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Synthetic Fused Silica Glass Based Low Loss 60-GHz-Band H-plane Substrate Integrated Waveguide Hybrid by Through Quartz Vias

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***Abstract* — We propose synthetic fused silica glass (quartz) based low loss 60-GHz-band H-plane substrate integrated waveguide (SIW) hybrids by through quartz vias. The quartz has low dielectric loss at millimeter-wave-band and is a candidate for compact and low-loss multibeam antennas such as Butler matrices. To evaluate loss and feasibility at 60 GHz, attenuation constants are evaluated and an H-plane hybrid is characterized. Attenuation constants of SIW lines are characterized by measurement and low loss characteristics are confirmed. The H-plane hybrid is designed and fabricated showing good agreement with simulation.**

Index Terms — synthetic fused silica glass, through quartz via (TQV), H-plane hybrid, substrate integrated waveguide (SIW).

I. Introduction

The pico/nanocell configuration using millimeter waves is expected to be a means of achieving even faster wireless communications, and multi-beam antennas are used as base station antennas [1]. Butler matrices [2] can form orthogonal multi-beams, which reduces interference between beams. Butler matrices using waveguides, SIWs, and microstrip lines have been investigated, and two-dimensional beam scanning can be achieved by cascading one-dimensional Butler matrices [3][4]. However, as the number of beams increases, the length along the tube axis becomes longer. To solve this problem, a two-plane coupler was proposed [5]. By using this component, two-dimensional beam scanning can be realized with half the length of a longitudinally connected Butler matrix. 4×4-beam and 8×8-beam Butler matrices [6][7] have been proposed. However, conventional 2-D Butler matrices consist of hollow metal structures, which pose size and weight challenges. We have proposed a glass Butler matrix as a low-loss dielectric substrate even in the millimeter-wave band. High efficiency can be expected from the compactness and low loss of the glass dielectric due to its wavelength-shortening effect. In this paper, we report the results of the measurement and evaluation of attenuation constants and H-plane hybrids.

II. Loss Evaluation of SIW Line

Straight SIW with three different line lengths are fabricated to evaluate attenuation constants and are attached with waveguide SIW transition as shown in Fig. 1. The layer structure of the SIW line is shown in Fig. 2 and is composed of two metal layers and a single synthetic fused silica glass (quartz) layer. The thickness of the quartz and the copper is 0.4 mm and 18 μm, respectively. The dielectric constant of the quartz is 3.7 measured at 64.9 GHz. The structure of the WG-SIW transition is shown in Fig. 3 and is composed of the WR-15 waveguide, parasitic dipole, and SIW. The diameter of the through quartz via (TQV) [8] is 0.1 mm and the width of the SIW is 1.62 mm. The dimensions of the parasitic dipole and the SIW cavity are adjusted to realize low reflection characteristics.

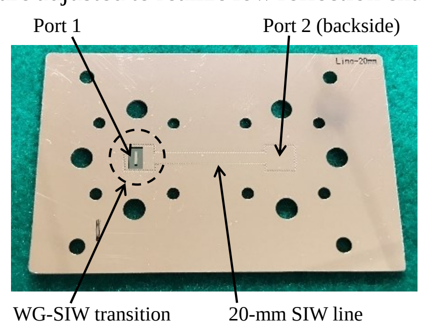


Fig. 1. 20-mm straight SIW line with WG-SIW transitions.

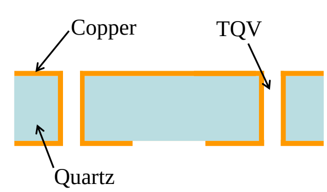


Fig. 2. The layer structure of the SIW line.

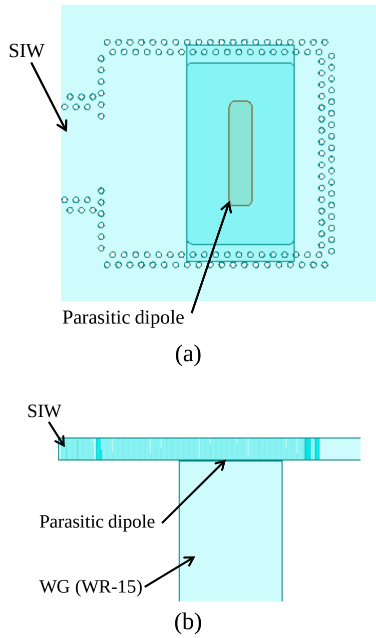


Fig. 3. WG-SIW transitions (a) top view (b) side view.

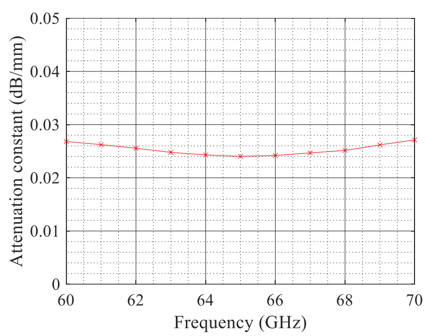


Fig. 4. Attenuation constants of the quartz SIW line with WG-SIW transitions.

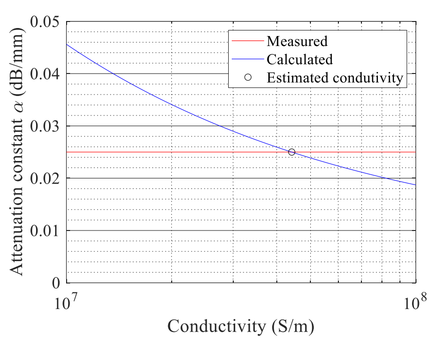


Fig. 5. Conductivity estimation by matching measured and calculated attenuation constants.

Transmission characteristics are measured by a vector network analyzer and attenuation constants are calculated as shown in Fig. 4. The estimated attenuation constant is 0.025 dB/mm at 62 GHz. Effective conductivity is estimated by simulation. The loss tangent of the quartz is 3.4×10^{-4} at 64.9 GHz measured by the balanced circular disk resonator (BCDR) method. The attenuation constant was calculated by the equation when only conductivity is changed as shown in Fig. 5. The estimated effective conductivity shows a very high value of 4.4×10^7 S/m at 62.0 GHz suggesting low roughness of the copper.

III. H-plane Hybrid

A. Design of the H-plane Hybrid

The structure of the H-plane hybrid is shown in Fig. 6. It is composed of four in/output SIW and a coupling region. In the coupling region, two modes, TE10 and TE20, propagate and the difference in the propagation constants results in cross-coupling to diagonal ports. The width of the coupling region controls the propagation constant of the two modes and the length controls the coupling amount between diagonal ports. The dimensions are optimized to realize an equal power division ratio of S31 = S41 and low reflections S11 and S21. The designed width w_c and length l_c is 3.09 mm and 2.20 mm, respectively.

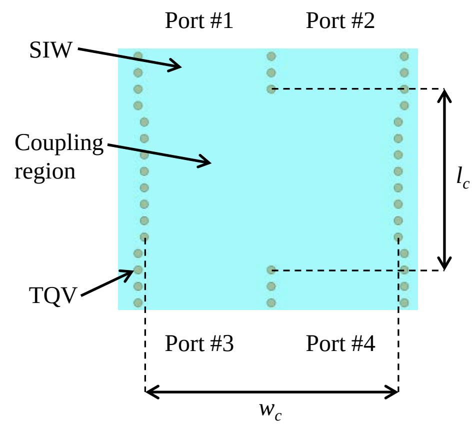
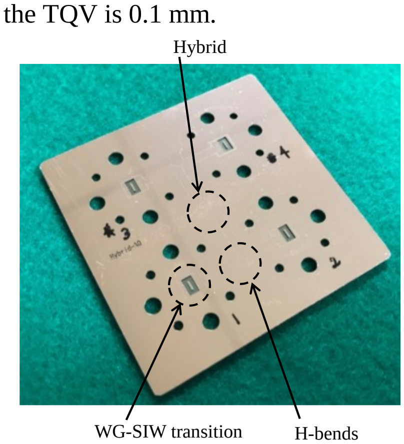


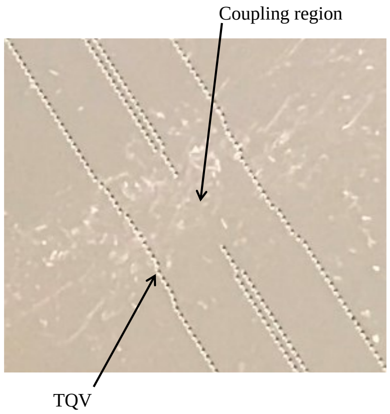
Fig. 6. Structure of the H-plane hybrid.

B. Measurement Results

The designed H-plane hybrid is fabricated by quartz and copper with thru quartz via (TQV) as shown in Fig. 7. Four WG-SIW transitions and H-bends are attached for S-parameter measurement. The thickness of the glass is 0.4 mm and the diameter of the TQV is 0.1 mm.



(a)



(b)

Fig. 7. Fabricated H-plane hybrid.

S-parameters of the H-plane hybrid are measured by a vector network analyzer and shown in Fig. 8 and Fig. 9 together with simulated ones. The measured reflection is suppressed below −10.0 dB from 58.5 GHz – 66.7 GHz showing good agreement with simulated results. The measured transmission also shows good agreement with simulated ones and the transmission ratio is shown in Fig. 10. The measured transmission ratio is within ±1.0 dB from 59.4 GHz – 63.9 GHz.

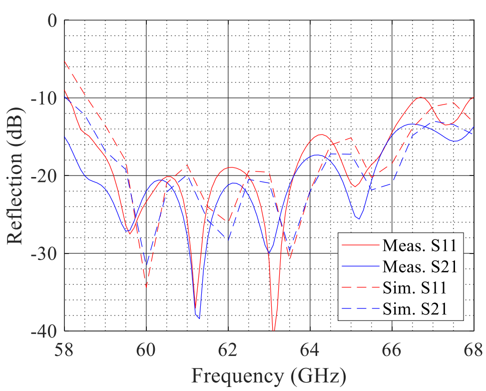


Fig. 8. Frequency characteristics of measured and simulated reflection.

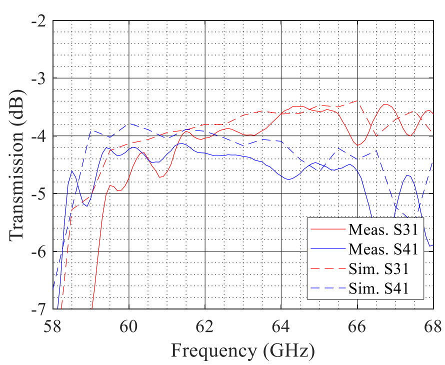


Fig. 9. Frequency characteristics of the measured and simulated transmission.

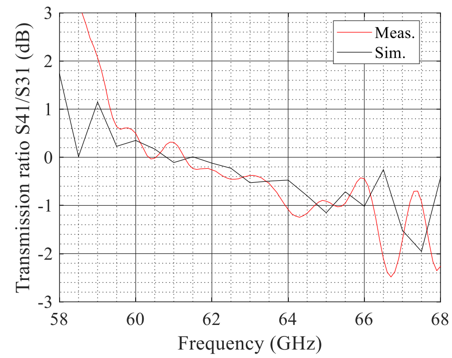


Fig. 10. Frequency characteristics of the measured and simulated transmission ratio.

IV. Conclusion

This paper presents a synthetic fused silica glass (quartz) based low loss 60-GHz-band H-plane substrate integrated waveguide (SIW) hybrids by through quartz vias. SIW lines were measured and showed a low loss of 0.025 dB/mm and high conductivity of 4.4 × 10^7 S/m at 62.0 GHz suggesting low roughness. The H-plane hybrid was designed and measured showing good agreement with the simulation. These results suggest that the synthetic fused silica glass is suitable for compact low-loss multibeam antennas in the millimeter-wave band.

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