Measured Return Loss and Predicted Interference Level of PCB Integrated Filtering Antenna at Millimeter-Wave

Jae-Wook Lee[1] · Bong-Soo Kim[2] · Myung-Sun Song[2]

Abstract

In this paper, an experimental investigation for return loss and a software-based prediction for interference level of single-packaged filtering antenna composed of dielectric waveguide filter and PCB(Printed Circuit Board) slot antenna in transceiver module have been carried out with several different feeding structures in millimeter-wave regime. The implementation and embedding method of the existing air-filled waveguide filters working at millimeter-wave frequency on general PCB substrate have been described. In a view of the implementation of each components, the dielectric waveguide embedded in PCB and LTCC(Low Temparature Co-fired Ceramic) substrates has employed the via fences as a replacement with side walls and common ground plane to prevent energy leakage. The characteristics of several prototypes of filtering antenna embedded in PCB substrate are considered by comparing the wideband and transmission characteristics as a function of bent angle of transmission line connecting two components. In addition, as an essential to the packaging of transceiver module working at millimeter-wave, miniaturization technology maintaining the performances of independent components and the important problems caused by integrating and connecting the different components in different layers are described in this paper.

Key words : Filtering Antenna, PCB, LTCC, Millimeter-Wave, Interference, SIW, SIA.

Ⅰ. Introduction

Recently, the development of wireless communication systems brings the fourth generation system with over 100 Mbps data rate from the third generation mainly focused on the voice and image service. In the fourth generation systems, the high-speed data transfer system for various multimedia services needs the wide bandwidth available in millimeter-wave. As a feasibility study, the applicability of millimeter-wave to home network composed of many multimedia services is now being investigated in IEEE millimeter-wave Interesting Group(mmWIG) extending to Study Group(SG) as well as Task Group(TG). In order to achieve the implementation of transceiver operating at millimeter-wave, it costs many efforts and time for the development of millimeter-wave devices and novel packaging. In addition, the communication systems working at millimeter-wave require low-profile, compact, low-loss devices, and highly advanced packaging technology.

As a candidate for the packaging technology in millimeter-wave, high temperature co-fired ceramic(HTCC) and low temperature co-fired ceramic(LTCC) substrates have been proposed at the expense of difficulties in manufacturing process and stability. As an advanced study for the application of general PCB to millimeter-wave systems and for the feasibilities of commonly-used advanced packaging and implementation technologies to millimeter-wave devices, we have experimentally investigated the transmission and reflection characteristics of PCB substrate integrated waveguide filter and combined characteristics of filtering antenna. Also we introduce the predicted interference level between two components using the commercially available software based on FDTD algorithm.

Studies on the design of waveguide filters in a single-layer or multi-layer have been presented in many literatures[1]~[5]. Especially, the various waveguides have been chosen to transfer information with low transmission loss and with little electromagnetic radiation loss in many millimeter-wave and high power systems. But, the waveguide cannot be employed in the planar transceiver structure due to the difficulties in connecting and packaging with small-sized active and passive components. In addition to that, the vertical sidewalls in waveguide can not be implemented in planar and embedded systems. To overcome the major disadvantages caused by using waveguide, all metal structures such as side wall for perfect electric conductor and circular-posts located at the symmetric axis in the waveguide for resonators have been replaced with a series array of via in PCB substrate and LTCC ma-

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terials.

In this paper, the design process and fabrication of waveguide-filter embedded in general PCB substrate by applying the design rule of air-filled WR-22 waveguide filters at 40 GHz are briefly introduced with the transition section between the embedded waveguide and 50 ohms microstrip line increasing the availability of measurement at the input and output ports. The cavity-backed aperture antenna integrated in organic PCB is also introduced with combined filtering antenna including the different feeding structures. The authors have shown the transition characteristics of microstrip-to-waveguide transition part along with the performance of single waveguide filter embedded in PCB and surrounded by various grounded via holes[1].

Ⅱ. PCB Substrate Integrated Waveguide(SIW) Filter

Consider the PCB substrate integrated waveguide filter with via fences instead of side walls as shown in Fig. 1. The proposed waveguide filter embedded in PCB substrate is divided into three important parts;

(1) 50 ohms input and output microstrip lines needed to measure and evaluate the performance of the SIW filter. The input/output microstrip lines might be connected with the signal tip of GSG(Ground-Signal-Ground) probe station or test fixtures using V-connector for measurements.

(2) The microstrip line-to-waveguide transition part to deliver the energy with a low loss into the PCB embedded waveguide. The length and the width of transmission line have been optimized to transfer the energy coming from the input port into the waveguide filter with a low loss.

(3) PCB substrate integrated waveguide(SIW) filter applicable to the band rejection of image signal and high-order harmonics, unexpectedly caused by the non-linearity of active devices, in millimeter-wave transceiver.

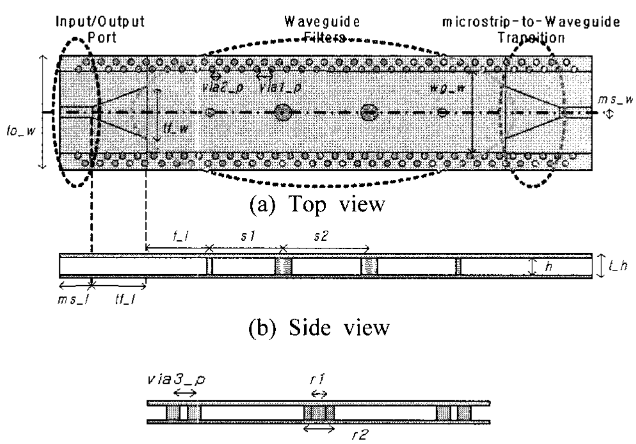


Fig. 1. A scattering geometry of the proposed waveguide filter embedded in PCB substrate.

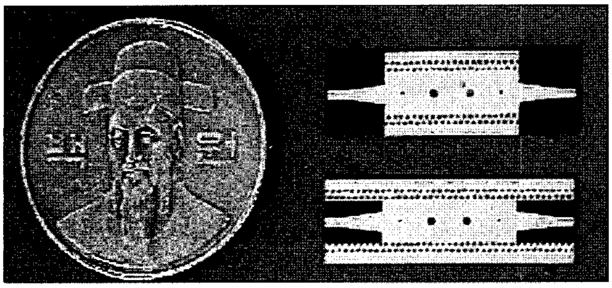
The detailed descriptions for symbols and the optimized values for parameters to satisfy the requirements of waveguide filter are listed in [1], [2]. In order to reduce the overall length and width of the embedded waveguide, the inside waveguide is filled with the higher relative dielectric constant(ε_r) and both the side walls are replaced with via fences. In this paper, an RT/Duroid 5880 substrate with relative dielectric constant, ε_r=2.2 and thickness, h=0.254 mm, has been used to evaluate the performance of waveguide embedded in dielectric substrate. Since TE_{10}-mode is usually treated as a fundamental and mainly propagating mode, the reduction of height in z-axis makes a good contribution to small-sized millimeter-wave system and miniaturized packaging technologies. The advantages in size-reduction of commonly-used and indispensable passive components in communication systems can bring us easy connection and powerful construction in embedded components in terms of packaging of multi-layer structures. From these results, the total length of waveguide filter integrated in organic PCB can be considerably minimized at the expense of a small dielectric loss due to the high relative permittivity of the employed dielectric substrates.

In terms of size-reduction ratio of the embedded waveguide filter, the reduction ratios, approximately 1.25 and 86 relative to waveguide filter composed of WR-22 standard waveguide in length and volume have been obtained, respectively, by assuming the existence of only TE_{10}-mode in waveguide.

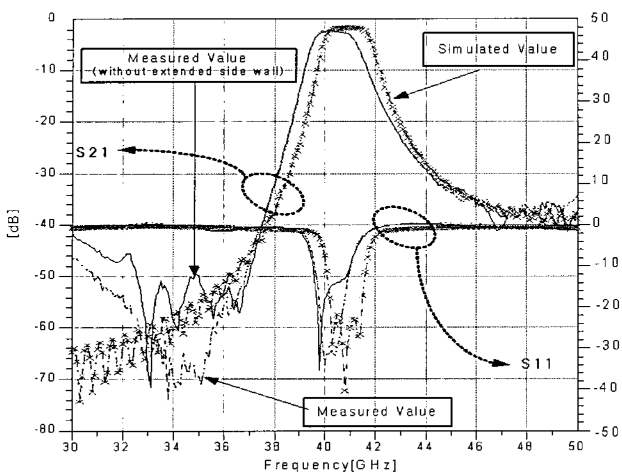
The via diameters used in Fig. 2(a) is 0.3 mm and 0.8 mm for via fences as a replacement with side walls and for circular-posts, respectively. The two rows for side wall of waveguide in Fig. 2(a) are extended in order to protect the leaky energy generated from the transition part. The microstrip input/output ports and transition part are mounted on the top side of waveguide filter. To investigate the effect of side wall on the transmission characteristics, two types of waveguide filter have been fabricated as shown in Fig. 2(a) and give a good agreement between the predicted and measured results as shown in Fig. 2(b).

Ⅲ. PCB Substrate Integrated Antenna(SIA)

To test the performance of proposed PCB substrate integrated antenna operating at 40 GHz, we have designed aperture antenna with cavity-backed resonator



(a) Photograph of waveguide filter



(b) Performances of the proposed filter

Fig. 2. Photograph of the fabricated waveguide filter as a single unit with measured and simulated results.

under the matched feeding line for antenna radiation efficiency. The employed substrate has a relative dielectric constant, ε_r=2.2, and thickness, h=0.254 mm of Rogers RT/Duroid 5880. To obtain the perfect ground effect at the top layer, the ground vias between the top and bottom layers are connected with circular-filled cylinder of 300 μm diameter through via holes in layer 1 as shown in Fig. 3 and connecting vias between the substrate and the resonant cavity of Fig. 4(b) are located around the corners of antenna structure.

Fig. 3 shows the entire aperture antenna structure integrated into organic PCB substrate. The feeding line on the bottom of the lowest layer is matched to 50 ohms impedance. The used strip widths, W_1, W_2, and the lengths, L_1, L_2 of matched feeding line at the input port for aperture antenna are W_1=820 μm, W_2=190 μm, L_1=7371 μm, and L_2=1872 μm, respectively.

To verify the simulated results, 40 GHz antenna using organic PCB material was implemented and measured. The bandwidth of microstrip antenna is proportional to the volume represented by length, width, and height of the overall antenna. In addition, the input impedance bandwidth of PCB substrate integrated antenna can be represented by the following approximate equation with

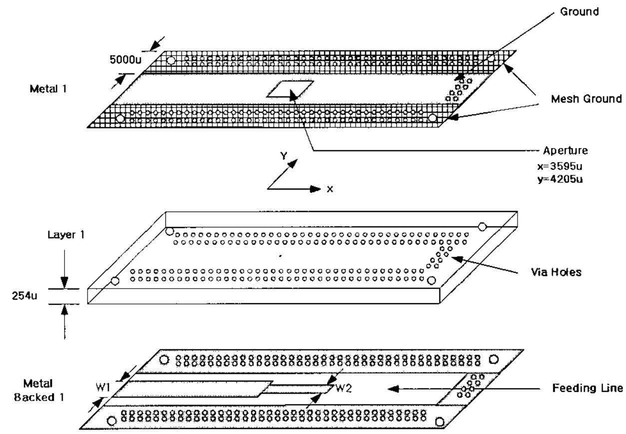
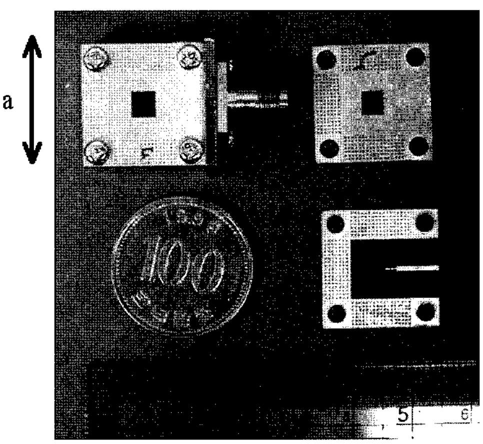
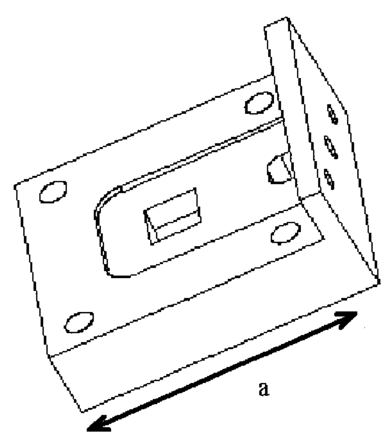


Fig. 3. Detailed description for the structure of PCB substrate integrated antenna(SIA) [μm].



(a) Photograph of fabricated antenna



(b) Cavity-backed resonator for improving the antenna radiation efficiency(antenna dimension=a×a, a=2 cm)

Fig. 4. PCB substrate integrated antenna with cavity-backed resonator.

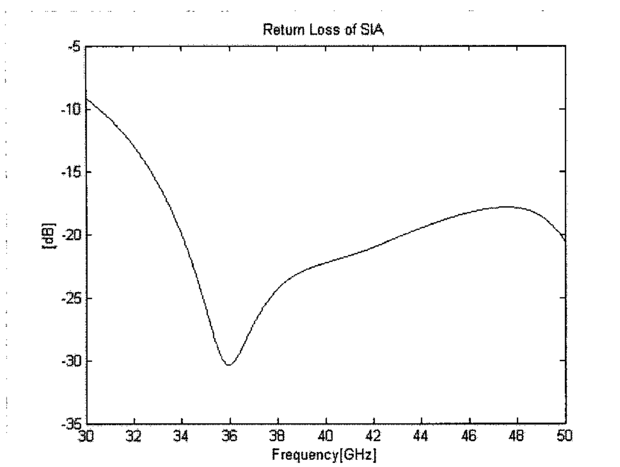
relative ratio to the bandwidth of LTCC substrate integrated antenna.

$$BWR \approx (h_{pcb} / h_{ltcc}) / \sqrt{\varepsilon_{r,pcb}/\varepsilon_{r,ltcc}} \quad (1)$$

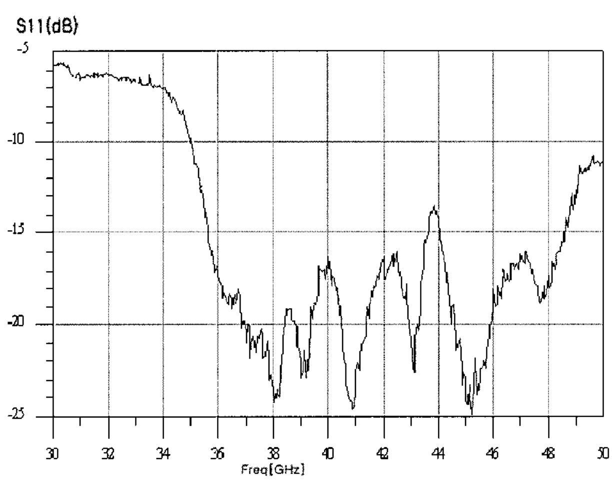
where h_{pcb}, h_{ltcc}, $\varepsilon_{r,pcb}$ and $\varepsilon_{r,ltcc}$ represent the height and permittivity of the employed substrates including PCB and LTCC materials, respectively.

Fig. 4 shows the photograph of PCB integrated antenna and the layout of the resonant cavity for radiation efficiency improvement. The results between Fig. 5(a) and (c) have a little deviation at the frequency range from 45 GHz to 50 GHz and the resonant frequency due to the misalignment between the feeding line and the center point of resonator.

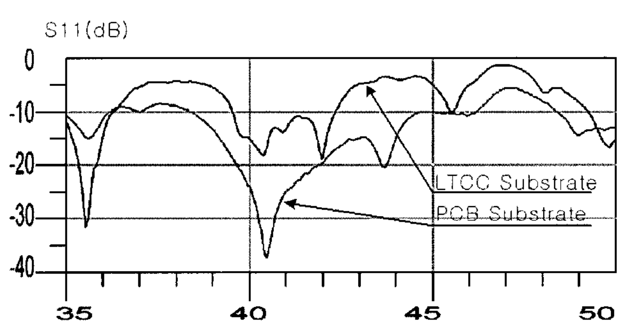
The descriptions for the results using LTCC materials in Fig. 5(c) is omitted and shown in [2].



(a) Predicted result with cavity



(b) Measured datum without cavity



(c) Measured data with cavity using different substrates

Fig. 5. Simulated and measured results with/without resonant cavity.

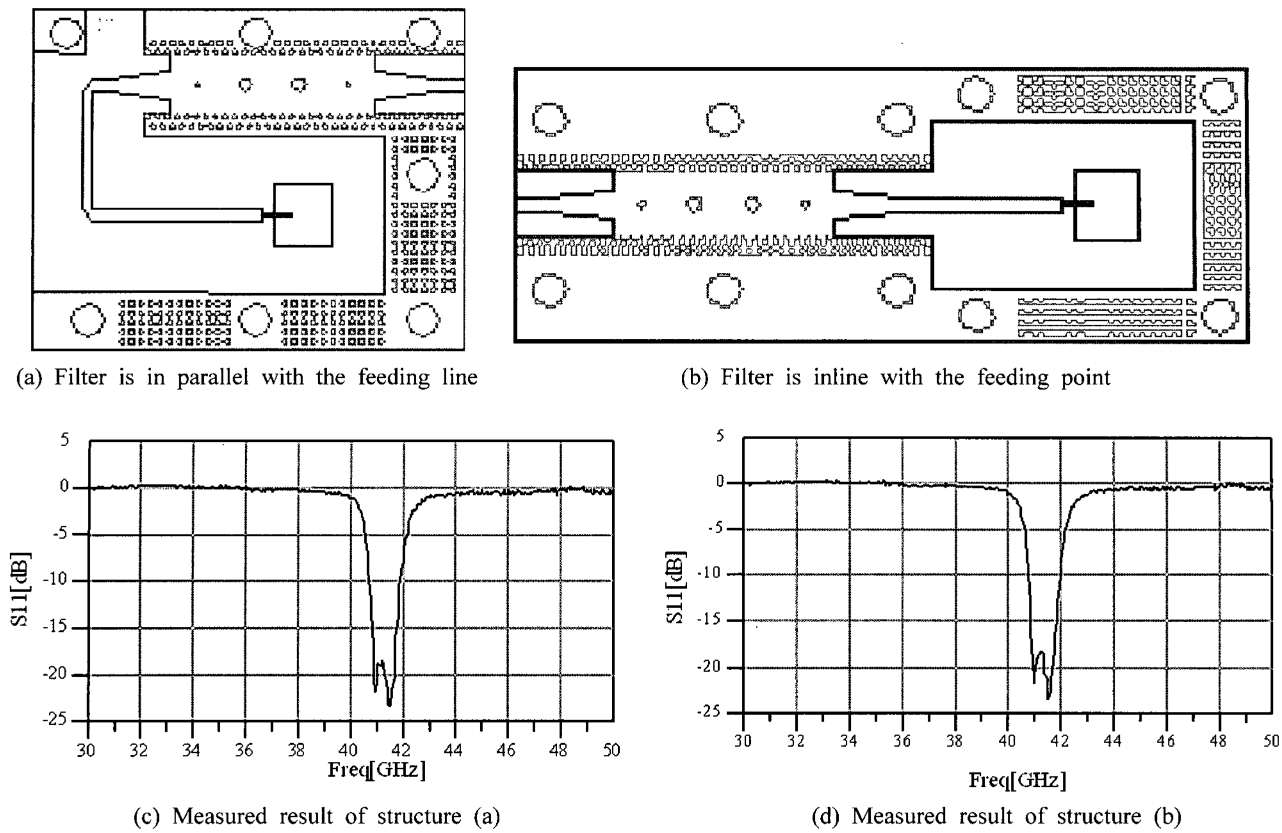
Ⅳ. The Characteristics of Filtering Antenna with Different Feeding Lines

Two passive components, which are waveguide filter bounded by via fences and cavity-backed aperture antenna with common ground at the top surface, are integrated and combined in PCB substrate. The characteristics of filtering antenna are described in terms of return loss. The overall size of the proposed filtering antenna working at millimeter-wave is 2 cm $\times$ 2 cm as a single aperture element. The 2×2 arrays can be arranged in the same size whereas the extension to 4×4 arrays can be obtained by removing the filter structure in the same size. Fig. 6(a) and (b) show the layouts according to the combining location between two components and these structures can be used to evaluate the interference level caused by the neighboring two components. The return loss characteristics of filtering antenna are similar to those of waveguide filter without antenna as shown in Fig. 6(c) and (d). This means that the impedance matching between the antenna input port and filter output port have been accomplished with the wideband characteristics of antenna. The experiments have been carried out in a laboratory with network analyzer 37397C of Anritsu and test fixture.

Fig. 7 describes the interference level between two components. From the given data, we can assume that the interference phenomena through mutual coupling are negligible in a single package composed of SIW filter and SIA. The port 1 is defined at the antenna input and the others are for SIW filter.

Ⅴ. Conclusion

In this paper, a single package composed of filter with via fence instead of side walls and antenna with aperture-coupled cavity backed structure has been suggested and implemented. As a goal of obtaining the miniaturized structure and less interference structure, several types of filtering antenna have been suggested and measured according to the different feeding structures. In terms of return loss, it is shown that the fabricated antenna maintains the independent characteristics of each component under the matched conditions between two components. In addition to that,



(a) Filter is in parallel with the feeding line

(b) Filter is inline with the feeding point

(c) Measured result of structure (a)

(d) Measured result of structure (b)

Fig. 6. Measured return loss of PCB embedded filtering antenna with different feeding structures.

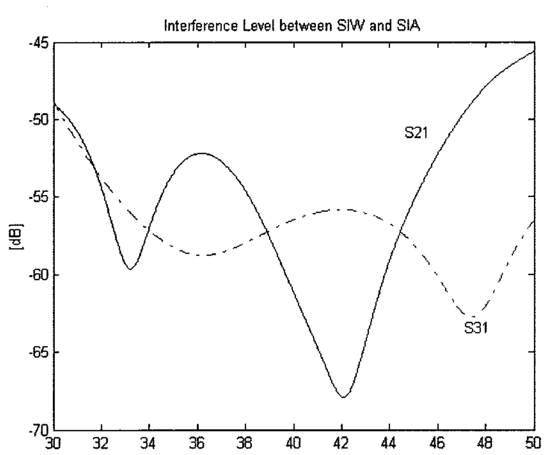


Fig. 7. Predicted interference level between SIW filter and SIA.

it has been shown that the interference level is negligible in a single package. As a result, it has been investigated that the miniaturized and low-cost filtering antenna satisfying the required specifications and maintaining the independent self-performance can be realized by using the general PCB substrate at millimeter-wave regime.

References

[1] Bong S. Kim, Jae W. Lee, Kwang S. Kim, and Myung S. Song, "PCB substrate integrated waveguide-filter using via fences at millimeter-wave", *2004 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1097-1100, Jun. 2004.

[2] Jae W. Lee, Bong S. Kim, Kwang S. Kim, Ki C. Eun, and Myung S. Song, "A comparison between PCB substrate integrated antenna and LTCC antenna at millimeter-wave", *Proceedings of the IASTED International Conference on Antennas, Radar, and Wave Propagation (ARP)-2004*, Banff, Canada, pp. 78-81, Jul. 2004.

[3] M. Ito, K. Maruhashi, K. Ikuina, T. Hashiguchi, and S. Iwanaga, "A 60-GHz-band planar dielectric waveguide filter for flip-chip modules", *IEEE Trans. Microwave Theory & Tech.*, vol. MTT-49, no. 12, pp. 2431-2436, Dec. 2001.

[4] Yu Rong, K. A. Zaki, M. Hageman, D. Stevens, and J. Gipprich, "LTCC wide-band ridge waveguide bandpass filters", *IEEE Trans. Microwave Theory & Tech.*, vol. MTT-47, no. 9, pp. 1836-1840, Sep. 1999.

[5] H. Uchimura, T. Takenoshita, and M. Fujii, "Deve-

lopment of a 'Laminated Waveguide' ", *IEEE Trans. Microwave Theory & Tech.*, vol. MTT-46, no. 12, pp. 2438-2443, Dec. 1998.

[6] B. Froppier, Y. Mahe, E. M. Cruz, and S. Toutain, "Desing of a filtering antenna: application to the electromagnetic horn", *IEEE Int'l Symposium on Antennas and Propagation*, 2003.

[7] Kwang S. Kim, Bong S. Kim, Jae W. Lee, Ki C. Eun, and Myung S. Song, "Low loss vertical transition for millimeter-wave LTCC module", *International Joint Conference of the 6th Topical Symposium on Millimeter Waves, TSMMW 2004, the 5th MINT Miliimeter-Wave International Symposium, MINT-MIS2004*, pp. 114-117, Feb. 2004.

[8] A. Kerkhoff, H. Ling, "Desing of a planar monopole antennas for use with ultra-wideband(UWB) having a band-notched characteristic", *IEEE Int'l Symposium on Antennas and Propagation*, 2003.

[9] G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave filters, impedance-matching networks, and coupling structures*, Artech House, pp. 450-459, 1980.

[10] D. Deslandes, K. Wu, "Integrated microstrip and rectangular waveguide in planar form", *IEEE Microwave and Wireless Components Letters*, vol. 11, no. 2, pp. 68-70, Feb. 2001.

[11] "CST Microwave Studio, Release 5.0", Tech. Rep., 2004.

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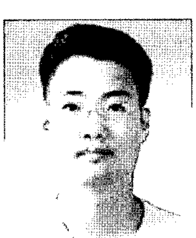

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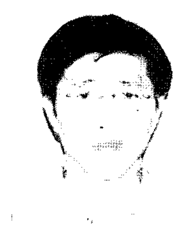

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