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120-GHz-Band Contactless Communication with SRR-Integrated Quartz Substrate

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Abstract

We achieved 10-Gbit/s data transmission using 120-GHz-band contactless communication technology, enabling seamless connection to a local area network (LAN) by simply placing devices on a desk. We propose a hollow waveguide with part of its top surface replaced by a quartz substrate integrated with split-ring resonators (SRRs). The transmission loss of the hollow waveguide with the quartz substrate was 1.1 dB at 125 GHz. When the dielectric sheet was in contact with the quartz substrate, the transmission loss from the hollow waveguide to the dielectric sheet was 11.0 dB at 125 GHz. We achieved 10-Gbit/s data transmission by contacting a dielectric sheet with the SRR-integrated quartz substrate.

1. Introduction

The use of wireless local area networks (LAN) has expanded as a convenient method for network connectivity. However, conventional wireless LAN technology is limited by the number of available access point channels and is susceptible to inter-channel interference, leading to unstable communication [1]. Sheet LANs are a promising solution for convenient network connectivity, addressing the limitations of wireless LANs [2]. This new communication method enables contactless LAN connections by simply placing mobile devices on a desk. We have been developing 120-GHz-band sheet LAN technology to achieve data rates exceeding 10-Gbit/s [3]. In this study, a 120-GHz-band signal was transmitted through a hollow waveguide, with part of its top surface replaced by a quartz substrate integrated with split-ring resonators (SRRs). We achieved 10-Gbit/s data transmission by contacting a dielectric sheet to which a receiver was connected. One challenge with 120-GHz-band sheet LAN technology is the high transmission loss of the glass substrate-integrated hollow waveguide and the contact loss between the glass substrate and the dielectric sheet.

To address this issue, we investigated the use of a hollow waveguide integrated with a quartz substrate instead of a glass substrate to solve the problem of high transmission loss in 120-GHz-band sheet LANs.

2. Design of SRR integrated hollow waveguide

Figure 1 shows a conceptual diagram of the proposed sheet LAN system. A portion of the top surface of the hollow waveguide was removed, and a quartz substrate was placed on top. As shown in Figure 1(a), when the dielectric sheet is not in contact with the quartz substrate, the SRRs on the quartz substrate reflect the 120-GHz-band signal traveling through the hollow rectangular waveguide, reducing the transmission loss from port 1 to port 2. When the dielectric sheet comes into contact with the quartz substrate (Figure 1(b)), the resonance characteristics of the SRR change, allowing a portion of the millimeter-wave signal propagating in the hollow waveguide to be transmitted through the quartz substrate and guided to the dielectric sheet.

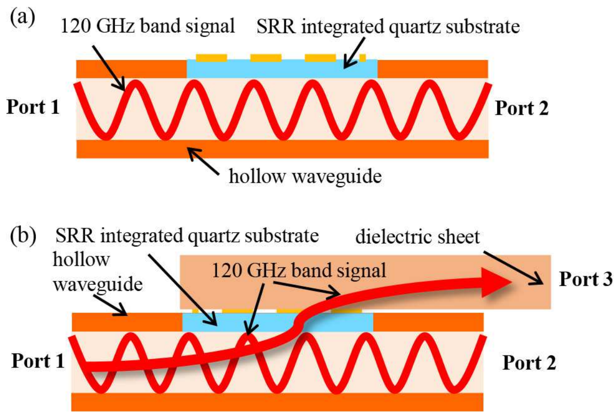


Figure 1. Concept diagram of the LAN sheet system (a) when no dielectric sheet contacts the quartz substrate, and (b) when a dielectric sheet contacts the quartz substrate.

Figure 2(a) shows the SRR unit cell simulation model. We simulated the transmission loss of a hollow rectangular waveguide with an SRR-integrated quartz substrate (S_{21}) when no dielectric sheet was in contact with it.

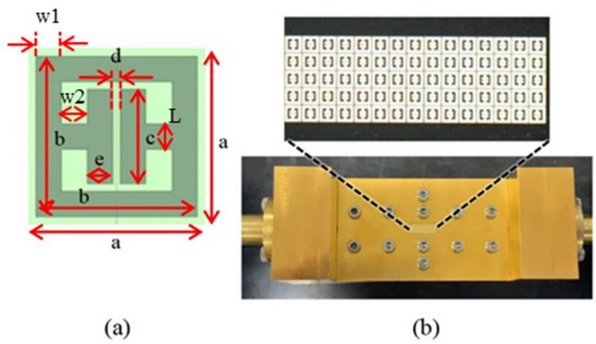


Figure 2. (a) Schematic diagrams of SRR unit cell, (b) Photograph of SRR integrated quartz substrate and hollow waveguide module.

The SRRs were integrated onto the quartz substrate, each measuring 7.714 mm x 3.6 mm with a thickness of 0.2 mm. The SRRs on the quartz substrate were formed using a 5-µm-thick gold film. A photograph of the SRR-integrated quartz substrate is presented in Figure 2(b). Next, we simulated the transmission loss of the hollow waveguide with part of its top surface replaced by a quartz substrate integrated with SRRs. The simulation was conducted using a 3D electromagnetic simulator based on the finite element method (FEM). The permittivity of quartz was set to 3.8. The settings for ports 1 and 2 are shown in Figure 1(a). The length of the hollow waveguide used in the simulation model is 12.7 mm. Figure 3 shows the dependence of S_{21} on the unit cell size (a). The largest S_{21} was obtained when the unit cell size (a) was 205 µm. The SRR parameters yielding the maximum S_{21} values were obtained through simulations. The SRR size parameters determined by the simulation are as follows: unit cell size (a): 500 µm, SRR side length (b): 410 µm, capacitor length (c): 200µm, capacitor width (e): 62µm, capacitor gap (d): 20 µm, linewidth (L, $w1$): 65 µm, and gap between impedance and capacitor section ($w2$): 68 µm.

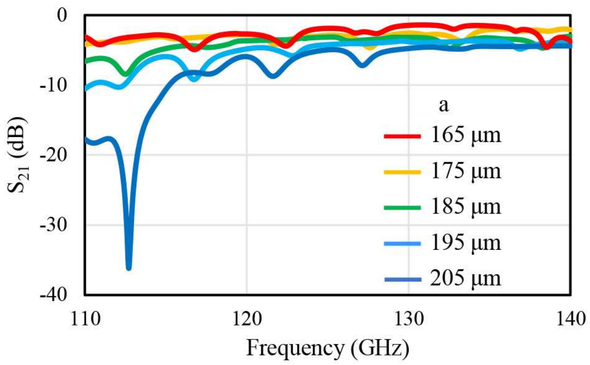


Figure 3. Simulation results of S_{21} for the hollow waveguide with its top surface replaced by the SRR-integrated quartz substrate.

Next, we fabricated an SRR-integrated quartz substrate and a hollow waveguide module, with part of the top surface replaced by the SRR-integrated quartz substrate. A photograph of the hollow waveguide module is shown in Figure 2(b). The transmission loss of the hollow waveguide module was measured using a vector network analyzer (VNA). Figure 4 shows the measurement results of the S_{21} characteristics of the hollow waveguide module shown in Figure 2(b). The simulation and measurement results of the hollow waveguide with part of its top surface replaced by the SRR-integrated glass substrate are also shown. The permittivity of the glass substrate was 5.3. The measured S_{21} at 125 GHz for the hollow waveguide module with the SRR-integrated quartz substrate was -1.12 dB. When the SRR integrated glass substrate was used, the measured S_{21} at 125 GHz was -2.57 dB. These results indicate that the hollow waveguide with the SRR-integrated quartz substrates exhibited 1.3 dB lower transmission loss compared with the one with the SRR-integrated glass substrates.

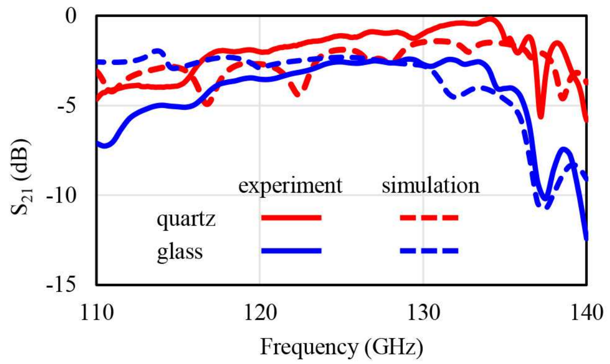
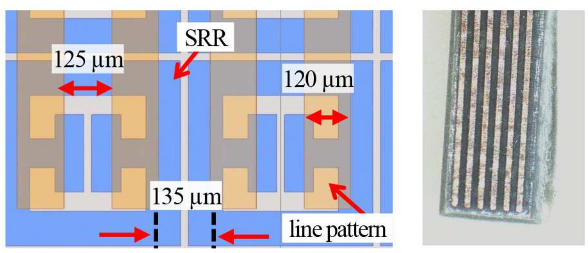


Figure 4. Simulation and experimental results of S_{21} for the hollow waveguide with its top surface replaced by either the SRR integrated quartz substrate or SRR integrated glass substrate.

3. Contactless communication using a dielectric sheet

We examined the possibility of enabling communication by guiding part of the 120-GHz-band signal propagating in the hollow waveguide into a dielectric sheet. This was achieved by bringing the dielectric sheet into contact with the SRR-integrated quartz substrate placed on the top surface of the hollow waveguide. Figure 5 shows the simulation results for the S-parameters when the dielectric sheet was in contact with the SRR-integrated quartz substrate. Rogers RT/Duroid 5880 was used as a dielectric sheet. A line pattern was added to the surface of the dielectric sheet in contact with the glass substrate to increase the proportion of the 120-GHz-band signal guided to the dielectric sheet. The permittivity of Rogers RT/Duroid 5880 was set to 2.2 in the 3D electromagnetic simulation. The length, width, and thickness of the dielectric sheets were 100 mm, 2.5 mm, and 0.78 mm, respectively. A diagram and photograph of the line pattern are shown in Figures 5(a) and 5(b), respectively. The line pattern was made of a 10-µm-thick copper film. The design layout of the line pattern is shown in Figure 5(a). The settings for ports 1, 2, and 3 are shown in Figure 1(b).



(a) (b)

Figure 5. (a) Schematic diagram and (b) photograph of the line pattern on the dielectric sheet.

The simulation and measurement results for S_{21} and S_{31} are presented in Figures 6 and 7, respectively. At 125 GHz, bringing the dielectric sheet with the SRR-integrated quartz substrate caused S_{21} to decrease from -1.1 dB to -3.8 dB.

S_{31} was -11.5 dB at 125 GHz. This result indicates that approximately one-tenth of the 120 GHz signal propagating inside the hollow waveguide was guided to the dielectric sheet when it was in contact with the SRR-integrated quartz substrate.

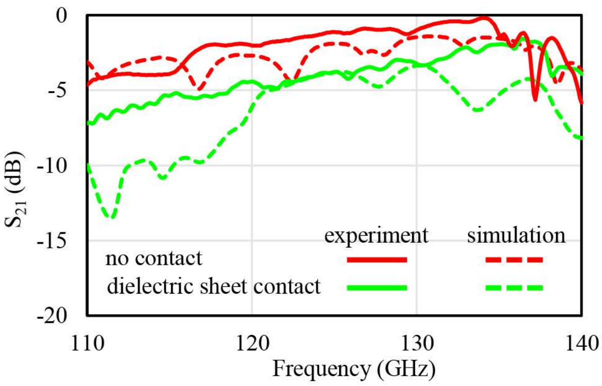


Figure 6. Simulation and measurement results of S_{21} before and after bringing the dielectric sheet into contact with the SRR-integrated quartz substrate.

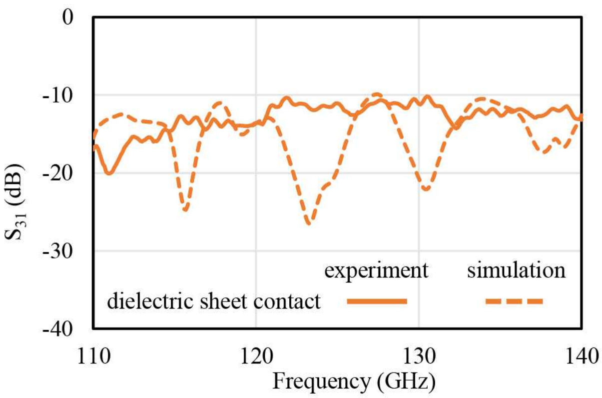


Figure 7. Simulation and measurement results of S_{31} after bringing the dielectric sheet into contact with the SRR-integrated quartz substrate.

Figure 8 shows a comparison of the S-parameter characteristics for the hollow waveguide using SRR-integrated quartz and glass substrates. When the dielectric sheet was not in contact with the hollow waveguide, the measured S_{21} at 125 GHz was -2.6 dB for the SRR-integrated glass substrate, while for the SRR-integrated quartz substrate, it was -1.1 dB. This indicates that using the quartz substrate reduces the transmission loss by 1.5 dB compared with the glass substrate. When the dielectric sheet was in contact with the hollow waveguide, the measured S_{31} at 125 GHz was -11.0 dB for the quartz substrate and -17.7 dB for the glass substrate. In particular, when the hollow waveguide and the dielectric sheet are in contact, the loss of the 120-GHz-band signal guided to the dielectric sheet is approximately 6 dB lower for the hollow waveguide with the quartz substrate than for the hollow waveguide with the glass substrate.

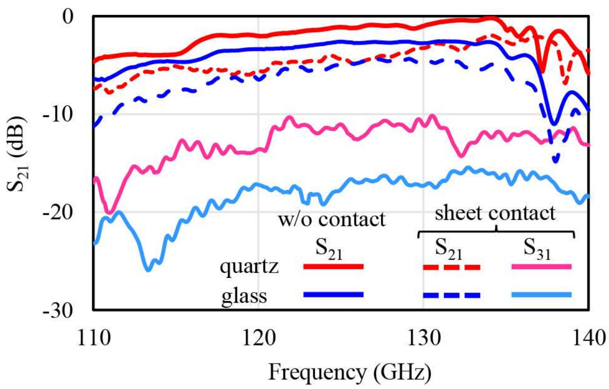


Figure 8. Measurement results of S parameter characteristics after bringing the dielectric sheet into contact with the SRR-integrated quartz substrate or glass substrate.

Finally, we verified the feasibility of data transmission through a dielectric sheet in contact with a quartz-substrate-integrated hollow waveguide. Figure 9 shows a photograph of the experimental setup for determining the data transmission characteristics of contactless communication. The setup consisted of a dielectric sheet and a rectangular hollow waveguide with an SRR-integrated quartz substrate. The measurement setup for data transmission employed an ASK modulation scheme and envelope detection. The 120-GHz-band transmitter generated wireless signals using photonics technology based on two-mode beating [4]. The hollow waveguide output port of the Tx module is connected to port 1 of the hollow waveguide module, as shown in Figure 9(a). Port 2 of the hollow waveguide module is terminated using a hollow waveguide terminator. One tip of the 100-mm-long dielectric sheet was placed in contact with the quartz substrate of the hollow waveguide module and the other tip was inserted into the input port of the Schottky barrier diode (SBD) detector.

Figure 10 illustrates the dependence of the bit error rate (BER) characteristics of contactless communication on the Tx output power. The Tx output power was measured at the output port of the 120-GHz-band amplifier module by replacing the hollow waveguide module with a power meter. When using the SRR-integrated glass substrate for the hollow waveguide, a BER of below 10^{-10} was obtained with a Tx power of over +0.4 dBm at a data rate of 10 Gbit/s. In contrast, when the SRR-integrated quartz substrate was used, a BER of 10^{-10} was obtained with a Tx power of over -6.2 dBm. In particular, when the hollow waveguide and the dielectric sheet are in contact, the loss of the 120-GHz-band signal guided to the dielectric sheet is approximately 6 dB smaller for the hollow waveguide with the quartz substrate than for the one with the glass substrate. Consequently, the required Tx power for 10-Gbit/s data transmission can be reduced by 6.6 dB using the SRR-integrated quartz substrate instead of the SRR-integrated glass substrate.

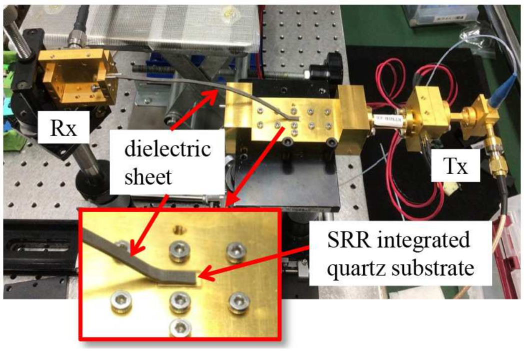


Figure 9. Photograph of the experimental setup for the contactless data transmission system using the hollow waveguide with the SRR-integrated quartz substrate.

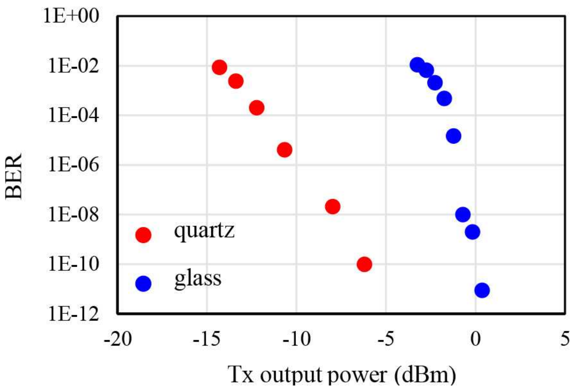


Figure 10. Bit error rate (BER) characteristics of the data transmission system using the SRR-integrated quartz substrate and glass substrate at a data rate of 10.0 Gbit/s.

4. Conclusions

We developed a rectangular hollow waveguide with an SRR-integrated quartz substrate and applied it to a 120-GHz-band high-speed contactless communication. The transmission loss of the hollow rectangular waveguide with the SRR-integrated quartz substrate was 1.1 dB at 125 GHz, which is 1.5 dB lower than that of the SRR-integrated glass substrate. The transmission loss from the hollow waveguide to the dielectric sheet at 125 GHz was 11.1 dB when the dielectric sheet was in contact with the quartz substrate. Furthermore, successful 10-Gbit/s data transmission through a dielectric sheet was achieved by placing it in contact with the quartz-substrate-integrated hollow waveguide. The required Tx power for 10-Gbit/s data transmission can be reduced by 6.6 dB when using the SRR-integrated quartz substrate compared with the SRR-integrated glass substrate.

5. Acknowledgements

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