Teflon	2.1
Vacuum	1.000 00
Water	80

SPECIFICATIONS

TYPICAL PROPERTIES	DATA
Thickness Range (mm +/- 15%)	0.25 – 1.0
Color	White
Dielectric Constant	1.7 +/- 5%
Dissipation Factor @ 1KHz	0.002
Dielectric Strength	102 V/mil (4 KV/mm)
Density	0.55g/cc
Elongation	10%
Tensile Strength	135 PSI minimum
Deflection	15% @ 100 PSI
Compression Set 23C, 22H / 100C, 70H	10% / 30%
Thermal Conductivity	0.11 W/mK
Temperature Range	-70°C to 177°C
Water Absorption	1.1 (% gain in 24h @ 70°F)
Outgassing ASTM E595-15	0.84% TML, 0.11% CVCM
RoHS / REACH (EU Regulation)	Compliant
Effective Frequency Range	60 Hz to 10 GHz

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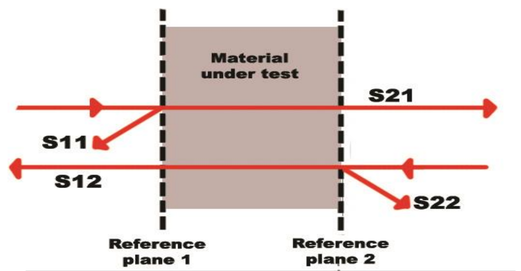
Laird Millimeter Wave Measurement Capabilities

Introduction

With 5G there is increasing interest in applications in the millimeter wave spectrum. Generally, millimeter waves are defined as frequencies above 18 GHz. As the frequency increases the wavelength will decrease, increasing the potential error in measuring and characterizing material properties.

As frequencies increase, there will be a greater need for absorber material to achieve EMI/EMC goals. Accurate parameter measurement is key to characterizing material properties for use in electromagnetic modeling software.

Parameter Measurement

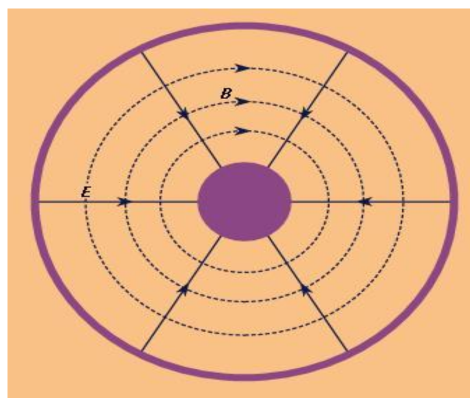


Full parameter characterization requires accurate measurement of reflection (S11)

Full characterization of absorber material depends on accurate measurement of the permittivity and permeability as a function of frequency. Permittivity (ϵ) is a measure of the material's response to the electric field. Permeability (μ) is a measure of the material's response to a magnetic field. Knowledge of ϵ and μ enables accurate prediction of absorber performance in electromagnetic modeling.

Permittivity and permeability are complex numbers. The real portion of each relates to the amount of electric/magnetic energy storage and wavelength compression in the material. The imaginary portion of each relates to the amount of electric/magnetic loss in the material.

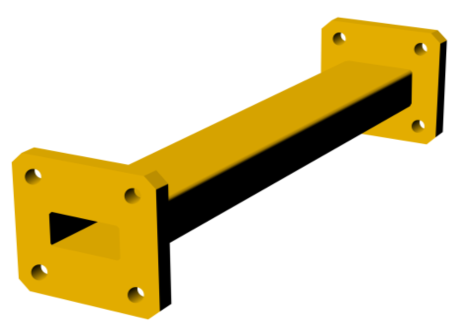
In order to measure the complex permittivity and permeability of absorber material, The reflection coefficient (S11) and transmission coefficient (S21) of a sample of known thickness must be measured. These coefficients are themselves complex and represent the magnitude and the phase of reflection and transmission measurements.



E and H field lines inside coaxial

To allow precise measurements of magnitude and phase, parameters are usually measured in 'closed' systems such as coaxial lines or waveguides. This enables controlled incidence angles of the energy upon the material and in the case of waveguides, known electromagnetic properties of the energy hitting the material.

A primary difficulty in measuring parameters is sample preparation. In the RF/microwave frequency band, parameter testing is straightforward using waveguides and coaxial lines. A 1" diameter line can be used up to 6 GHz. A 7mm diameter coaxial line can be used up to 18 GHz. While waveguides can be rather large at frequencies below 6 GHz or so, rectangular samples are relatively easy to fabricate compared to coaxial samples.



Microwave waveguide

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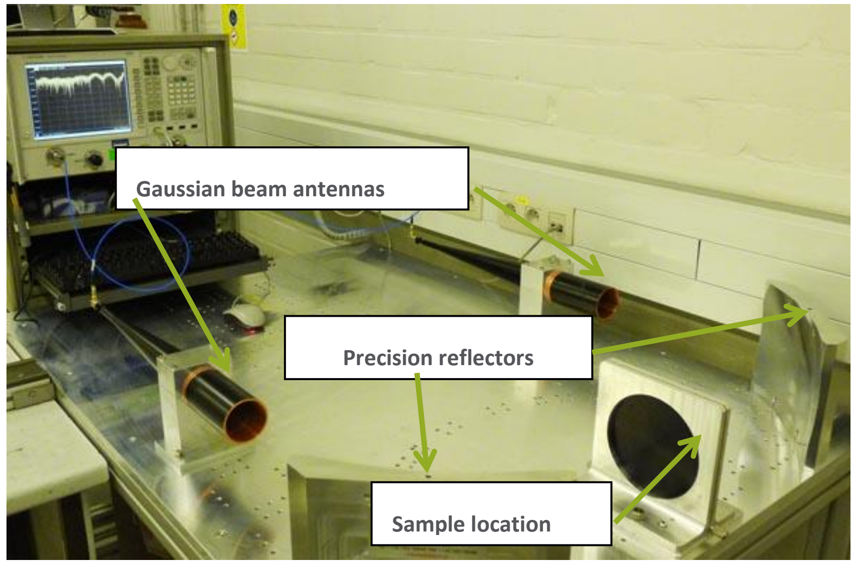


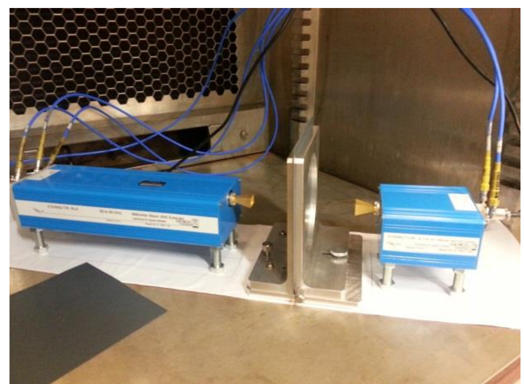
In the millimeter wave band, machining samples for coax or waveguide becomes progressively more difficult as the frequency increases. A 7mm line will begin to see multimode affects at 18 GHz. A 3.5 cm line will see multimode affects at about 36 GHz. Coaxial samples are too small to machine accurately at these frequencies so waveguides must be used but waveguides also have size limitations. A waveguide to cover the 18-26.5 GHz band is 10.7mm x 4.3mm. To cover 26.5-40 GHz reduces the needed sample size to 7.1mm x 3.6mm. Here the issue becomes not only the small sample size but precision calibration standards are more difficult to fabricate.

Beyond 40 GHz, sample size and difficulty in calibration standards precludes coax/waveguide parameter measurements. Free space techniques must be used.

Quasi-optical test bench

In free space it is difficult to guarantee that the signal impinging on the sample is a plane wave. At lab distances, the signal from most antennas is still fairly spherical which will greatly add to measurement error. At Laird we use a quasi-optical bench developed by Thomas Keating. Gaussian beam horn antennas are used. Precision machined reflectors are used to generate a plane wave at the sample location. The quasi-optical bench enables precision full parameter measurement and characterization up to 67 GHz.

Beyond 75 GHz, frequency extension units are used to characterize material as high as 90 GHz.



Frequency extension units to expand capability to 90 GHz

Conclusion

Laird's ability to measure and characterize material parameters of absorber in the millimeter wave band up to 90 GHz is unparalleled in the industry. Accurate material parameters measurements are essential to ensuring excellent absorber performance in demanding high frequency applications.