Metal-Plated Plastic Waveguide Filter Using Injection Molding Process

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Abstract — **A metal-plated plastic waveguide filter for Ka-band wireless internet access systems is presented. As the filter is made using a plastic injection-molding process, the influence of indispensable draft angle on waveguide walls was precisely considered in design. By merging this design technique with the high-accurate molding technique, it was achieved none electrical tuning. It also realized the mass-productivity and cost reduction of waveguide components over Ka-band.**

I. Introduction

For commercial use of Ka-band terrestrial wireless internet-access system [1] and satellite internet-communication system [2], a mass-productivity and a low cost of ODU (Outdoor Unit) transceiver equipment are required. High cost RF components in Ka-band ODU are chiefly MMICs and waveguide filters. Since the wavelength is short in a frequency band 20GHz or more, the filter needs severe dimensional accuracy of 20 micron meters or less. For this reason, the conventional metal waveguide filter manufactured by machining is expensive. Alternatively the application of metal die-cast process is limited up to Ku-band because the accuracy of the process is about 50 micron meters. Our high precision simulation-design technology and high precision plastic injection molding process technology realized this accuracy.

In this paper, the design method of plastic waveguide filter is described, taking the inevitable draft angle of waveguide wall into consideration. And experiments under ambient temperature and heat shock conditions are demonstrated. Good results were obtained. Consequently, it is shown that the developed plastic waveguide technology is fully utilizable.

II. Design

A. Structure

The LCP (liquid crystal polymer) was chosen as a plastic material, because the thermal expansion coefficient is equivalent to aluminum and it is suitable for injection molding process and for steady plating with anti-peeling. In addition the density is 60% of aluminum.

Fig.1 shows the structure of plastic waveguide filter manufactured by using injection-molding process. This filter has several cavity-resonators coupled mutually by inductive irises. The melted plastic is injected by high pressure into the precise metallic mold, and it is taken out after hardening. Metal which is sufficiently thicker than the skin depth is plated on the all surface of this plastic. Plated plastic parts are assembled with screw and waveguide filter is formed. Here, copper was plated as a conductive metal and thin nickel plating was superposed on the copper for anticorrosive.

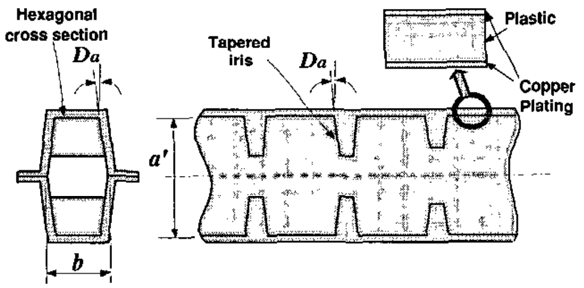

Fig.1 Metal-plated plastic waveguide band-pass filter

In a molding manufacturing process, in order to take out the plastic waveguide parts smoothly from a metallic mold, a draft angle D_a of waveguide wall is inevitable. For this reason, the waveguide transverse section becomes hexagonal shape, and irises become taper forms.

B. Design considering the draft angle

In the design of a plastic injection-molding waveguide component, the influence of the draft angle D_a and the contraction must be taken into consideration. As shown below, design procedures 5 to 7 which relate to the plastic injection-molding process were added to design procedures 1 to 4 of the conventional waveguide filter furthermore. Especially in design procedures 4 and 6, the influence of a dimensional error needed to be investigated and to be decided the tolerance, and it has calculated by

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the high precision full-wave analysis simulator using mode matching technique, which has been developed in-house [3], [4]. Since this simulator can increase the number of the evanescent modes if needed and can make simulation accuracy higher, if a waveguide filter can be manufactured with high precision, it will become unnecessary to tune the pass-band frequency or return loss performances etc. Design procedures are shown as following;

1. Design of fundamental filter based on the equivalent circuit
2. Simulation of the fundamental filter, and performance verification
3. Design of physical dimension for rectangular waveguide filter
4. Simulation of the rectangular waveguide filter, and performance verification
5. Design of the waveguide resonator width a' in consideration of the draft angle in the transverse cross-section of waveguide
6. Design of the resonator length and the iris thickness in consideration of the draft angle in the longitudinal cross-section of waveguide
7. Design of the metallic mold in consideration of the contraction

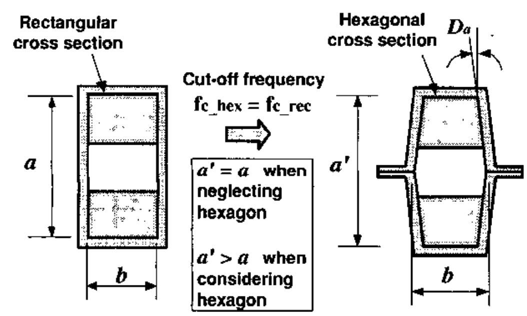


Fig.2 Design of hexagonal waveguide cross-section

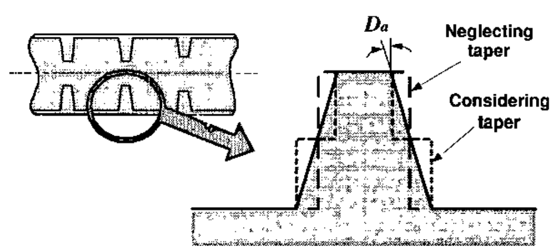


Fig.3 Model of tapered iris for mode-matching simulation

In above-mentioned design procedure 5, as shown in Fig.2, it proceeds so that the fundamental mode cut-off frequency f_{c_hex} of hexagonal waveguide becomes equal to TE_{10} mode cut-off frequency f_{c_rec} which is the fundamental mode of rectangle waveguide verified in procedure 4, as given by

$$f_{c\_hex} = f_{c\_rec} = C_0 \ / \ (2a) \qquad (1)$$

C_0 is the velocity of light, and a is the width of rectangular waveguide. The cut-off frequency of hexagonal waveguide is solved by the 2-dimensional finite element method approximated by quadratic function. And Fig.3 shows the model of tapered iris, which is approximated by steps for mode-matching simulation.

In Fig.4 (a), (b), and (c), solid lines show in common

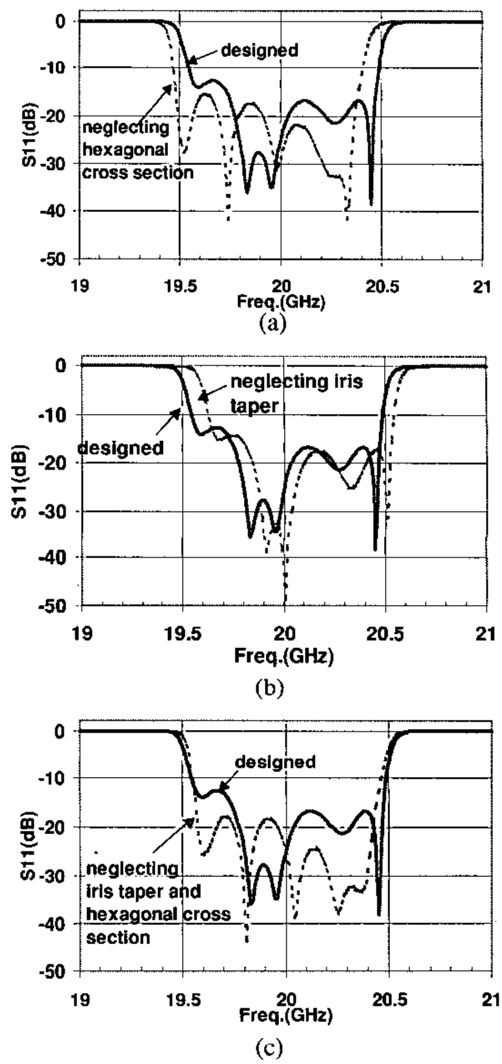


Fig.4 Simulated return loss of designed and modified filters

the calculated return loss of the 20GHz band-pass filter with 7 cavity resonators, designed as a first prototype. From 19.8 to 20.4GHz, return loss is more than 16.5dB. In this prototype design, optimization of RF performance is omitted, paying attention to investigating the influence of a draft angle. In the design of a metallic mold, the draft angle was fixed 0.8 degrees, and the physical size was designed. And in each Fig.4 (a), (b), and (c), broken lines denote the return loss of modified filters under the following conditions, respectively.

In Fig.4 (a), regardless of only transverse draft angle, the hexagonal shape in cross section is neglected. Then the pass-band frequency is lower 70MHz as compared with the proper design. It is the reason that a resonant frequency of rectangular waveguide cavity is lower than a hexagonal one having same width.

In Fig.4 (b), regardless of only longitudinal draft angle, the tapers in irises are neglected. Then pass-band frequency is higher 70MHz on the average, and bandwidth is narrow. It is the reason that the equivalent length of cavity becomes short and coupling between cavities is weakened, because the iris is assumed to have uniform thickness and to be thicker at the top than the model in proper design procedure, as shown in Fig.3.

In Fig.4 (c), regardless of both transverse and longitudinal draft angles, there is no hexagon and taper. By canceling out the phenomena in Fig.4 (a) and (b) mutually, the change of pass-band frequency is small. However the bandwidth becomes narrower. Moreover, the return loss differs greatly in pass-band.

As a result, it turns out that consideration of a draft angle is important for the plastic filter design.

III. MEASURED RESULTS

A. Measured result of prototype filter

The photograph of the 20GHz band-pass plastic filter is shown in Fig.5. Measured value as a solid line is shown in Fig.6 and the design value is shown as a broken line for comparison. The new design procedure stated above II is appropriate, since the measured result corresponded with the design value within 15MHz.

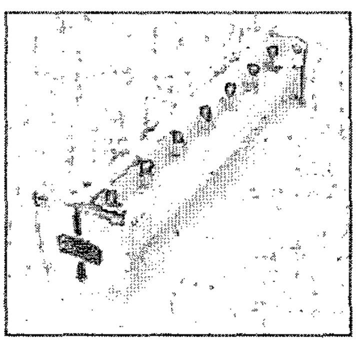
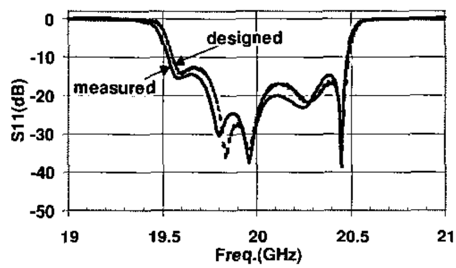


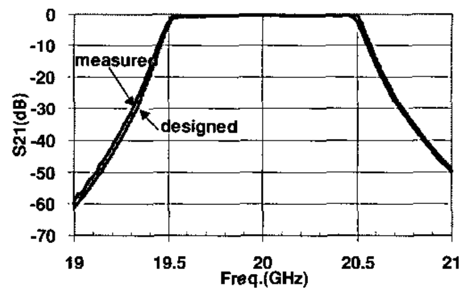
Fig.5 Photograph of 20GHz plastic filter

Fig.7 shows the measured return loss and insertion loss of seven filters manufactured by using single mold. The pass-band frequency variation is within 35MHz and the return loss is 16.1dB or more from 19.8 to 20.4GHz. Consequently, provided that a metallic mold is precisely designed and is faithfully machined, and a highly precise plastic injection molding is proceeded, then it is shown that the wavegide filter with stable performance can be quickly manufactured in large quantities by no tuning.

In spite of carrying out nickel-plating on copper, the minimum insertion loss is 0.35dB. Moreover, the insertion loss of plastic filter with copper plating without nickel is 0.25dB, and 0.2dB of conventionally machined copper filter. It becomes clear that the insertion loss of a plating plastic waveguide filter is equivalent to a conventional metal one.



(a) Return loss



(b) Insertion loss

Fig.6 Measured results compared with design

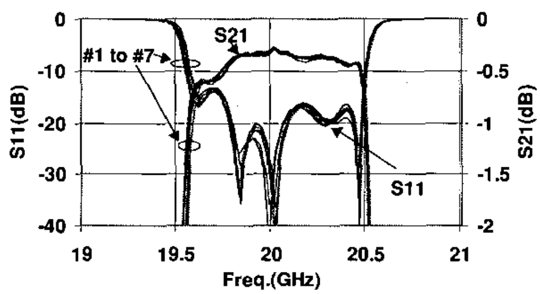


Fig.7 Measured results of seven prototype filters

B. Return loss improvement

Furthermore, we improved the return loss of plastic filter based on design procedure. The measured result of return loss is shown in Fig.8. More than 24dB return loss was obtained. The verification of the designing method

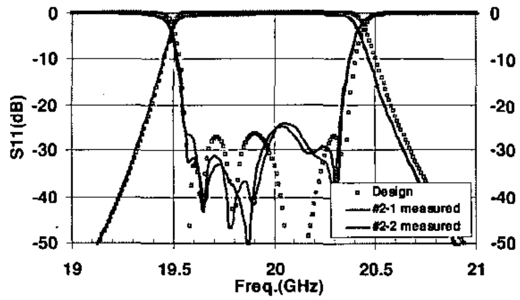


Fig.8 Improvement of return loss

was completed. In addition, center frequency was a little low and bandwidth became narrower than the designed value, but it is thought of because that the dimensional error within 20 micrometers exists actually.

IV. TEMPERATURE DEPENDENCE AND HEAT SHOCK ENDURANCE

The thermal expansion coefficient of LCP is about $30*10^{-6}$. It is nearly same coefficient as aluminum, that is, $23*10^{-6}$. Since the temperature change rate in frequency characteristic is in agreement with the thermal expansion coefficient *Te*, as given by

$$f_d \ / \ f_0 = Te \qquad (2)$$

Then the the pass-band frequency change f_d at -40 to +80 degree-C will be expected to be 72MHz.

The temperature dependence of prototype filter is shown in Fig.9. The pass-band frequency change was 87MHz, it almost agrees with above prediction.

Fig.10 shows the heat shock test result up to two thousand cycles from -55 to +125 degree-C. The transition time was 6 minutes, and holding was 30 minutes. No deterioration was observed.

V. CONCLUSION

The mass production and cost reduction of Ka-band waveguide component are enabled by combination of high precision design technology and plastic injection-molding technology. The developed plastic waveguide filter has equivalent performances to conventional metal one.

REFERENCES

[1] M.Matsumoto, "Issues on the Use of Radio Spectrum and Its Prospects in Japan," *IEICE, Proc., Contribution*, vol.85, No.4, pp.227-231, Apl.2002.

[2] P.Chitre, R.Gupta, "Satellite Systems for Multimedia and Internet Traffic," *2001 IEEE MTT-S International Microwave Symposium, Dig.*, WE4D, pp.1129-1132,May 2001.

[3] M.Miyazaki, H.Yukawa, T.Nishino, S.Urasaki, T.Takagi, H.Kurebayashi, "Design of Iris-Coupled Broadband Waveguide Filter Using Modified Reflection-Zero Frequencies," *IEICE, Trans.*, Vol.J81-C-I, No.11, pp.642-649, Nov.1998.

[4] N. Yoneda, M. Miyazaki, T. Horie, M. Yamato, T. Noguchi, "Analysis and Design Techniques of Waveguide Circuits Using Electromagnetic Theory," *MWE2000 Microwave Workshop Dig.*, pp.61-66, Dec.2000.

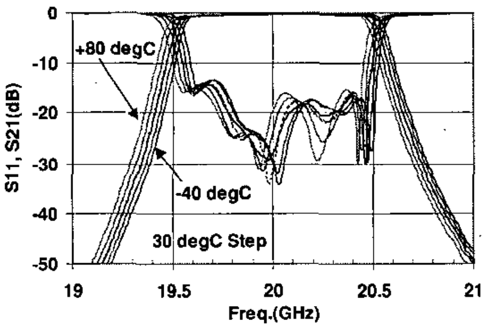


Fig.9 Temperature dependence of plastic filter

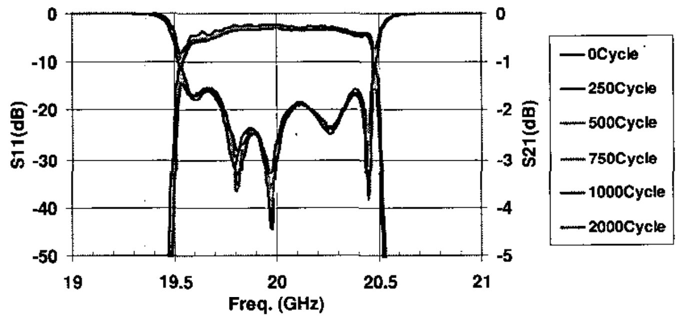


Fig.10 Heat shock endurance of plastic filter
(Transition time: 6 minutes from -55 to +125 degree C)