Tunable Active Filters having Multilayer Structure using LTCC

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Abstract — **Two types of tunable filter have been developed at 400MHz and 800MHz frequency band respectively. These filters have been fabricated with LTCC (Low Temperature Cofired Ceramics) multilayer technologies assisted by varactor diodes. Filter size is 5.6x5.6x3.0 mm. Each filter has about 11% and 13% tuning range of frequency with controlling voltage of 1-4V, IL<2.0 dB, and has attenuation more than 40 dB at fo+-30% respectively. Temperature stability data is also discussed.**

I. INTRODUCTION

Tunable devices are widely applied in modern radio system. For example VCO (Voltage Controlled Oscillator) are very common in mobile radio systems such as a cellular phone, 2-way radio, etc. In general, fixed filters such as a dielectric resonator filter, SAW (Surface Acoustic Wave) filter and multilayer ceramic filter are used as microwave filter in such mobile radio system.

Recently, many mobile systems have been developed. As a result, the demands for a filter having wide bandwidth and sharp attenuation performance have been rapidly increased. Filters having many poles are designed to achieve such demands. This increases the difficulties of design and mass production of microwave filters. Tunable filters are known to be effective to solve these problems.

In some application, it is required for microwave filters to tune its pass frequency band [1]-[2]. Automatic tuning is preferable because the manual tuning procedure needs skill and know-how according to microwave filter technology. Usually the manual tuning procedure causes higher cost, lower productivity and becomes a bottleneck in mass production. Also it is known that automatic tunability of selective channel might attain weakened specification of filter compared with fixed filter.

LTCC technology is well known to be suitable to build multilayer structure in which many passives are able to be embedded [3]. LTCC process utilizes high conductivity metal such as pure silver for inner conductor material and brings the benefit of low loss in microwave application. LTCC is applied in many electronic components and modules such as filters, baluns, automotive engine control modules, and motherboards for super computer, etc.

In this paper, the tunable microwave filters at 400MHz and 800MHz are described. The tunable filters have a multi-layer structure in which more than 10 passives are embedded with LTCC technology and have a compact size, 5.6x5.6x2.4 mm. The tunability is attained with the help of varactor diodes. It is usually known that varactor diodes suffer from decrease of unloaded quality factor with increase of microwave frequency. To avoid this decrease of quality factor, RF circuits have been adjusted to achieve low loss at microwave frequency. Transmission properties and temperature properties are presented.

II. DESIGN AND FABRICATION

Fundamental equivalent circuit of tunable filters is shown in Figure 1 and Table I. The passband frequencies are designed as 400MHz and 800MHz respectively. These filters are implemented in a three dimensional lumped element topology having two-pole band pass response with both sides notched. All passive components except for resistors are designed to be embedded in the LTCC substrates.

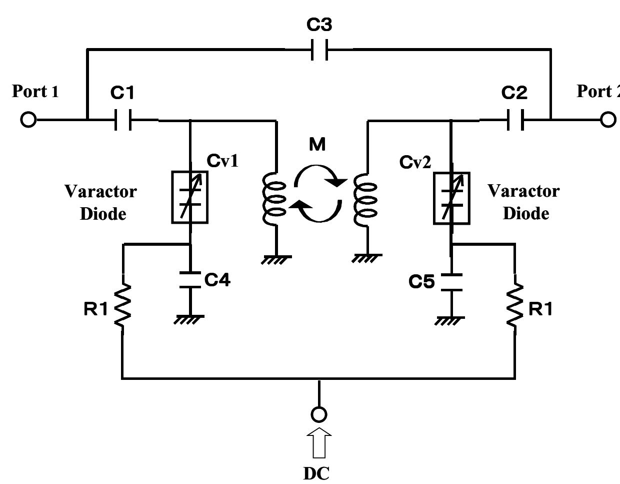

Figure 1. Circuit configuration of tunable filter

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TABLE I
DESIGN PARAMETERS OF TUNABLE FILTERS

	C1, C2 (pF)	C3 (pF)	C4, C5 (pF)	Cv1 – Cv2 (pF)	L1, L2 (nH)	Coupling Coefficient	R1, R2 (ohm)
400MHz	3.1	0.28	27.5	10.0-18.0	11.0	0.1	>10000
800MHz	1.0	0.02	15.0	2.0-4.0	7.9	0.1	>10000

Performances of these tunable filters are simulated using finite element method. Filters are fabricated by ordinary LTCC process. The substrate materials are $BaO-TiO_2-Nd_2O_3-SiO_2-B_2O_3$ for 400 MHz and $CaO-Al_2O_3-SiO_2-B_2O_3$ for 800 MHz respectively [3]-[4]. Dielectric characteristics of them are summarized in Table II.

These LTCC materials are sheet-casted to 0.07mm and 0.1mm thick tape. Electrode patterns are formed by screen-printing method. Pure silver is applied to both internal and external electrodes. RuO_2 resistors are printed on the surface to apply DC voltage to varactors for 800 MHz filter contrary to chip resistor mounted for 400MHz filter. After stacking the printed sheets, the stacked blank is cut into pieces, and then co-fired in the furnace around 900 degree-C for 1hr in air. Varactors (Toshiba, 1SV305 for 400MHz, 1SV285 for 800MHz) are mounted on the top surface to control pass band frequency with DC voltage. Temperature properties of tunable filters are measured after 1 hr soaking in the oven in which temperature changes from –20 to +80 degree-C. Temperature coefficient of frequency (Tcf) of tunable filter is calculated by the following equation:

$$Tcf=(f_{-20}-f_{+80})/-100f_{+25} \quad (1)$$

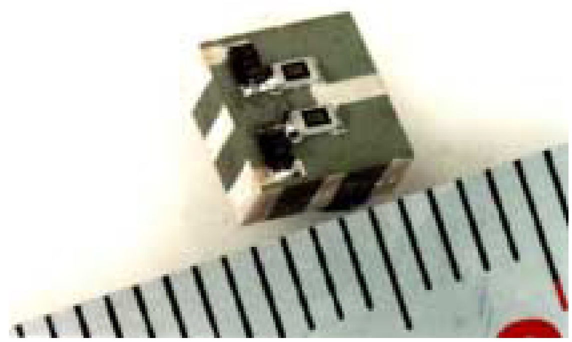
f_T: center frequency of 3dB bandwidth at T degree-C

III. RESULTS AND DISCUSSION

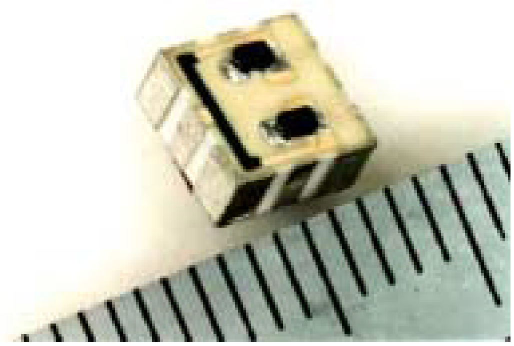
Figure 2 shows the photographs of tunable filters. The overall sizes of both filters are 5.6 mm x 5.6 mm x 3.0 mm (5.6 mm x 5.6 mm x 2.4 mm excluding varactor height). The differences in outside color are derived from LTCC material. $CaO-Al_2O_3-SiO_2-B_2O_3$ is white after sintering contrary to the green color of $BaO-TiO_2-Nd_2O_3-SiO_2-B_2O_3$. The measured transmission data of actual filters are shown in Figure 3 superimposed with the electromagnetic simulation results. Good co-relationships are confirmed between the measured data and the simulation results. Also excellent performances of both filters for practical use are confirmed that insertion losses are less than 2.0 dB, and attenuation on both sides of pass band at fo +-30% are more than 40 dB respectively.

TABLE II
DIELECTRIC CHARACTERISTICS OF LTCC MATERIALS.

Material	Dielectric Constant	Q·f (GHz)	Tcf (ppm/℃)
$CaO-Al_2O_3-SiO_2-B_2O_3$ [3]	7.7	2000	-35
$BaO-Nd_2O_3-TiO_2-SiO_2-B_2O_3$ [4]	75	2500	10



(a)



(b)

Figure 2. Photographs of Mutilayer tunable filters
(a) 410-470MHz tuning range with 1.2-3.7 V
(b) 780-870MHz tuning range with 2.0-4.0 V

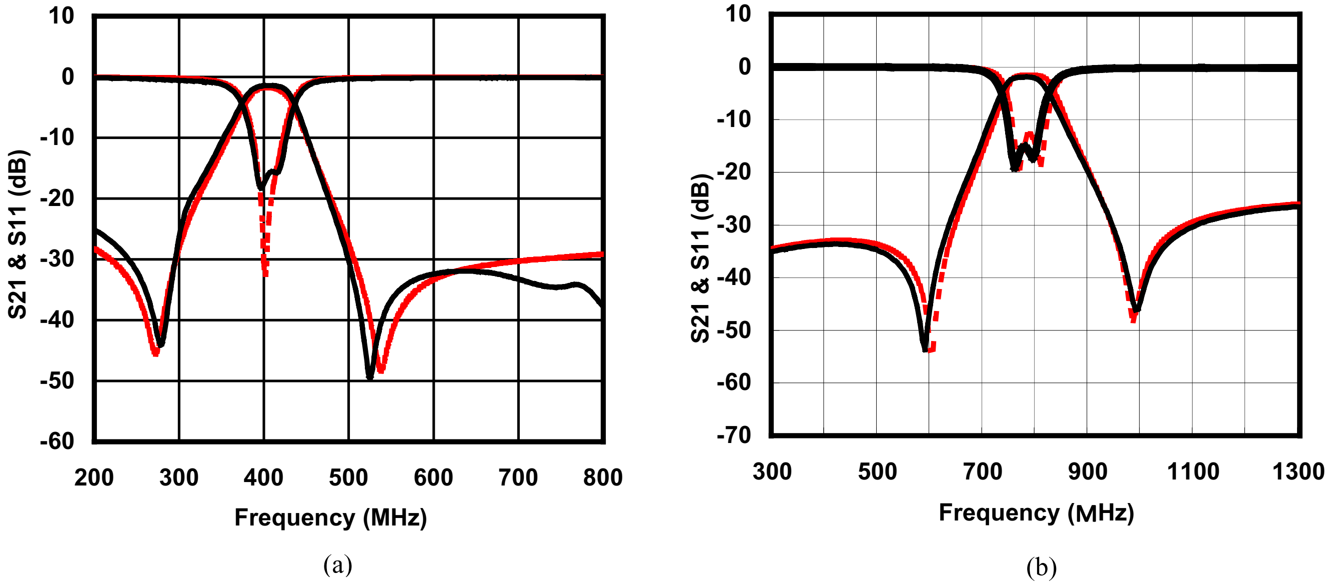


Figure 3. Measured response and simulation results.
(a) 400MHz filter (1.2 V) (b) 800MHz filter (2.0 V)
measured
simulation

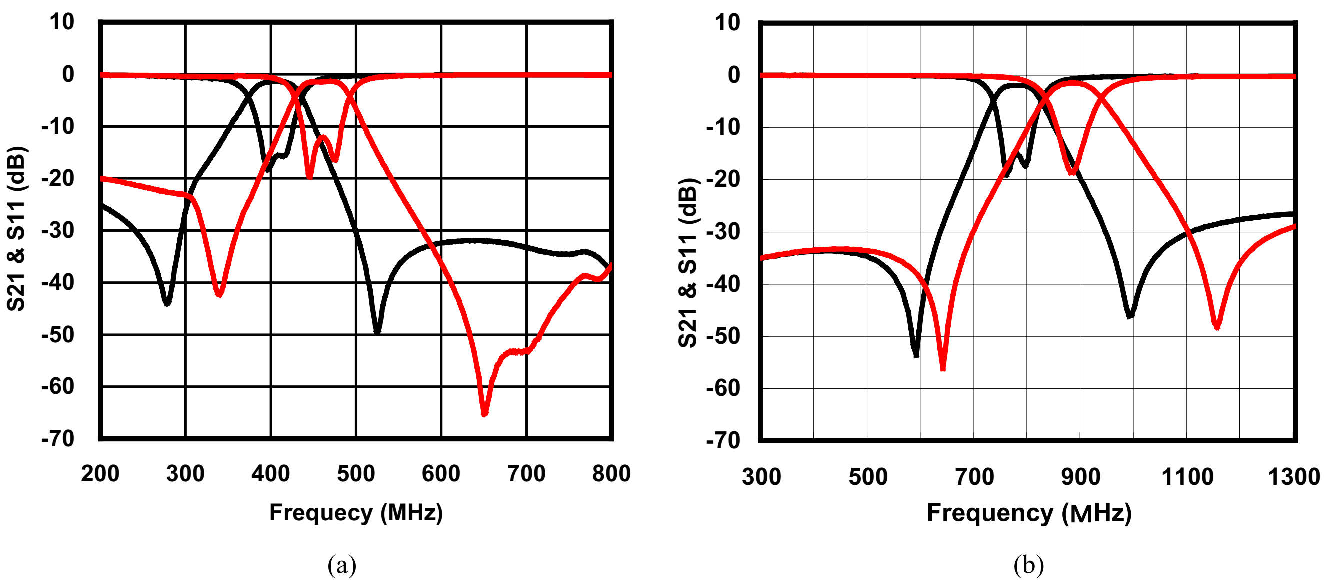


Figure 4. Measured response of tunability.
(a) 400MHz filter 1.2V 3.7V
(b) 800MHz filter 2.0V 4.0V

TABLE III
MEASURED PERFORMANCE OF TUNABLE FILTERS

Tunable Filter	Tunable frequency (MHz)	Tuning Voltage (V)	Band Width (MHz)	Insertion Loss (dB)	Attenuation at fo+-30% (dB)	Tcf (ppm/deg-C)
400MHz	410-470	1.2-3.7	66	1.4	>40	-98.7
800MHz	780-870	2.0-4.0	82	1.8	>40	-154.8

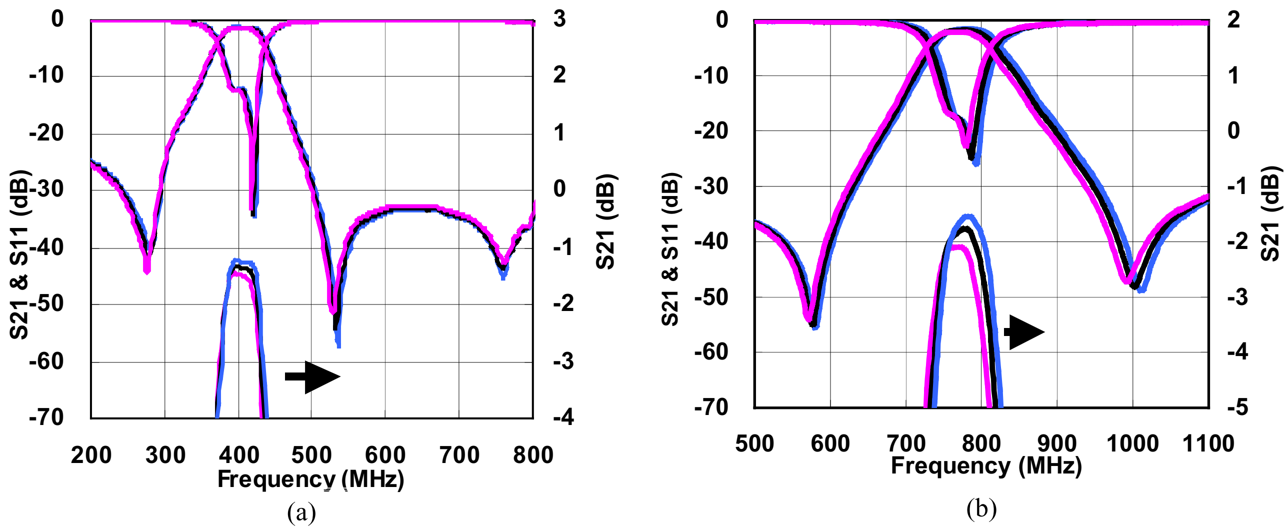


Figure 5. Measured responses versus temperature
(a) 400MHz filter (1.2 V)
(b) 800MHz filter (2.0V)

-20deg-C
+25deg-C
+80deg-C

Figure 4 shows the measured data of tunability according to applied voltage to varactor diodes. 400MHz filter is tuned from 410MHz to 470MHz with tuning voltage as 1.2 volts to 3.7 volts. The 800MHz filter is tuned from 780MHz to 870MHz with 2 to 4 volts. Temperature characteristics are summarized in Figure 5. Temperature coefficient of resonant frequency for 400MHz filter has been found to be stable as –98.7 ppm/deg-C contrary to that of 800MHz filter as –154.8 ppm/deg-C. Performances of tunable filter are summarized in Table III. Tcf of varactor diode is +7.0% and +5.5% at measured voltage for 400MHz and 800MHz filter respectively. Small temperature coefficient of resonant frequency of $BaO-TiO_2-Nd_2O_3-SiO_2-B_2O_3$ contributes good temperature stability of 400MHz filter. Though 800MHz filter has larger temperature coefficient than 400MHz filter, it is enough to be used in a practical use if bandwidth is large enough to channel width because this filter is tuned to each frequency channel.

IV. Conclusions

Practical tunable filters have been developed at 400MHz and 800MHz frequency band respectively. These filters have multilayer structures and have been fabricated with LTCC technology. $CaO-Al_2O_3-SiO_2-B_2O_3$ and $BaO-Nd_2O_3-TiO_2-SiO_2-B_2O_3$ are applied as LTCC materials for 400 MHz filter and for 800 MHz filter respectively. The performance of these filters have been confirmed to have excellent properties for practical use, that is, insertion losses are less than 2.0 dB at room temperature, and attenuations on both sides of pass band are more than 40 dB. Temperature stability has been found to be enough for practical use.

References

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