Electronically Tunable LTCC Based Multi-Layer Filter for Mobile Handset Application

Mohammed Rahman, Khosro Shamsaifar

Paratek Microwave Inc., 6935G Oakland Mills Road

Columbia, MD 21045

***Abstract* — A novel tunable bandpass filter for mobile handset application is reported. Combline topology has been used for this filter and it has been implemented in LTCC multi-layer technology for small size. The filter can be tuned over DCS, PCS, and UMTS bands used in mobile communication without degrading the response. It has less than 4.3 dB insertion loss over the entire tuning range and has a small foot print. Simulated and measured responses of the filter show good correspondence.**

I. INTRODUCTION

Electronically tunable microwave filters have found wide applications in microwave systems. The fast tuning capability of the electronically tunable filter makes it suitable for the applications in mobile radio systems. The electronically tunable filters can use either dielectric varactors or semiconductor varactors as tuning elements. The dielectric varactor based tunable filters provide superior performance in terms of loss, IP3, and power-handling compared to semiconductor varactor based tunable filter specifically at higher frequencies.

Tunable filters have been developed at Paratek for radio frequency applications. They are tuned electronically by using dielectric varactors. Tunable filters offer service providers flexibility and scalability, which were never possible before. A single tunable filter solution enables radio manufacturers to replace several fixed filters covering adjacent frequencies. This versatility provides RF front-end tunability in real time applications and decreases deployment and maintenance costs through software controls and reduced component count. Also, fixed filters need to be wide band so that total number of filters to cover desired frequency range does not exceed reasonable numbers. Tunable filters, however, are narrow band, but they can cover even larger frequency band than fixed filters by tuning the filters over a wide range. Additionally, narrowband tunable filters are appreciated from the systems point of view, because they provide better selectivity and help reduce interference from nearby transmitters.

Several electronically tunable filters [1]-[3] have been reported recently. But none of them are for Tri-Band (DCS, PCS, and UMTS) mobile handset application. The tunable filters in [1] are for 400 MHz and 800 MHz application and may not be suitable for Tri-Band filter due to the reason that these are diode varactor based lumped design, which might give higher loss at L-Band application. The filters in [2] are for low frequency application, whereas the filters in [3] are for L Band application. But the filter size is large in both cases.

The filter to be reported in this paper is a tunable one implemented in Low-Temperature Co-fired Ceramic (LTCC) technology in order to reduce the size. With LTCC technology, the filter is implemented in multi-layers and resistors used in the biasing circuit are embedded. The tuning elements are voltage-controlled dielectric capacitors known as Parascan^{TM} Varactors developed at Paratek. Since the tunable dielectric capacitors show high Q, high IP3 (low inter-modulation distortion) and low cost, the tunable filter in this paper has the advantage of low insertion loss, high power handling and low cost. The Tri-Band filter will replace three fixed filters and two switches.

II. DESIGN AND FABRICATION

Table I shows the Transmit and Receive frequency bands of Tri-Band handsets. The filter needs to be tuned over three transmit frequency bands and it is intended to be used between the power amplifier and the preamplifiers in the transmit chain of the handset.

Table I
Transmit and Receive frequency bands of Tri-Band handset

	DCS Band	PCS Band	UMTS Band
Transmit	1710-1785	1850-1910	1920-1980
Receive	1805-1880	1930-1990	2110-2170

The electrical specification for the filter is shown in Table II.

0-7803-7695-1/03/$17.00 © 2003 IEEE

Table II
Specification of the Tunable Tri-Band Transmit filter

Parameter	Requirement
Frequency Range	1710-1980 MHz
Bandwidth	5 MHz min.
Return Loss	>15 dB
Rejection	>30 dB @ (f0+80) MHz

To meet the specification, a three-pole asymmetric filter with one transmission zero in the higher side of the passband is chosen. Combline topology is used to achieve the transmission response. The conventional tunable combline filter topology is shown in Figure 1 .

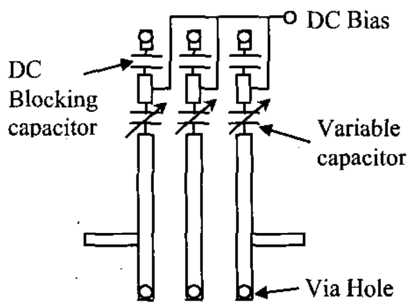

Figure 1 A 3-pole tunable combline filter

A combline resonator is normally greater than one eighth of a wavelength but less than a quarter of a wavelength depending on the capacitor value. If the combline resonator is implemented in one layer, the filter size is generally large. Therefore, the combline resonators are implemented in multi-layer topology to miniaturize the filter. The combline resonators are formed by stripline and microstrip line sections.

Dupont 951 tape system is used for Low-Temperature Cofired-Ceramic (LTCC) implementation of the filter. It has a dielectric constant of 7.8 and a loss tangent of 0.005. Nine tape layers are used and among them top seven layers are 8.3 mils thick and the bottom two layers are 3.7 mils thick. Figures 2 and 3 show the layer definition and the overlaid layers of the filter, respectively. Top and Bottom layers are shown in Figure 4. As shown in Figure 3, each resonator has two sections. One is stripline section and the other is microstrip section on the top layer. In order to achieve better Q from the resonator structure, a good portion of the resonator has been implemented in the stripline form. The stripline sections are formed in Layer-5 between the ground plane Layers-2 and -8, whereas Layer-8 acts as the ground plane for the microstrip line in Layer-9. The stripline sections (Layer-5) and the microstrip sections (Layer-9 / Top Layer) of the resonators are connected by the vias going through the apertures in the top ground plane (layer 8). The microstrip portions of the resonators are folded back as shown in Figure 3. Therefore, the size of the filter is reduced by almost half. All the inner ground planes are connected to bottom ground plane through lot of vias. The tuning components (Dielectric varactors) and the DC blocking capacitors are mounted in the Mcirostrip portions of the resonators.

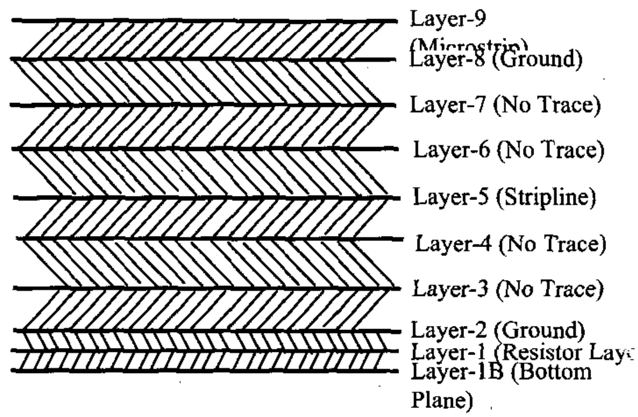

Figure 2 Layer definition of the filter

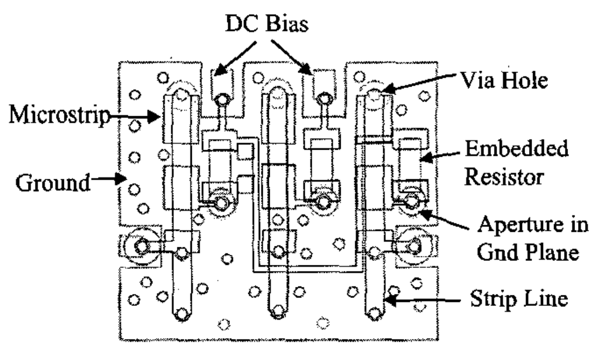

Figure 3 Overlaid layers of the multi-layer filter

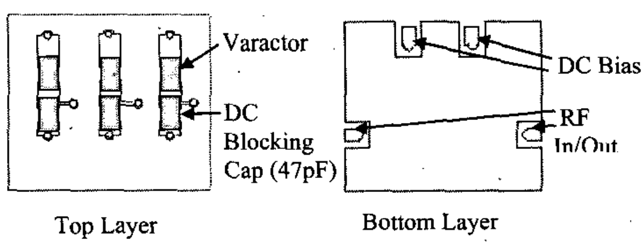

Figure 4 Top and Bottom layers of the filter

The resonators are arranged in such a way that the desired cross coupling between the two end resonators can be achieved. The cross coupling between the two end resonators helps to create a transmission zero on the high side of the filter passband and provide additional rejection. This type of response is desired for the transmit filters in the handset application. The combline resonators are shorted to both ends. Therefore, the DC blocking capacitors are necessary to apply DC voltage to the varactors for tuning. The DC biasing circuit is implemented by short length of high impedance line and high resistor (25k). The resistors are implemented by using resistor ink in Layer1, as shown in Figures 2 and 3. It is possible to use conventional quarter wavelength high impedance lines with quarter wavelength radial stubs for the biasing circuits. But it occupies a good amount of space, which makes the tunable filter larger. One of the good characteristics of the Parascan™ varactors, developed at Paratek is that they draw current in the few uA range. Therefore, the voltage drop across the resistor in the biasing circuit is very small.

Finally, in order to make the tunable filter surface mountable, the RF input/output lines and the DC biasing lines are taken to the bottom plane through apertures in the inner ground planes. This multi-layer filter simulation is performed using IE3D simulator and the simulated frequency response of the filter is shown in Figure 5. The Quality Factor (Q) of the varactors is assumed to be 100 in the simulation. It is found from the simulation that varactors with a capacitance range of 2.0 pF to 1.4 pF will be required to tune the frequency from 1710 MHz to 1980 MHz.

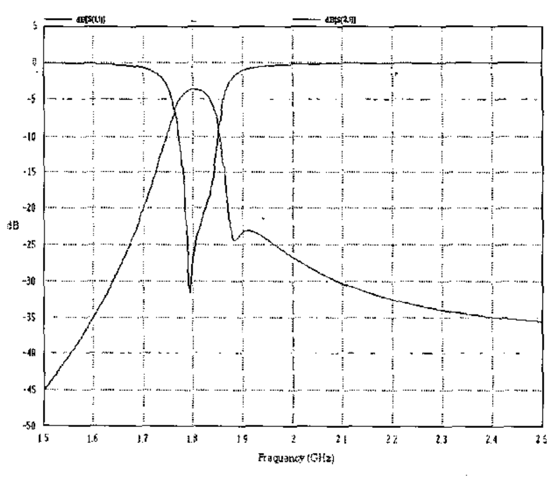

Figure 5 Simulated response of the 3-pole tunable filter

III. RESULTS AND DISCUSSION

The filter is surface mount type and the assembled filter size is 7.5mm X 6.5mm X 2.0mm. A test fixture board and a mechanical housing was designed to test the filter. The filter was mounted on the test fixture board and tested using Agilent Vector Network Analyzer. The filter is tuned to different frequencies by applying different bias voltage to the varactors of the filter. The measured responses of the three-pole filter tuned to 1656 MHz and 1983 MHz are shown in Figures 6 and 7.

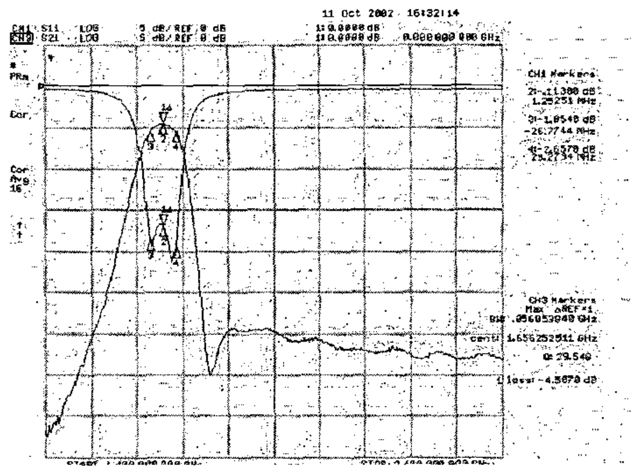

Figure 6 Measured response of the tunable 3-pole filter tuned to 1656 MHz

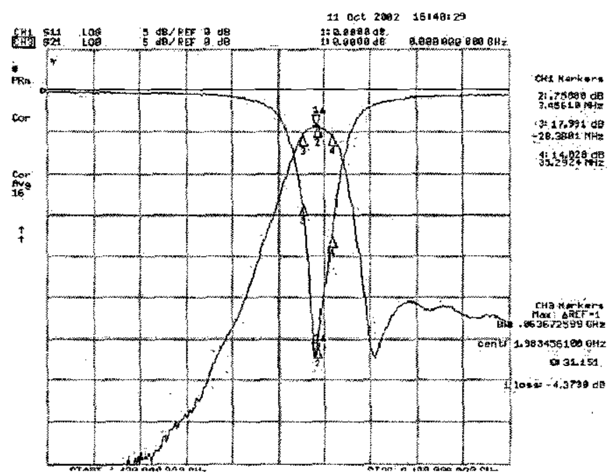

Figure 7 Measured response of the tunable 3-pole filter tuned to 1983 MHz

The filter shows more tuning than required specially in the lower side due to the fact that varactors used to build the filter have more capacitance range than required. It is obvious from the measured responses that the filter can be tuned from the low to high frequencies without degrading the responses. The filter has more bandwidth at higher frequencies compared to lower frequencies. This is due to the fact that for a fixed percentile bandwidth, at higher frequencies the absolute bandwith is higher than that at lower frequencies. The filter shows 4.5 dB or better insertion loss and better than 15 dB return loss across the whole tuning range. The insertion loss includes the test fixture loss of approximately 0.2 dB and hence the filter loss is 4.3 dB or better. The measured responses matches quite well with the simulated responses. For handset application, it is desirable to have a very small footprint and low insertion loss. The filter size can be further reduced by using high dielectric constant LTCC tape and using smaller DC blocking capacitors and varactors. In this filter, the size of the varactors and DC blocking capacitors were 0603. The insertion loss of the filter is contributed by conductive and dielectric losses of the fixed part of the filter implemented in LTCC and the varactor loss. At this frequency, the loss of the fixed part of the filter is dominated by conductive loss and it is possible to improve the conductive loss using better conductive metalization. The conductivity of the metalization (13 MS/m), used in this filter is much less than pure copper (49 MS/m) or silver (72 MS/m). On the other hand, the loss due to varactors can be reduced by improving the varactor Q (Quality Factor).

V. CONCLUSION

A compact LTCC based electronically tunable 3-pole filter has been designed, fabricated, and tested. The filter can be tuned over three frequency bands and has an insertion loss of 4.3 dB and return loss of better than 15 dB over the frequency range of DCS, PCS, and UMTS bands of the mobile communications handset. The tunable Tri-Band filter can replace three fixed filters and switches in the transmit section of the mobile Handset. The filter size can be further reduced by using high dielecric constant LTCC tapes and smaller DC blocking capacitors and varactors. The filter loss performance can also be further improved by using highly conductive metalization and improving the varactor Q.

REFERENCES

[1] K. Kageyama, K. Saito, H. Murase, H. Utaki, and T. Yamamoto, "Tunable Active Filters having Multilayer Structure using LTCC", 2001 *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1445-48 May 2001.

[2] A. Tombak, F. Ayguavives, J. Maria, G. Stauf, A. Kingon, and A. Mortazawi, " Tunable RF Filters Using Thin Film Barium Strontium Titanate Based Capacitors" , 2001 *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1453-56 May 2001.

[3] X. Liang, and Yongfei Zhu , " Hybrid Resonator Microstrip Line Electrically Tunable Filter" , 2001 *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1457-60 May 2001.