A QUASI-OPTICAL MICROWAVE FOCUSED BEAM SYSTEM FOR MATERIALS MEASUREMENT

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ABSTRACT

A fundamental part of the work of the BAE SYSTEMS Advanced Technology Centres Materials Group at Towcester (UK) is the microwave characterisation of the electronic parameters of lossy materials.

This paper describes a Quasi-optical microwave system for the free space measurement of material parameters in the frequency range 5 GHz to 18 GHz. The system employs two spherical reflectors which are illuminated from the side by gausian beam forming antennas. This produces a well defined parallel beam between the reflectors. The 5 GHz ro 18 GHz frequency range is covered in three bands with three pairs of corrugated feed antennas. An advantage of this system is that the beamwaist diameter (or illumination area) is essentially the same for each of the three frequency bands

The measurements are taken using a vector network analyser under computer control. The parallel beam enables a "Through,Reflect,Line" calibration technique to be used. After calibration the sample under test is placed in the beam (mid way between the reflectors) and the four microwave 'S' parameters are recorded automatically in complex form. The permittivity, permeabilty or lumped admittance (if the sample is very thin <λ/50) for the material are then determined from the 'S' parameters.

The operation and performance of the system is discussed and some material parameter measurement results are given.

Keywords: Microwave Materials Measurement, Quasi-optical Measurements, Microwave Permittivity, Microwave Permeability

1.0 Introduction

The BAE SYSTEMS Advanced Technology Centres Materials Group at Towcester (UK) is involved in the development of stealth technology for land, sea and air applications. This involves the development of new radar absorbent materials and structures. A fundamental part of this development is the electromagnetic characterisation of the materials at microwave frequencies to provide a data base which can be used in electromagnetic field solving codes for the design of stealthy components and structures.

At Towcester a quasi-optical focused beam system has been set up for the measurement of flat sheet samples of materials over the frequency range from 5 GHz to 18 GHz. This paper describes the system, examines its performance against the target specification and gives some material measurement results.

2.0 The System

The system (illustrated in Figure 1) consists of two spherical reflectors which are illuminated by two offset gaussian beam forming corrugated feed horns. The frequency range is covered in three bands (i.e 3 pairs of corrugated feeds). The reflectors are 500 mm in diameter and are mounted 1 metre apart so that they face each other and are carefully aligned on boresight so that a parallel beam is formed between the reflectors. The beam waist diameter is nominally 200 mm and the depth of field is 500 mm. An advantage of this design is that this beam configuration is maintained across all three bands. The reflectors have been machined to a standard which enables them to be used up to 110 GHz. Therefore the frequency range can easily be extended by just adding pairs of horns.

The antenna/reflector combinations are mounted on separate platforms. One is fixed with the sample mount. The other is mounted on linear guides and is moved back and forth by a precision stepper motor to facilitate calibration and measurement.

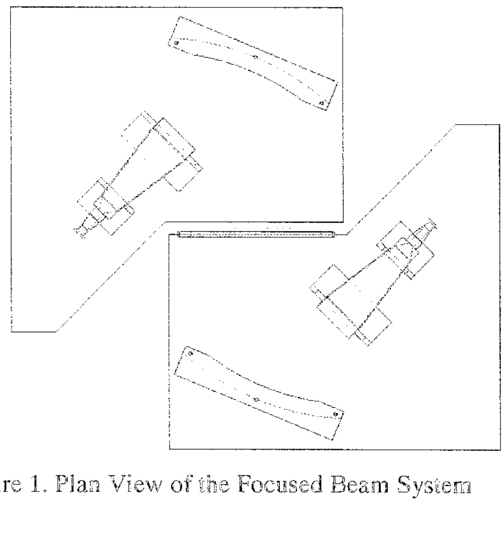


Figure 1. Plan View of the Focused Beam System

3.0 The Performance of the System

The target specification set for the system was as shown in Table 1 below.

Waveguide Size at Antenna Input	Flange Type	Design Freq	Useable Bandwidth
WG14	UAR70	7.0 GHz	5 – 8 GHz
WG16	UBR100	10.0 GHz	8 – 12 GHz
WG18	UBR140	14.5 GHz	12 – 18 GHz

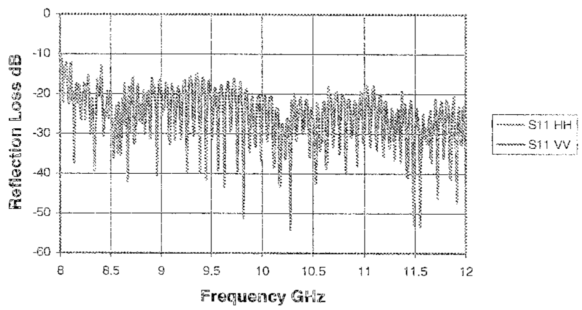
Other Parameters	
Beam Waist Diameter	200 mm +/- 10 mm At a Position 500 mm from the Reflector
Depth of Field	>200 mm Centred on a Position 500 mm From the Reflectors
Phase Variation Across the Beam	7.0 GHz - 8° 10.0 GHz - 6° 14.5 GHz - 4°
Reflection Loss at the Input to the Antennas	>20 dB
Transmission Loss Through the System	<0.5 dB
Cross Polar Attenuation	>35 dB

Some basic measurements were carried out to see how well the system complied with this target specification. A vector network analyser was used to perform measurements on the system through the waveguide input ports to the corrugated feeds. For each band, a full 2 port calibration was carried out at the waveguide output ports of the coaxial to waveguide transistions, which feed the corrugated horns, using a "Through Reflect Line " (TRL) technique. After the calibration was complete, the transitions were reconnected to the corrugated feeds and the following measurements were carried out.

1. Transmission loss through the system for Vertical (V) and Horizontal (H) polarisations of the corrugated feed horns.
2. Reflection loss at the waveguide input ports for V and H polarisations.
3. Reflection loss with a short circuit plate at the measurement plane for V and H polarisations.
4. The cross polar transmission loss with each corrugated feed horn rotated through 90°.

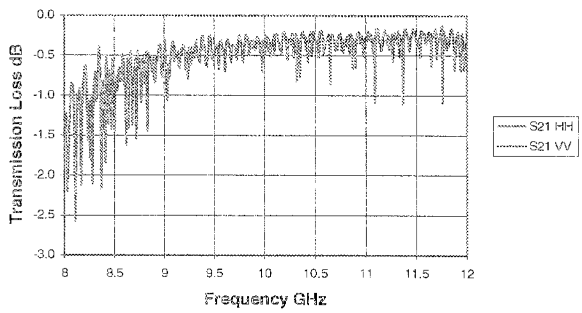
The results of the measurements for the 8 – 12 GHz frequency band only are shown here. The measured results for the other two bands showed a very similar trend,
The measured transmission loss through the system is shown in Figure 2. It can be seen that the transmission loss is typically -0.3 dB over most of the band but the performance deteriorates in the bottom 20% of the band.

Figure 3. Measured Reflection Loss for WG 16 Band



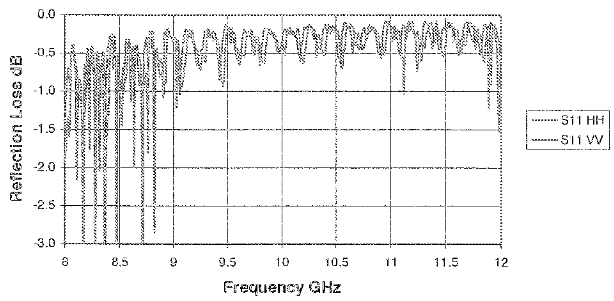
This shows that the beam is well formed above 9 GHz and that most of the energy is concentrated within the beam waist.

Figure 2. Measured Transmissioin Loss for WG16 Band



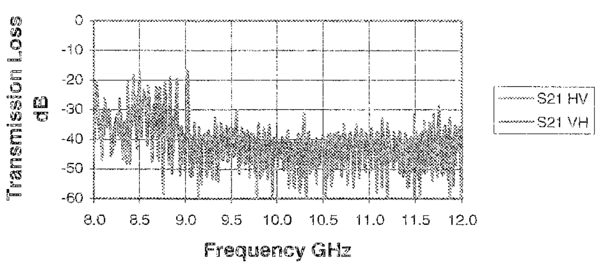
The measured reflection loss at the input ports to the corrugated feeds is shown in Figure 3. It can be seen that the reflection loss was in excess of –20 dB for most of the frequency band.
A plot of the measured reflection loss given when a short circuit plate was placed at the measurement plane is given in Figure 4. This trace mirrors the the transmission loss plot demonstrating the good free space match of the corrugated feed horns.

Figure 4. Measured Reflection Loss with Short Circuit



The result of the crosspolar transmission loss measurement is shown in Figure 5. It can be seen that the cross polar attenuation is typically –40 dB above 9 GHz.

Figure 5. Measure Cross Polar Attenuation



A rudimentary attempt to plot the field in the beam waist was carried out using a coaxial monopole probe. The vector network analyser was used as the detection system and was calibrated (using a response/isolation technique) with the probe at the centre of the beam waist. The transmitted field was set to V polarisation and the probe was moved horizontally across the beam in steps and the coupled value recorded for each step. This procedure was repeated for horizontal scans at various distances from the reflector. Figure 6 shows the magnitude of the coupled values measured across the beam for scans at 100mm steps moving away from the reflector. The beam waist is defined when the field voltage falls by 8.7 dB from the maximum (e^-1). It can be seen that the measured beam waist is very close to 200 mm in diameter. The traces plotted for the various positions relative to the reflector sit on top of each other, indicating that the depth of field is in excess of 500 mm.

Figure 7 shows the relative phase variation measured across the beam as the probe is moved from the centre to the edge of the beam at various distances from the reflector. The results indicate that the phase variation across the beam waist is approximately 10°.

Figure 6. Field Plot of the Beam Waist at Various Distances from the Reflector

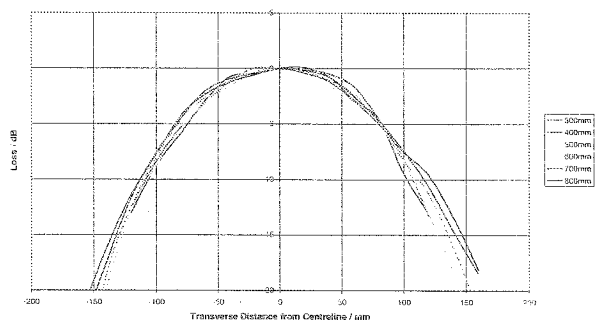
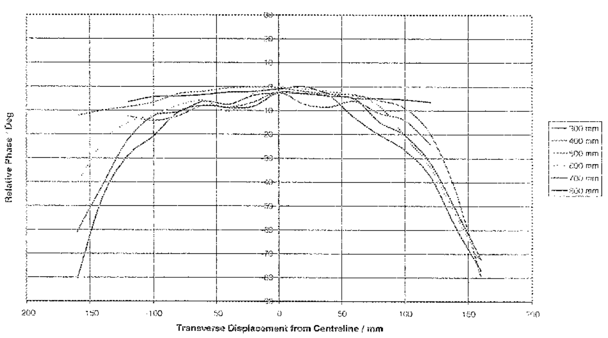


Figure 7. Measured Relative Phase (at 10 GHz) Across the Beam Waist at Various Distances from Reflector



4.0 The Focused Beam System in Use

The complex 'S' parameter measurements from the system are taken automatically using a vector network analyser under computer control. A full two port 12 term error correction is implemented using the TRL calibration technique. This defines an imaginary pair of measurement ports which is achieved by moving one half of the system (thus one of the measurement ports) to take account of the thickness of the short circuit plate and subsequently to introduce a $\lambda/4$ length of line. This type of calibration is made possible by the fact that the depth of field is maintained over a distance greater than $\lambda/4$.

A photograph of the system with the WG16 horns mounted is shown in Figure 8 below.

The sample to be measured is mounted orthogonal to the beam at the measurement plane. The movable port position is adjusted to take account of the thickness of the sample. The four complex 'S' parameters are then recorded automatically.

The material parameters i.e. lumped admittance for a thin lossy sheet or permittivity and permeability for sheet material are then calculated (using the Nicholson,Ross – Weir technique for permittivity/permeability) off line from the measured 'S' parameters.

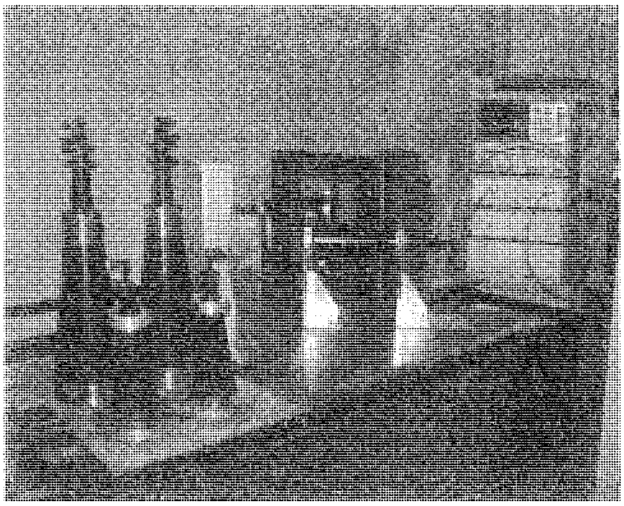
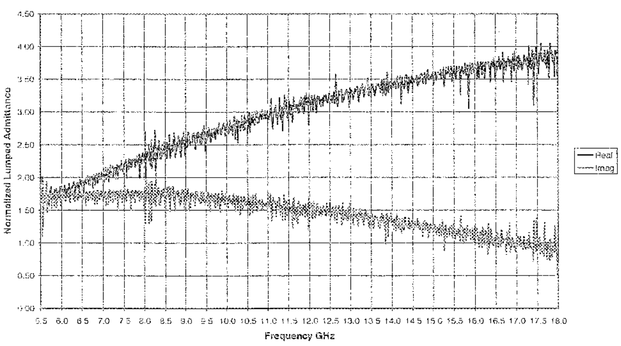


Figure 8. The focused Beam System in Use

Figure 9 shows a plot of the lumped admittance of a thin lossy sheet of material 100μm thick determined from measurements taken over the three bands from 5 GHz to 18 GHz. It can be seen that the results for the three bands are continuous with slightly more noise on the measurement at the 8 GHz band change over point.

Figure 9. Measured Lumped Admittance of Thin Lossy Sheet Material



The permittivity and permeability determined from the results of measurements carried out on a sheet of magnetic material are shown in Figure 10 and 11 respectively.

Figure 10. Measured Permittivity of a 4mm Thick Sheet of Magnetic Material

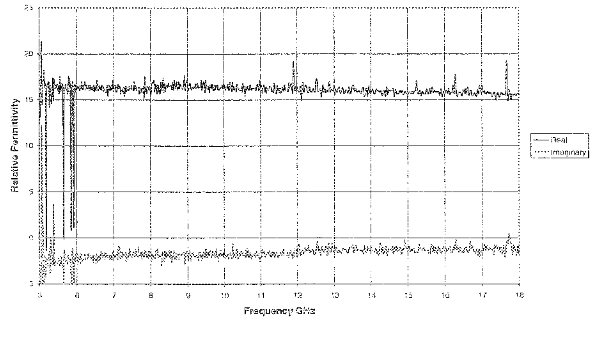
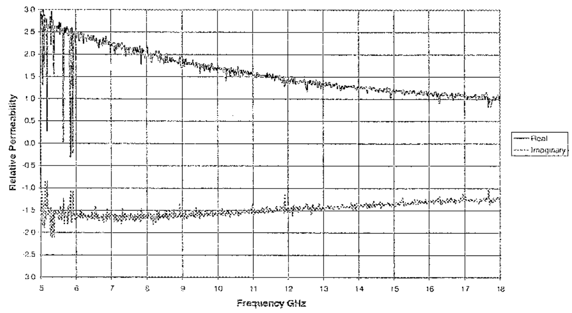


Figure 11. Measured Permeability of a 4mm Thick Sheet of Magnetic Material



5.0 Conclusion

A Quasi-optical microwave focussed beam measurement system which can be used to determine the electromagnetic parameters of sheet materials has been demonstrated. The system generally exceeded the target specification set for it The deterioration in performance at the lower ends of the frequency bands does not have a significant affect on the evaluated parameters.and gives reliable measurements across the frequency range from 5 GHz to 18 GHz.

This technique is important because the grain size of some materials is too large to allow their characterisation using waveguide measurements and it is also quite often preferred to carry out the measurements on sheet materials.

The measured results from this system are used regularly for the design of RAM products and good agreement has been achieved between the predicted and measured performance for these products.

5.0 REFERENCES

[1] Baker-Jarvis,J.,"Transmission/Reflection and Short-circuit Line Permittivity Measurements",NIST Technical Note, 1341, July 1990.

[2] Nicholson, A.M., and Ross.G., "Measurement of the Intrinsic Properties of Materials by Time domain Techniques", IEEE Trans., 1970, IM-19, pp. 377-382.

[3] Weir,W.B., "Automatic Measurement of Complex Dielectric Constant and Permeability at Microwave Frequencies", Proc IEEE, 1974, 62, pp. 33-36, Jan 1974.

[4] Ghodgaonkar, D.K., Varadan, V.V., and Varadan, V.K., "Free Space Measurement of Complex Permittivity and Complex Permeability of Magnetic Materials at Microwave Frequencies", IEEE Trans, Instrum. Meas., Vol 39, No 2, pp. 387-394. April 1990.

[5] Bailey,M.C., "Design and Evaluation of an Electromagnetic Beam Waveguide for Measuring Electrical Properties of Materials" NASA Technical Paper 3418, February 1994.

[6] Clarricoats, P.J.B., and Olver,A.D., "Corrugated Horns for Microwave Antennas", Peter Peregrinus Ltd,1984.

[7] Wylde,R.J., "Millimeter-wave Gaussian Beam-mode Optics and Corrugated Feed Horns",ProcIEE,Vol 131,Pt.H, No4,August 1984.

6.0 Acknowledgement

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