# A Ku-band Low-loss Stripline Low-pass Filter for LTCC Modules with Low-impedance Lines to Obtain Plural Transmission Zeros

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*Abstract* — **A Ku-band low temperature co-fired ceramics (LTCC) multi-layered stripline low-pass filter (LPF) is presented. By employing a low-impedance line as an inductive element in a resonator, plural transmission zeros can be obtained near passband, therefore, presented LPF realizes excellent attenuation characteristics despite a small number of resonators. The LPF has extremely low insertion loss and compact dimensions, especially thin profile, and is suitable for RF-modules. An LPF with 0.9mm*0.9mm*0.4mm dimensions has been fabricated and measured results shows validity of the proposed structure.**

## I. Introduction

Recently, LTCC is growing rapidly as one of key technologies for many RF-applications, such as wireless communications. LTCC can provide compact and low-cost RF-modules with high-density multi-layered structures and embedded passives [1]-[3]. In these modules, as microwave monolithic integrated circuits (MMIC's) are also mounted on surface of LTCC, it often becomes important to control thermal condition for their steady operation. However, thermal conductivity of LTCC is not good compared to other ceramic materials [4]. Accordingly, embedded passive circuits for the modules are desirable to have low-loss characteristics to reduce power consumption of MMIC amplifiers and thin profile to decrease thermal resistances of LTCC multi-layered structures.

In this paper, a Ku-band LTCC multi-layered stripline LPF to suppress harmonics and spurious of power amplifier MMIC's is presented. The LPF gives extremely low insertion loss and compact dimensions, especially thin profile. Therefore, it is appropriate for embedding into transmitter modules.

The presented LPF is a kind of semi-lumped element filters with parallel resonators for producing transmission zeros at stopband. Circuit elements in semi-lumped element LPF's mainly consist of transmission line segments. For realizing inductive elements, transmission line segments with high characteristic impedance are conventionally employed [5]-[7]. Here, a series reactance of a transmission line segment varies as sinusoidal function of frequency, not is proportional to frequency like that of a lumped-inductor. We focus our attention on that point and propose to apply a transmission line with low characteristic impedance to realizing an inductive element in a resonator. Though electrical length of a transmission line segment becomes larger by adopting a low-impedance line, period of sinusoidal function concerning a series reactance can be made small and two transmission zeros can be acquired near passband. Obtaining two zeros per a resonator leads to reduction of the number of parallel resonators that will have low Q factor due to their small volumes and gives LPF with low insertion loss and excellent attenuation characteristics. Also, since there are not any high impedance lines in the filter circuit, distance between two ground conductors of stripline becomes small. An LPF with 0.9mm* 0.9mm*0.4mm dimensions is fabricated at Ku-band and measured results shows validity of the proposed structure.

## II. Configuration

Fig.1 illustrates cross-sectional view of an LTCC multi-layered transmitter module mounted on a printed wiring board (PWB) using ball grid arrays (BGA). Several passive circuits are embedded in multi-layered structure of a package composed of LTCC, and MMIC's are mounted on the package and connected to transmission lines or bias lines on the package using bond-wires. An LTCC lid seals up the package. In this module, thermal VIA's are placed in LTCC multi-layered structure under power amplifier MMIC's to compensate poor thermal conductivity. Embedded passives are desirable to have low insertion loss and thin profile.

Fig.2 shows a configuration of proposed stripline LPF. This filter is a kind of semi-lumped LPF's with only one parallel resonance circuit for obtaining transmission zeros, and filter degree of this LPF is 3. A parallel-plate capacitor is placed centrally in filter circuit and a transmission line with low characteristic impedance is laid out around the capacitor since the transmission line has relatively large electrical length at cut-off frequency. The capacitor and the transmission line are connected in parallel at each end. A VIA hole is used for the



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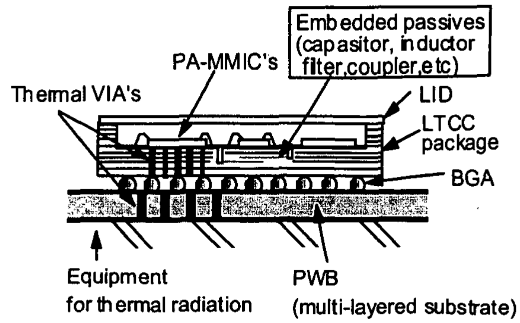



Fig.1. LTCC RF-module mounted on PWB using BGA.

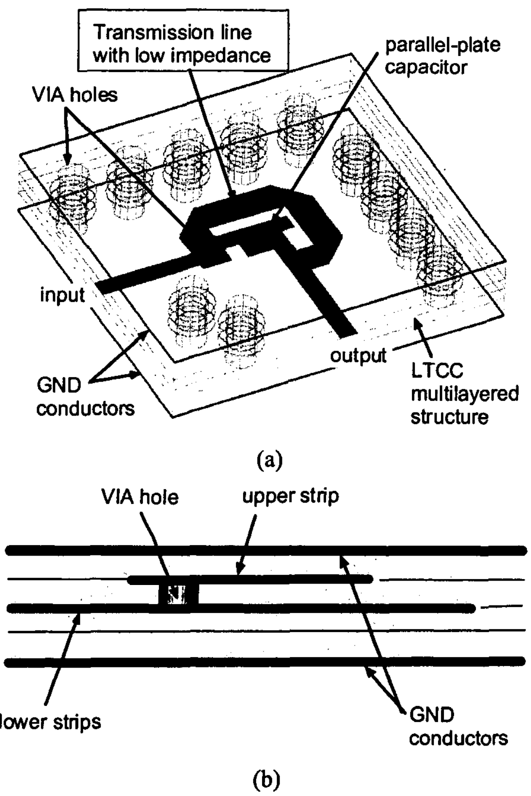



Fig.2. Proposed stripline LPF, (a) Pattern layout and (b) Cross-sectional view.

connection at one end of the capacitor. At the two ends of the capacitor, input or output transmission lines are also connected, respectively.

### III. DESIGN TO OBTAIN PLURAL TRANSMISSION ZEROS

Fig.3 shows an equivalent circuit of the LPF illustrated in Fig.2. Provided that dimension of the parallel-plates capacitor is smaller enough than wavelength for ease of explanation, equivalent circuit of the parallel-plates capacitor is expressed as $\pi$-circuit composed of three elements, $C_s$ and two $C_p$'s. $C_s$ is a series-capacitive element and $C_p$'s are shunt-capacitive elements, respectively. Electrical length of transmission line connected with the parallel-plate capacitor is $\theta_t$ and characteristic impedance is $Z_t$.

Fig.4 shows an equivalent expression of transmission line segment [8], where $X_t$ is a series reactance and $B_t$'s are shunt susceptances. They are represented as functions of $Z_t$ and $\theta_t$. Prototype filter circuit for designing proposed LPF is shown in Fig.5. The equivalent circuit shown in Fig.3 is required to coincide with prototype filter shown in Fig.5 at cut-off frequency $\omega_c$. Hence,

$$\omega_c C_s - (1/Z_t)\csc\theta_c = -1/(\omega_c L_0) \quad (1)$$

$$\omega_c C_p + (1/Z_t)\tan(\theta_t/2) \approx \omega_c C_0 \,. \quad (2)$$

$\theta_c$ is electrical length of transmission line segment with low characteristic impedance at cut-off frequency $\omega_c$.

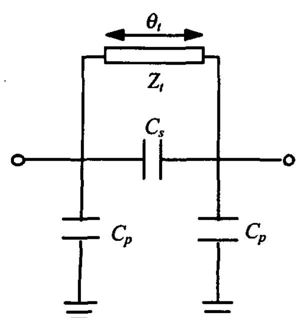
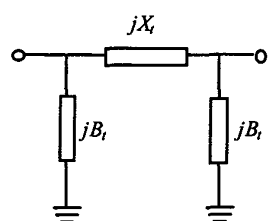



Fig.3 Equivalent circuit of LPF in fig.2




$X_t = Z_t \sin\theta_t$

$B_t = (1/Z_t)\tan(\theta/2)$

Fig.4. Equivalent expression of transmission line.

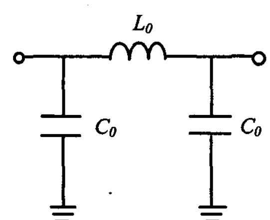



Fig.5. Prototype filter.

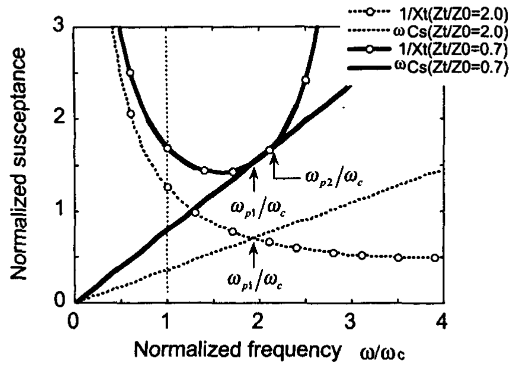



Fig.6. Frequency dependence of susceptances of circuit elements concerning parallel resonator.

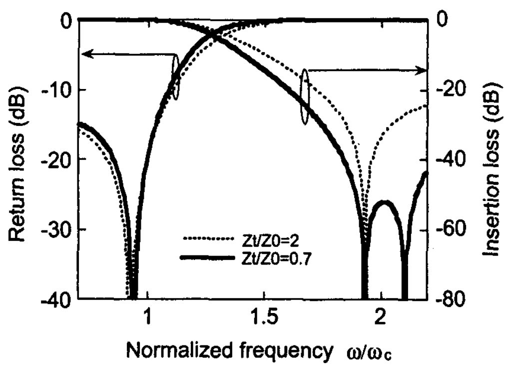



Fig.7. Simulated return and insertion losses of LPF's using resonator in Fig.6.

At frequency $\omega_{p1}$ that is a resonance frequency of parallel resonator composed of $X_t$ and $\omega C_s$, next equation is obtained:

$$\omega_{p1} C_s = (1/Z_t)\csc(\theta_c \omega_{p1}/\omega_c) . \qquad (3)$$

After $\omega_c$, $\omega_{p1}$, and $Z_t$ are adopted, $\theta_c$ and $C_s$ are obtained by solving (1) and (3). These equations contain a transcendental equation and need to be solved numerically.

$Z_t$ is a parameter that designers can select arbitrarily. When $Z_0$ is impedance of external circuits, value of $Z_t$ is conventionally selected to be larger than $Z_0$ as possible since large value of $Z_t$ leads to reduction of both width of strip conductors and an electrical length $\theta_c$, and makes filter dimensions small.

On the other hand, reactance $X_t$ that is correspond to an inductive element in resonator varies as sinusoidal function of frequency. A transmission zero appears at frequency where summation of susceptances of two elements in parallel resonator is equal to zero. In case that $Z_t$ is large, namely when $\theta_c$ is small, since $1/X_t$ is almost inversely proportional to frequency near cut-off frequency $\omega_c$ and $\omega C_s$ is proportional to frequency, only one transmission zero appears near $\omega_c$. But in case that $Z_t$ is small, namely when $\theta_c$ is large, $1/X_t$ can vary rapidly near $\omega_c$ because of small period of sinusoidal function included in $X_t$. Fig.6 shows frequency dependences of susceptances of circuit elements concerning parallel resonator. The frequency dependences are simulated using parameters obtained from (1) and (3) for Tchebyscheff response with 0.05dB ripple level, when $Z_t/Z_0$ is equal to 2 and 0.7. When $Z_t/Z_0$ is equal to 0.7, it is clear that two susceptances, $1/X_t$ and $\omega C_s$, are equal at another frequency near $\omega_{p1}$. Return and insertion loss characteristics are simulated in above two cases and shown in Fig.7. At $Z_t/Z_0$=0.7, two transmission zeros appear near passband. In result, steeper rejection characteristics and better rejection characteristics are obtained. Using $C_s$ and $\omega_c$ obtained from (1) and (3), 2nd lowest zero frequency $\omega_{p2}$ is evaluated by solving next equation:

$$\omega_{p2} C_s = (1/Z_t)\csc(\theta_c \omega_{p2}/\omega_c)$$
$$\omega_{p1} \le \omega_{p2} < \omega_c \pi/\theta_c . \qquad (4)$$

## IV. Experimental Results

At Ku-band, proposed LTCC multi-layered stripline LPF was designed and fabricated for BGA transmitter modules of mobile satellite communication terminals. Design procedure is as follows. At first, values of circuit elements in Fig. 3 and 4 were determined according to a method described in previous section and initial pattern arrangement was fixed from the initial values. Using EM simulator for planar circuits (e.g. Agilent Momentum), the initial patterns were optimized.

Fig.8 shows a photograph of the fabricated LTCC test-chip in which a proposed multi-layered LPF is embedded. Permittivity of LTCC materials is 7.0. Dimensions of the pattern of fabricated LPF are 0.9mm*0.9mm, and thickness, namely distance between ground conductors, is 0.4mm. In Fig.9, measured return loss and insertion loss characteristics are shown with calculated results using EM simulator. The measured data in Fig.9 (a) contain characteristics of transitions and input transmission lines since the test-chip were evaluated through LRM calibration technique using on-wafer measurement system. In Fig.9 (a), measured results shows good agreement with calculated results though there is a little difference in frequencies of transmission zeros, about 5%. Especially, two transmission zeros appears and more than 30dB rejection around 30 GHz band is obtained in measured

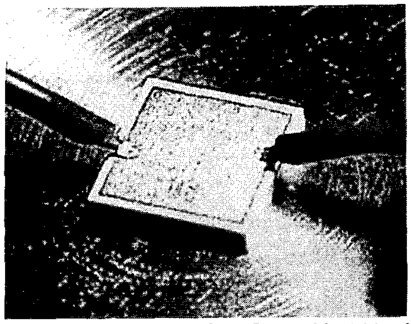
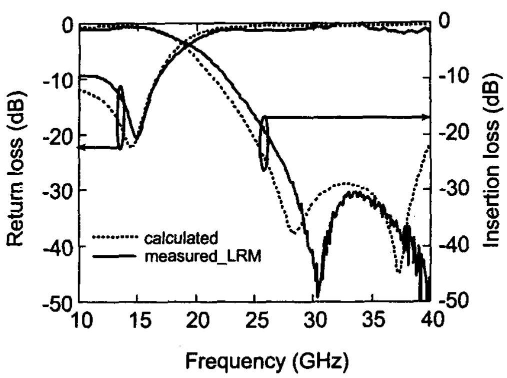
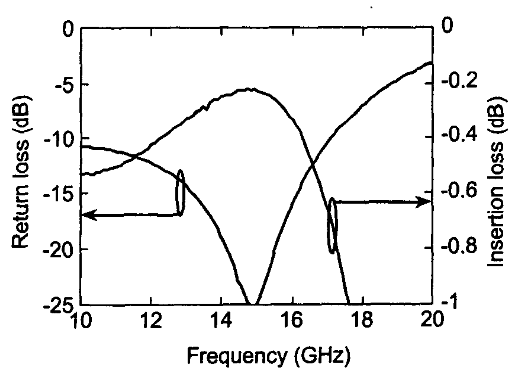


Fig.8. Fabricated Ku-band LTCC LPF test-chip (chip size; 8mm * 8mm*1mm).




(a)




(b)

Fig.9. Measured return loss and insertion loss of fabricated LPF chip. (a) Through LRM calibration and (b) through TRL calibration around cut-off frequency (including 2mm long input transmission line).

results. In order to acquire pure characteristics of the fabricated LPF, measurements through stripline TRL calibration have been made. Measured insertion loss and return loss in or around passband through TRL calibration are shown in Fig.9 (b). In this figure, measured data include only characteristics of input transmission line with 2mm length and one 90deg corner in addition to LPF circuits. Insertion loss is about 0.3dB at frequency band from 13GHz to 16GHz. From these results, it is verified that the fabricated LPF has extremely low loss characteristics.

## V. CONCLUSION

In this paper, an LPF employing transmission line with low characteristic impedance for plural transmission zeros near passband has been proposed. The LPF fabricated at Ku-band realized excellent attenuation characteristics in spite of a small number of resonators for zeros, as well as a small number of degrees of prototype filters. In addition, it provided compact dimensions, especially thin profile. Proposed LPF is appropriate as an embedded filter in LTCC multi-layered modules because of their low loss characteristics and thin profile.

## REFERENCES


[1] C. H. Lee, A. Sutono, S. Han, and J. Laskar, "A compact LTCC Ku-band transmitter module with integrated filter for satellite communication applications," 2001 IEEE MTT-S Int. Microwave Symp. Dig., vol. 2, pp. 945-948, May 2001.

[2] Dan Amey, Peter Barnwell, Ray Brown, Frank Gaughan, Sam Horowitz, Andy London, Rodd Novak, Don Slutz, and Dave Wilcox, "Ceramic technology for integrated packaging for wireless," 1999 Radio Frequency Integratec Circuit (RFIC) Symp. Dig., pp.63-66.

[3] M. P. R. Panicker, "Microwave & millimeter wave ball grid array (BGA) packages," in 7th Topical Meeting Elect. Performance Electron. Packaging Dig., 1998, pp. 233-236.

[4] Karl Suss, "An aluminum nitride high power dissipation RF packaging platform," Microwave J., pp. 172-184, Oct. 2001.

[5] M. Miyazaki, H. Asao, and O. Ishida, "A broadband dielectric diplexer using a snaked strip-line," 1991 IEEE 554,1999. MTT- S Int. Microwave Symp. Dig., vol. 2, pp. 551-554.

[6] Dong Hwan Lee, Yong Woo Lee, Jun Seok Park, Dal Ahn, Hyung Seok Kim, and Kwang Yong Kang, "A design of the novel coupled line low-pass filter with attenuation poles," 1999 IEEE MTT-S Int. Microwave Symp. Dig., vol. 3, pp. 1127-1130, June 1999.

[7] R. J. Wenzel, "Small Elliptic-Function Low-Pass Filters and Other Applications of Microwave C Sections," IEEE Trans. on MTT, vol.MTT-18, no.12, pp.1150-1158, Dec. 1970.

[8] G.Matthaei, L.Young, and E. M. T. Jones, "Microwave filters, impedance-matching networks, and coupling structures," Artech House, 1980.