Loss Evaluation of the 60-GHz Small Antenna in the Package for Wireless Data-Transfer Systems

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***Abstract*—This paper evaluates the loss factors in the 60-GHz small antenna in a package for a mobile terminal of the wireless data-transfer system. The loss evaluation shows the potential of the improvement in each part of the antenna. The transmission losses of the microstrip line (MSL) and the post-wall waveguide have been discussed. The estimated gain has been compared with the measured gain in the 60 GHz band. The loss factors of the small antenna including the reflection loss, dielectric loss, conductor loss both in the microstrip line and in the post-wall waveguide have been evaluated.**

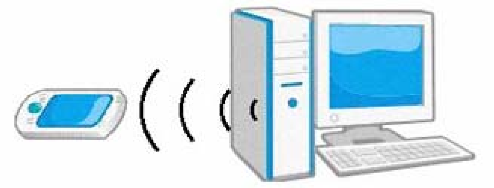
I. INTRODUCTION

Wireless data-transfer systems as shown in Fig.1 are expected as a practical attractive application in the millimeter-wave band. A cost-effective small package with an end-fire radiation antenna has been developed for the mobile terminal in the wireless local area network (WPAN) applications [1], [2]. The specifications of the antenna for the system are a gain of 6 dBi gain with a beamwidth of 40˚-60˚in both E and H plane in the frequency range of 59-66 GHz.

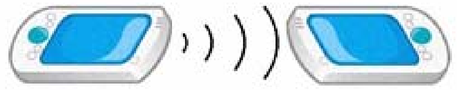
The configuration of the small antenna is shown in Fig.2. The 60GHz CMOS chip was mounted in the package made of low-cost, multilayered substrate and connected to the antenna by bonding wires. The antenna is fed by the carried chip through a ground-signal-ground (G-S-G) pad. The feeding circuit of the antenna was made of a microstrip line (MSL) layer and a post-wall waveguide layer. The power is radiated from the side face of the substrate with the end-fire radiation direction.

The directivity of the antenna is limited by the antenna size. In order to enhance the gain and hold the same beam performance in the same frequency band, the improvement of the antenna efficiency is very important. The loss evaluation of each part of the antenna is necessary to show the picture of the components of the loss factors. Thus, we can aim at the lossy part of the antenna and try to reduce the loss and enhance performance of the antenna.

In this paper, the loss factors including the reflection loss, the dielectric loss and the conductor loss both in the MSL and in the post-wall waveguide have been evaluated. A reasonable gain estimation of the antenna in the small package has been done at 60 GHz band. The estimated results of the loss factors have been compared with the measured total loss at 61 GHz.



(a) Download from fixed terminal to mobile terminal



(b) Mobile-to-mobile communication

Fig. 1. Application of data-transfer system

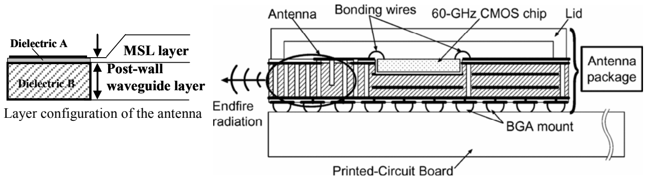


Fig. 2. Configuration of the antenna and the package on a PCB

TABLE I
TYPICAL ELECTRIC PROPERTIES AND THICKNESS OF THE SUBSTRATE FOR EACH LAYER IN THE PACKAGE

	MSL Layer	**Post-wall waveguide layer**
Dielectric	Dielectric A	Dielectric B
ε_r	3.06 ± 0.04 (50.6GHz)	Vertical: 3.53 ± 0.03 (28.5GHz) Horizontal: 4.01 ± 0.01 (49.8GHz)
tan δ	0.018 ± 0.001 (50.6GHz)	Vertical: 0.0075 ± 0.0010 (28.5GHz) Horizontal: 0.0053 ± 0.0002 (49.8GHz)
Thickness	0.03 mm	0.86 mm
Conductivity σ	Copper: 58 x 10^6 S/m (DC)	

II. TRANSMISSION LOSS OF THE POST-WALL WAVEGUIDE

The antenna is fed by the post-wall waveguide from a MSL-post-wall waveguide transition. The transmission loss of the MSL and post-wall waveguide can be estimated by the analytical formulas [3], [4]. The measured electric properties of the substrates have been shown in Table.1. The complex permittivity of the dielectric A and B as shown in Fig.2 are extrapolated to 60 GHz band from the measured value in the lower frequency.

The effective conductivity is approximated by exponential function fitting for extrapolation reflecting the surface roughness of copper [4]. In this paper, the condition of the surface roughness is assumed as same as the case of PCB in Ref.[4], and the formula of the effective conductivity for the broad wall (copper clad) is set to $\sigma_{ci} = 58 \text{ x } 10^6 e^{-0.0192f}$ S/m, and for the narrow wall (posts) is set to $\sigma_p = 58 \text{ x } 10^6 e^{-0.0272f}$ S/m in calculation, where f is in gigahertz.

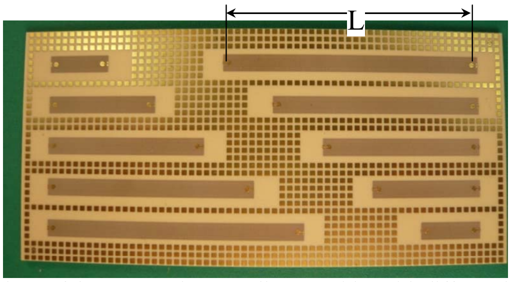


Fig. 3. Photo of the measured post-wall waveguides with different length (L=10, 20,30,40,50 mm)

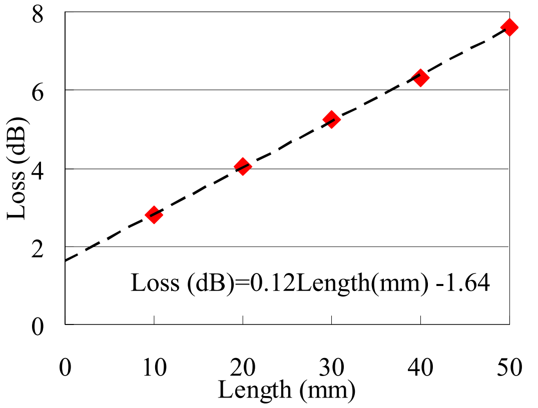


Fig. 4. Measured loss of the fabrication post-wall waveguide at 60GHz

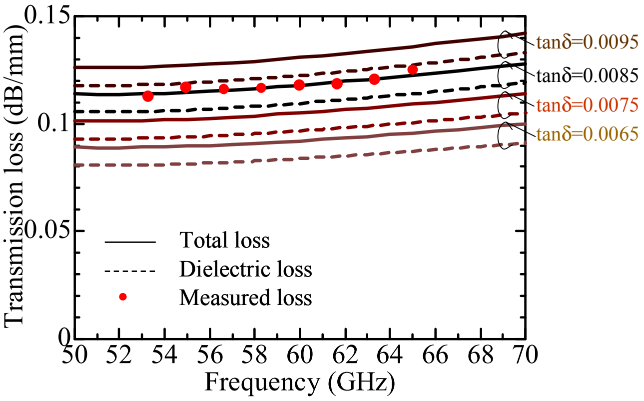


Fig. 5. Estimated loss and measured loss of post-wall waveguide

The S-parameters of different length of post-wall waveguides as shown in Fig.3 have been measured by the vector network analyser. By linear fitting, the slope gives the loss in unit length while the intercept gives the insertion loss of the input at the certain frequency as Fig.4. Fig.5 shows the calculated transmission loss with the loss tangent of 0.0065-0.0095. The solid lines are the total loss, the dashed lines are the dielectric loss and the dots are the experiment result of the loss in unit length in the frequency band of $S_{11} < -10$ dB. The loss of each waveguide has been calculated. The measured transmission loss of the post-wall waveguide is 0.12 dB/mm with the insertion loss of 0.82 dB of each transition. The measured loss is close to the line of the calculation result with the loss tangent of 0.0085.

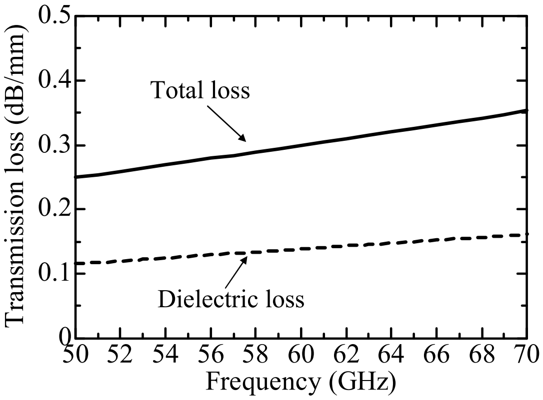


Fig. 6. Estimated loss of MSL

Fig. 6 shows the estimated loss of MSL with 60 μm-width line on the 30 μm-thick substrate in the input part. Comparing the transmission loss of the post-wall waveguide with the MSL, the ratio of the components of the dielectric loss and the conductor loss in the total loss are different. The dielectric loss is more than 90% of the total loss in the postwall-waveguide while about half of the total in the MSL in the 60 GHz band. Moreover, the transmission loss of the post-wall waveguide is only about half of the MSL. In another word, for the same length, the loss of the MSL will be double to the post-wall waveguide.

III. MEASUREMENT AND LOSS EVALUATION OF THE ANTENNA

The antenna in Ref. [2] has been designed. In order to measure the independent characteristic of the antenna in the chamber, it was mounted on the test jig transition as shown in Fig.7. The jig is a gold-plated waveguide-Conductor-backed coplanar waveguide (CBCPW) transition. The power is input from the WR15 standard waveguide and the antenna is fed by the CBCPW.

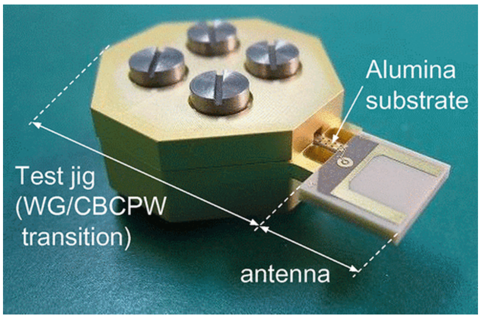


Fig. 7. Measured antenna with the test jig

Fig.8 shows the characteristics of the antenna with test jig. The dots show the experimental gain in the chamber. The blue line is the simulated directivity (HFSS v11) and the red line is the gain which is considered the losses in the each part of the antenna. In the design frequency band of 59-66 GHz, the measured gain agrees to the estimated gain.

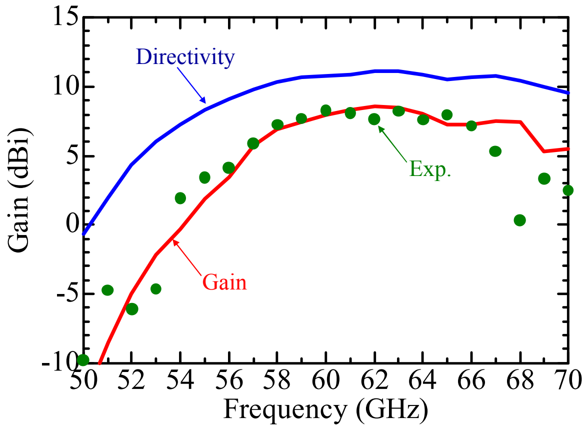


Fig. 8. Measured antenna gain with jig

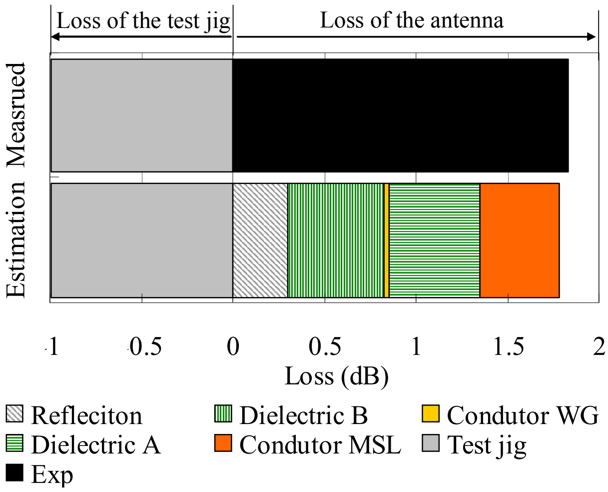


Fig. 9. Loss factors of the antenna at 61GHz

The test jig would affect the directivity of the antenna; however, the loss factors in the propagation of the antenna are same. For instance, the loss factors at 61 GHz of the measured antenna have been shown in Fig.9. The left side from the origin is the measured insertion loss due to the test jig, it is an extract loss which should be separated from the loss of the antenna; the right side from the origin is the estimated loss of the antenna. The loss factors [5] of the small antenna are as follows: The loss of the jig is about 1 dB, the reflection loss is 0.30 dB, the dielectric loss is 1.01 dB in which the dielectric A loss in the MSL is 0.49 dB and the dielectric B loss in the post-wall waveguide and radiation is 0.52 dB. The 0.46 dB conductor loss is the sum of 0.43 dB in the MSL and 0.03 dB in the waveguide and radiation. The total loss for the antenna is 1.78 dB the estimation and 1.83 dB for the experiment with an error of ±0.20 dB due to the measurement system error and the fabrication error.

IV. CONCLUSION

The transmission losses of the post-wall waveguide and the MSL in the small antenna for the wireless transfer system have been discussed. The estimated and measured gains of the antenna with the test jig are in a good agreement. The loss factors of the antenna, including the reflection loss, the dielectric loss, the conductor loss and the loss in the test jig in the measurement, have been quantitatively evaluated. The total loss of the antenna is estimated 1.78 dB at 61 GHz. The dielectric loss of 1 dB is due to the high loss tangent of the substrate. The 90% of 0.46 dB conductor loss is resulted in the microstrip line due to the small thickness of the substrate. The reduction of these losses will be taken into consideration in antenna optimization to achieve a minimum of loss.

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