Loss of WR10 Waveguide across 70-116 GHz

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***Abstract*— The losses of ~1.2 m long WR10 (2.54x1.27 mm²) rectangular waveguides were measured at room temperature across the 70-116 GHz band. Ten different waveguide modules were machined in two different materials (Aluminum alloy and Brass) using different surface roughness (Ra) and different split-block waveguide geometries (E-plane and b-edge) as to establish the dependency of the losses on the various parameters.**

The measurements of the various units were performed with the IRAM mm-wave Vector Network Analyzer (MVNA) across the 70-116 GHz single-mode band of the WR10 waveguide.

***Index terms*---WR10 waveguides, losses, machining, surface roughness, gold plating.**

I. WR10 WAVEGUIDE MECHANICAL BLOCKS

Ten modules with ~1.2m long WR10 rectangular waveguide were fabricated at IRAM: five in Brass (CuZn39Pb3) and five in 6060 Aluminum AlMgSi. Each module consists of two split blocks in which the waveguide was machined in a meandering pattern that fits on a surface of 140x71 mm^2. Fig. 1 shows photos of some of the assembled units together with the internal details of one of the two module halves.

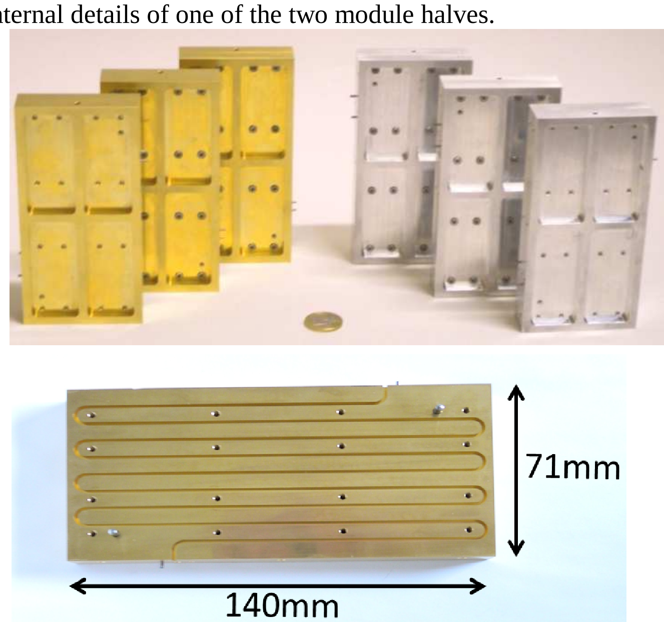

Fig. 1. Top: six assembled WR10 waveguide modules (three in Brass on the left, three in Aluminium on the right). Bottom: one disassembled split-block half showing the ~1.2 m long WR10 waveguide long cut.

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A. Different split-block geometries:

Two different WR10 split-block geometries, the E-plane split and the b-edge split, were adopted for the modules, as illustrated in Fig. 2.

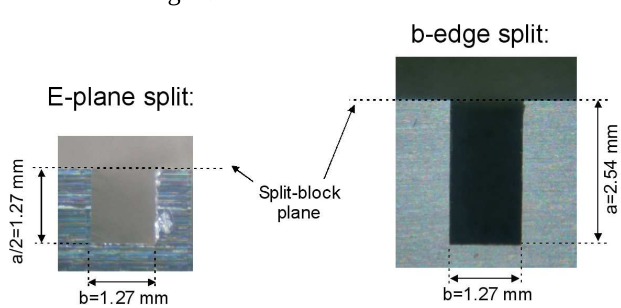

Fig. 2. Photo of WR10 waveguide cut adopted on the two split block geometries. Geometry 1: along the E-plane (left). Geometry 2: along the b-edge (right).

B. Different surface roughness:

The waveguide cuts in each module were fabricated using a numerically controlled milling machine (using machining parameters Ω=9000 rpm and V=45 mm/min). A conventional carbide drill as well as a diamond drill were used. A better surface finish is obtained using the diamond tool. Photos of the WR10 waveguide cuts fabricated with the two drill types are shown in Fig. 3.

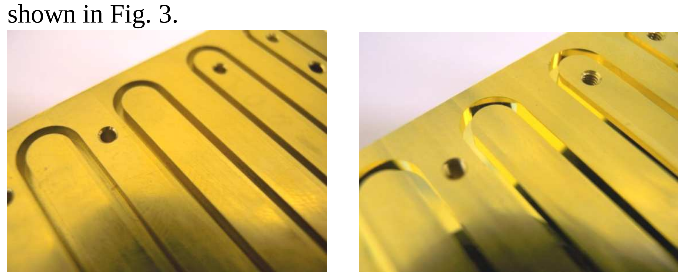

Fig. 3. Left: WR10 waveguide machined with carbide tool. Right: WR10 waveguide machined with diamond tool showing the specular effect at the waveguide bottom.

The achieved surface roughness (Ra) was measured at the bottom of the waveguide cut (narrow side) using a non-contacting optical laser equipment. The roughness along the waveguide walls (wide side) was not measured. The losses are expected to be lower in a smooth waveguide with surface irregularities which are small in comparison to the skin depth. Assuming an electrical conductivity of 1.38x10^7 S/m and of 3.24 x10^7 S/m for, respectively Brass and Aluminium, the corresponding skin depths at 100 GHz are δ_{Brass}=0.40 μm and δ_{Alu}=0.28 μm. The measured surface roughness at the bottom of the waveguides machined with carbide tool were about Ra~0.34 μm for the Brass modules and about Ra~0.15 μm for the Aluminum modules, i.e. similar in value to the skin depth. The measured Ra of the waveguides machined with diamond drill was about 0.04 µm in Brass module and about 0.02 µm in Aluminum modules, i.e. one order of magnitude less than the skin depth.

II. ELECTRICAL MEASUREMENT RESULTS

The S-parameters of the waveguide modules were measured across 70-116 GHz using a Vector Network Analyser (VNA) with WR10 mm-wave extension modules developed at IRAM [1]. A photo of the measurement setup is shown in Fig. 4. The typical uncertainty on a transmission measurement across the WR10 band of the mm-wave VNA is of the order of ~0.1 dB. To make an accurate measurement, it is necessary for this intrinsic uncertainty to be considerably smaller than the transmission to be measured. Accurate transmission measurements of low-loss devices are indeed difficult at mm-wavelengths. However, the loss of our ~ 1.2 m long WR10 waveguides, of order ~1 dB, could be measured with high accuracy, therefore decreasing the relative uncertainty of the measurement.

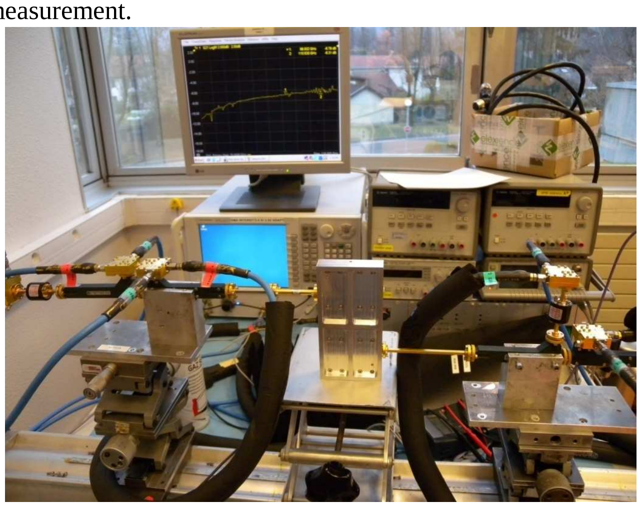

Fig. 4. Test setup for transmission loss measurement of WR10 waveguides across 70-116 GHz. A WR10 Aluminium module is connected to the mm-wave extension heads of the Agilent PNAX Vector Network Analyzer.

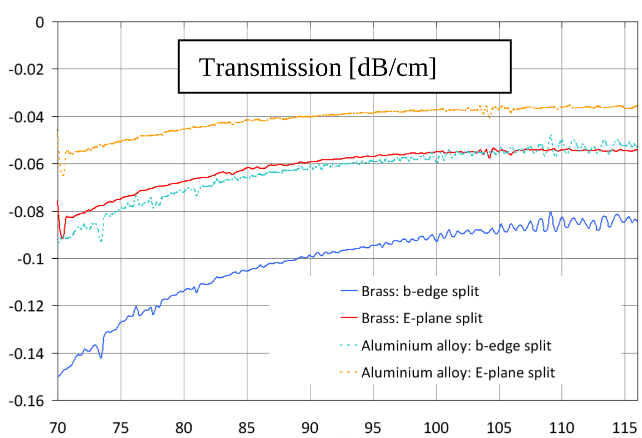

Fig. 5. Measured |S21| transmission per unit length (in dB/cm) of Brass and Aluminium alloy WR10 waveguide modules with split-block along the E-plane and the b-edge.

A. *Dependence of losses on split-block geometry (b-edge cut versus E-Plane cut):*

The measured transmission of Brass and Aluminium waveguide modules with waveguide cut along the E-plane and along the b-edge was rescaled to unit length. The measured results, expressed in dB/cm, are shown in Fig. 5. The highest transmission is found for the Aluminium alloy module with E-plane cut (dashed yellow curve), whose average value is about -0.04 dB across the 70-116 GHz band. As expected, the highest losses were measured for the Brass module with b-edge cut (solid blue curve), whose value ranges between -0.016 and -0.08 dB.

B. *Dependence of losses on surface roughness Ra:*

The measured |S21| transmission (in dB/cm) of Brass and Aluminium alloy waveguide modules fabricated with different milling tools (different surface roughness) are shown in Fig. 6. Electromagnetic simulation of the waveguide modules were performed with the 3D software CST Microwave Studio [2]. Using the theoretical electrical conductivity of 1.38×10^7 S/m and 3.24×10^7 S/m for, respectively Brass and Aluminium, the simulated results match closely the transmission measurements for modules machined with diamond drill.

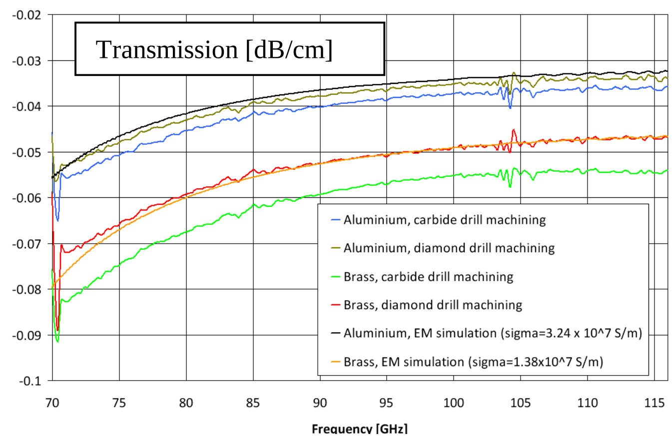

Fig. 6. |S21| transmission per unit length (in dB/cm) of Brass and Aluminium alloy waveguide modules with different surface roughnesses. All waveguide modules are cut along the E-plane. The electromagnetic simulation results of transmission of perfectly smooth WR10 waveguides made of Brass (solid yellow curve) and Aluminium (solid black curve).

III. CONCLUSION

The losses of a WR10 rectangular waveguide across 70-116 GHz are confirmed to be lower for E-plane cut geometry than for b-edge geometry. CNC milling machining with a diamond tool results in lower surface roughness than with a standard carbide tool. The measured losses are very close to electromagnetic simulation results with theoretical DC electrical conductivity values. The 6060 Aluminium AlMgSi has lower losses than Brass CuZn39Pb3.

ACKNOWLEDGMENT

We thank Laurent Coutanson at IRAM for the fabrication of the WR10 modules.

References

[1] F. Mattiocco and M. Carter, *80-360 GHz very wide band millimetrer wave network analyzer,* International Journal of Infrared and Millimeter Waves, Vol.16, No 12, 1995.

[2] CST Microwave Studio, CST AG Bad Nauheimer Str. 1964289, Darmstadt, Germany, http://www.cst.com