CTG's SP324 RF Spot Probes – Lab Quality Materials Measurements in a Small Package

Compass Technology Group
Alpharetta, GA USA
info@compasstech.com

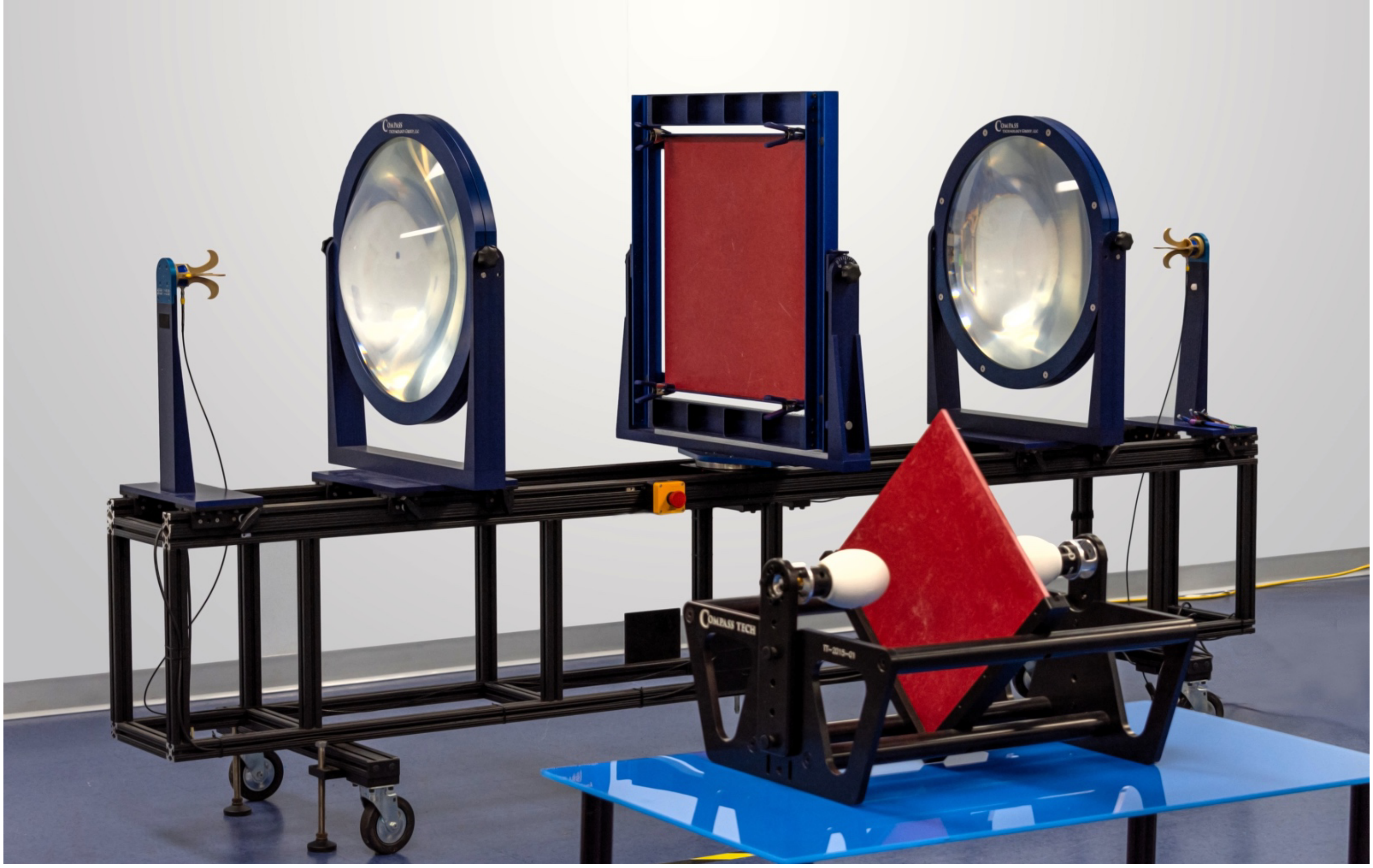

Figure 1. Laboratory Focused Beam (background) and Table Top Probe System (foreground)

***Abstract*—In a laboratory, microwave characterization of materials is often accomplished with a free-space focused beam, which uses either lenses or shaped reflectors to focus RF energy onto a specimen. For the 2-20 GHz band, 60 cm diameter lenses can be spaced 77 cm from the specimen to form a Gaussian beam, simulating a plane-wave at the specimen location. An alternative method uses dielectrically loaded antennas near a specimen, which is a more compact and lower cost fixture. That said, the probe method has the disadvantage of slightly reduced accuracy. This paper directly compares a laboratory focused beam system to an alternative measurement system based on recently developed RF spot probes. The spot probes are specially designed antennas encapsulated in a dielectric and optimized to provide a small illumination spot 7 to 8 cm in front of the probe. The resulting comparisons show that the spot probe method can be 'almost' as good as the higher fidelity, laboratory focused beam method.**

I. INTRODUCTION: FREE SPACE MEASUREMENTS

Free space microwave measurement of dielectric or magnetic materials transmits RF energy onto a specimen to calculate intrinsic permittivity and permeability from the transmission and/or reflection. A popular implementation of this method is the focused beam [1][2], which combines feed antennas with either lenses or shaped reflectors. These focusing elements control the beamwidth and phase taper of the incident energy. In other words, a focus is formed in front of the lens or reflector and the specimen is placed at that focus to approximate plane-wave illumination.

An example of a typical measurement system is shown in the background of Figure 1. This system uses 60 cm diameter lenses and to work at frequencies of 2 GHz and higher. The total system is approximately 3 m long. In a larger laboratory setting the size of this fixture is acceptable, but in manufacturing or field situations a smaller device is needed. For example, it may be desirable to measure materials ‘in-situ’, where the sensor is small enough to be brought to a component under test. The small spot-probe antennas also pictured in the foreground of Figure 1 are such devices. They are shown installed in a table-top fixture but can also be mounted in handheld or robotic systems for use in manufacturing, depot, or even field applications.

II. SP324 SPOT PROBES

The idea of dielectric probes for material measurements goes back to at least the 1970s where Musil, Zacek, et al. measured transmission through material specimens [3]. They used dielectric rods inserted into horn antennas and placed adjacent to a specimen. Their probes successfully characterized the complex, dielectric permittivity of Si specimens at millimeter wave frequencies. Since then, others have used computational tools to improve the dielectric rod antenna design [4].

Most recently, CTG developed a sophisticated new probe called the SP324. Like its predecessors, the SP324 probe also includes both metallic and dielectric components. In contrast to conventional dielectric rod antennas, the SP324 optimizes both dielectric shape and metallic elements into an integrated sensor. The result is compact and rugged with even better performance. Figure 2 shows an integrated SP324 probe fed with a single SMA port in the rear. It transmits and receives with linear polarization from 3 to 24 GHz. It also has an added dielectric lens at the radiating end, which can be optionally removed for tight spaces.

The SP324 design was optimized with a Finite Difference Time Domain (FDTD) code, which can also calculate the radiated fields of the probe. The simulations launch a wide-band pulse from a coaxial port and march through time to determine the E and H fields within the simulation space. Example plots of the E-fields emanating from the tip of the probe at 10 GHz are shown in Figure 3. The plotted data is normalized to the peak field at the probe tip.

Figure 2. Photograph of SP324 spot probe

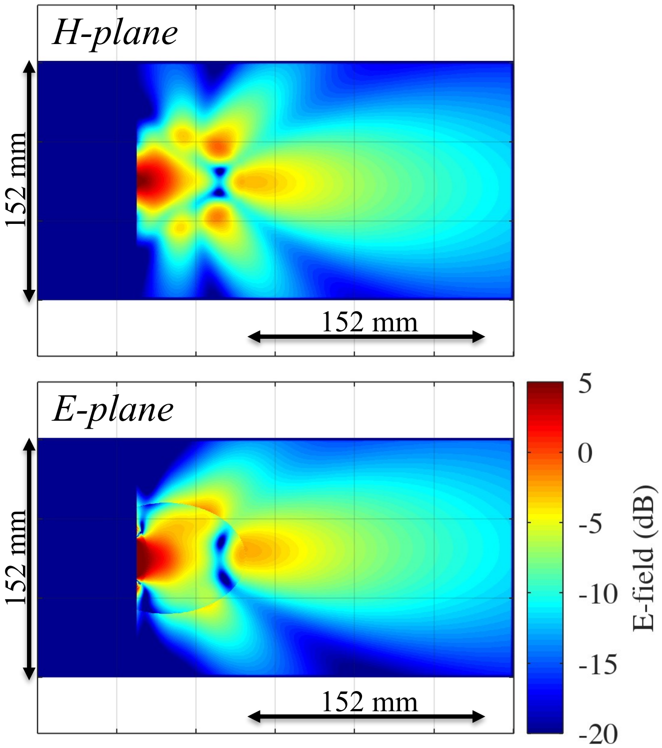

Figure 3. Computed E-fields at end of probe at 10 GHz

The following plots correspond to a 76 mm standoff distance between the probe tip and the specimen, though other standoff distances are possible. When a pair of probes is used for transmission, the probe separation is thus 152 mm. Having some separation between the probe and the material under test provides a safety margin in situations where the test article may be damaged by direct contact. Figure 4 shows the E- and H-plane beamwidth versus frequency. The data show that the beam profile is approximately circular in shape. The measured VSWR is shown in Figure 5.

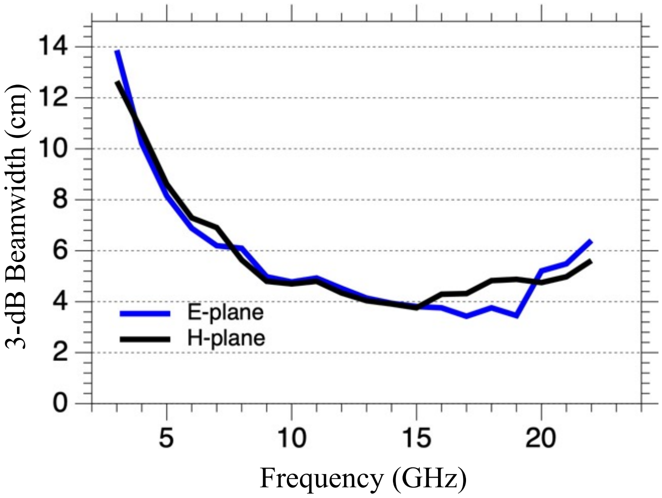

Figure 4. E- and H-plane beamwidth 76 mm from probe

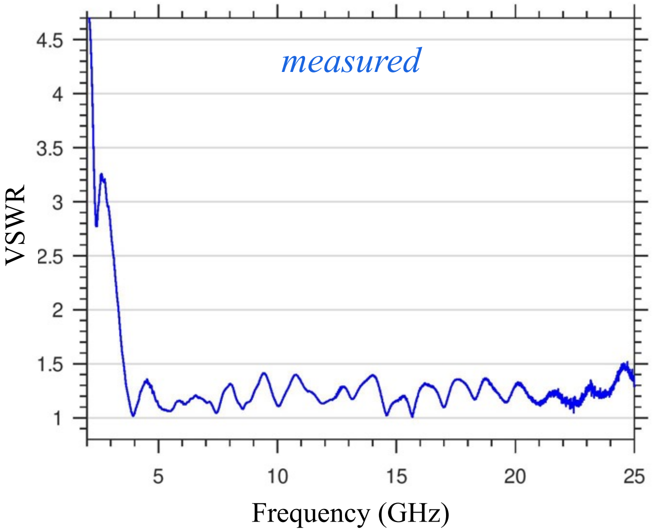

Figure 5. Measured VSWR of SP324 probe

III. COMPARISON MEASUREMENTS

The focused beam, free space technique has become a measurement standard used by many laboratories for microwave permittivity and permeability of materials; therefore, it is a useful benchmark to evaluate the accuracy of SP324 probes. Figure 6 shows Rexolite (crosslinked polystyrene) and fiberglass composite properties. A standard iterative method was used to solve for complex permittivity [2]. Both the real (solid lines) and imaginary (dashed lines) permittivity curves show agreement between the focused beam (FB) and the probe tabletop system (TT).

While Rexolite and fiberglass are low loss materials (imaginary permittivity near 0), a more interesting material is a carbon loaded foam absorber. The carbon is conductive and the resulting permittivity data shown in Figure 7 indicates a rapidly changing imaginary part due to this conductivity. The real permittivity is lower than the imaginary permittivity primarily because the dominant mechanism here is the carbon conductivity. Because it is foam, most of the volume is air, which keeps the real permittivity to a moderate level as shown.

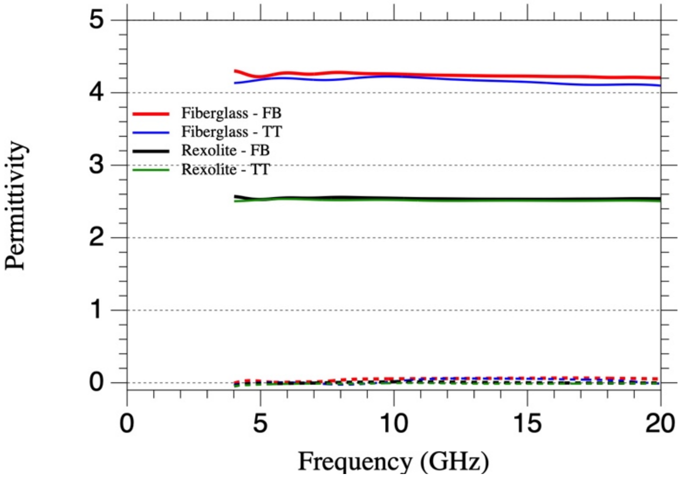

Figure 6. Measured dielectric permittivity of Rexolite and fiberglass, (solid lines = real, dotted lines = imaginary)

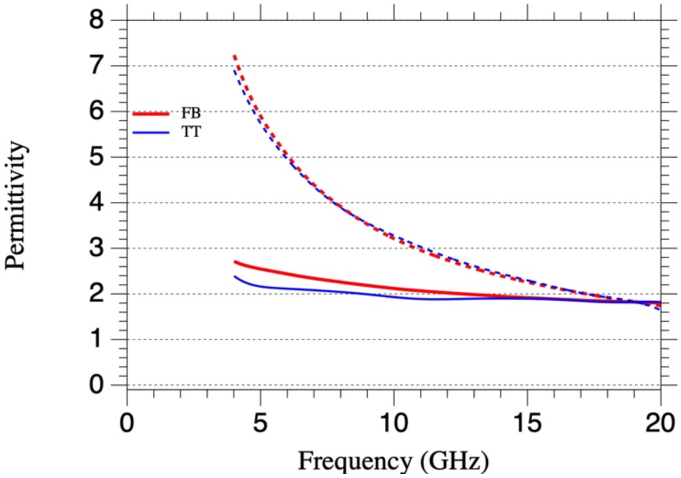

Figure 7. Measured real (solid) and imaginary (dashed) permittivity of a lossy carbon-loaded foam

A more challenging material to measure is one with both magnetic and dielectric properties, such as the commercial magnetic absorber in Figure 8. Dielectric permittivity is shown in the top plot while the bottom plot shows magnetic permeability. The real permittivity or permeability are shown as solid lines while the imaginary data are dotted lines. These data were inverted from all four transmission and reflection scattering parameters (S11, S22, S21, S12). The four-parameter method minimizes reflection phase errors from specimen displacement relative to the calibration plane [2]. As Figure 8 shows, the probe agrees with the focused beam even in a full two-port measurement where all the S-parameters are used.

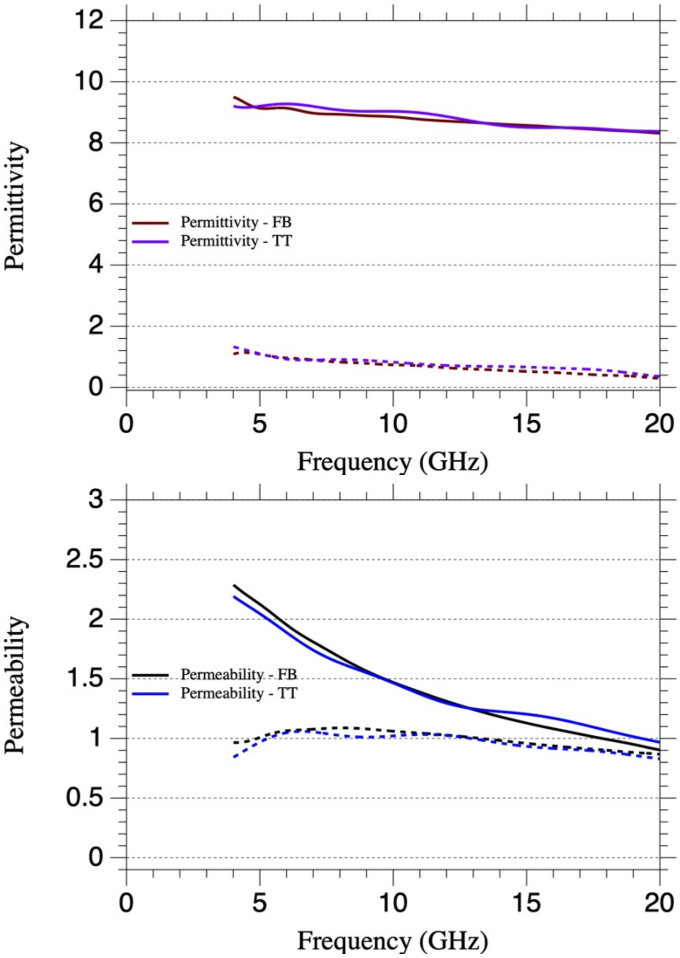

Figure 8. Measured permittivity (top) and permeability (bottom) of a commercial magnetic absorber

The final class of materials tested in this paper are thin resistive sheets (sometimes called resistive card). These materials consist of thin alloy layers on 75 to 150 micron Mylar substrates. A comparison between the focused beam and the probes for a commercial building window tint is shown in Figure 9. The plot shown is the real (solid lines) and imaginary (dashed lines) sheet impedance in ohms/square. As in the other materials, agreement between the probes and the focused beam is excellent.

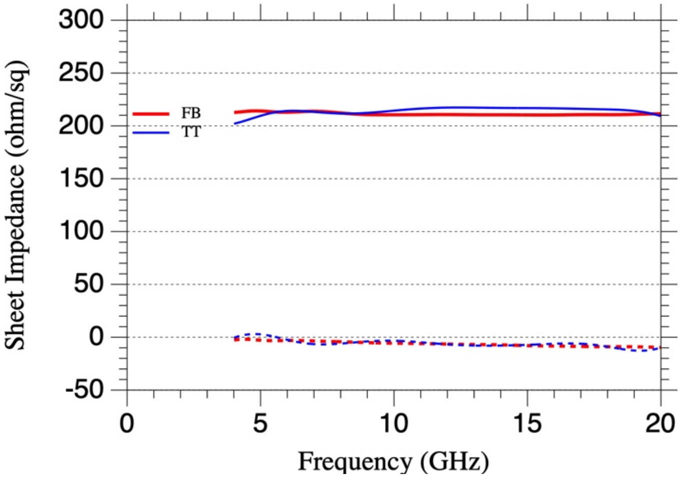

Figure 9. Measured sheet impedance of commercial window tint.

IV. CONCLUSIONS

This paper compares microwave material measurements of two different free space fixtures: a lens-based focused beam and compact spot probes. The specially designed spot probes are lower cost and more compact than focused beam lenses with horn antennas. Thus, they are more convenient for in-situ applications such as manufacturing quality assurance or testing of repairs in a depot. To this end, Compass Technology Group already has many aerospace customers employing their probe technology in manufacturing and repair facilities. As the comparisons in this paper show, the measured results from the spot probes are nearly equivalent to the more expensive, laboratory-grade focused beam method.

REFERENCES

[1] J. Musil, F. Zacek, Microwave Measurement of Complex Permittivity by Free Space Methods and their Applications, Elsevier, New York, 1986

[2] J.W. Schultz, Wideband Microwave Materials Characterization, Artech House, ISBN: 9781630819460, 2023

[3] J. Musil, F. Zacek, A. Burger, J. Karlovsky, “New Microwave System to Determine the Complex Permittivity of Small Dielectric and Semiconducting Samples,” 4th European Microwave Conference, 66-70, 1974

[4] R. Diaz, J. Peebles, R. Lebaron, Z. Zhang, L. Lozano-Plata, “Compact Broad-Band Admittance Tunnel Incorporating Gaussian Beam Antennas,” U.S Patent 788948, 2007