MINIATURE LTCC FILTERS FOR DIGITAL RECEIVERS

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ABSTRACT

The integration of high quality narrow band pass filters into the low power RF system of advanced radar digital receivers is demonstrated by Low Temperature Cofired Ceramic (LTCC) technology. Using Computer Aided design, simulations, and yield analysis, a strip line LTCC filters were designed with 100% yield to tolerances in materials and manufacturing processes. LTCC materials technology and processes used in the filters development is presented. Sample results of measured filter performances under extreme temperature cycling conditions is presented which demonstrates the excellent potential of the LTCC filters technology.

I. INTRODUCTION

Modern RF avionics sensors implement most of the electronic functions in MIC technologies. Filters are used throughout the low power RF subsystems of any radar to preserve the fidelity of the transmit and receive signals. As requirements have continued to increase for the radar range, target cross section, minimum detectable target velocities, and Synthetic Aperture Radar (SAR) target resolutions, the need for high fidelity signal processing drives toward more stringent filter requirements throughout the receiver and exciter hardware. The more stringent requirements have a direct effect on the complexity of the filters and filter banks in the system. With current filter technologies the resultant filters and filter banks become a large percentage of the low power RF system cost, weight, volume and reliability. As an example, Fig. 1 illustrates the volume and losses associated with typical filter functions within a low power RF system as compared to the volume associated with other analog functions. The chart illustrates six primary types of filter bank functions throughout a typical modern aircraft radar. These include both L-band and X-band frequencies. The volume associated with these filter bank functions are compared to the typical volume associated with other low power RF functions such as mixers, amplifiers, and switches. MMIC and ASIC technologies made significant impact on the volume of these other functions, however, the current state of the art in filter technology is clearly behind that in standard semiconductor technologies.

The objective of this paper is to present results of the Miniature RF Filter development program, which leverages new LTCC technologies [1], [2] and manufacturing processes to demonstrate the ability to close this gap, allowing a reduction in overall life cycle costs attributable to filter functions. We have successfully demonstrated an integrated, miniature LTCC RF filter-multiplier multichip module. The paper addresses aspects of the filters development in three areas

a. LTCC material system and processing
b. LTCC filter design and simulations (yield analysis)
c. Test results on samples of LTCC manufactured filters.

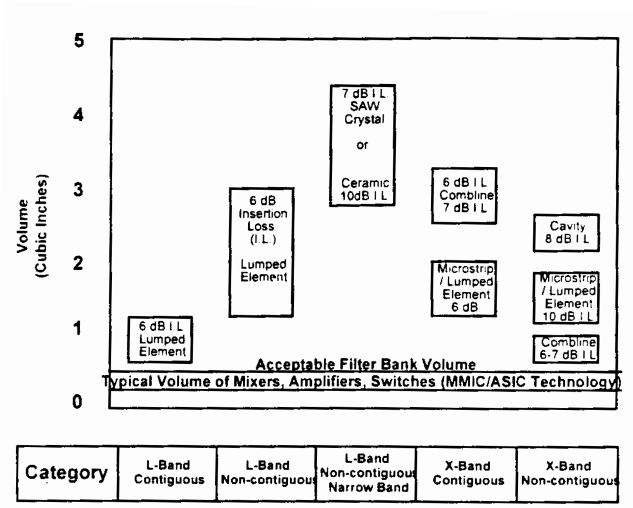

Fig. 1. A comparison of filter bank functions to other low power functions

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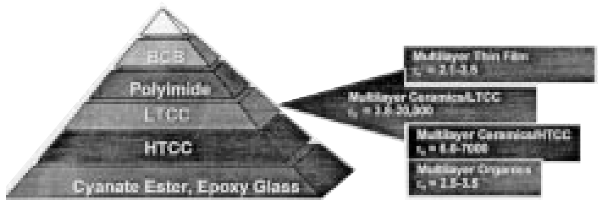

Fig. 2. Relative circuit density for packaging technologies

II. LTCC MATERIAL SYSTEM AND PROCESSING

LTCC is a glass ceramics composite which provides a unique and versatile approach to highly integrated, high performance electronic packaging. The technology offers significant benefits in terms of design flexibility, density, and reliability. The multilayer capability of LTCC technology allows multiple circuitry's to be handled in a single self-contained, hermatic package. Monolithic LTCC structures incorporating buried components allow increased design flexibility by providing a mechanism for establishing both strip line and microstrip within the same medium. The ability to integrate digital, analog, RF, microwave, and buried passive components in this manner reduces assembly complexity and improves overall component and system reliability by reducing part count and interconnections. Additionally, the reduced weight of LTCC packages and the low loss characteristics of the dielectric and conductors makes LTCC an ideal candidate for high performance commercial and military electronic systems.

The LTCC material system consists of a low firing temperature ceramic with multilayering capability of high conductivity metals (gold, silver, and copper) used in thin film processes. This combination of material technologies allows for low temperature (<1000°C) processing of 3 dimensional packages and the use of conventional chip and wire technologies for the fabrication of various complex LTCC packages.

LTCC is a glass matrix ceramic with crystalline filler added or formed from the glass during the firing process. Since the glass phase of a material is essentially a supercooled liquid, it will densify at lower temperatures than the crystalline phase. The crystalline filler is added for thermal expansion match to the semiconductor chip, to control the densification behavior of the LTCC, and to achieve specific electrical performance. This is a significant advantage over crystalline High Temperature Cofired Ceramics (HTCC) materials which require firing temperature >1600°C. These high temperatures limit the metallizations to more refractory, lower conductivity metallization such as tungsten molyebdenum, and manganese. These metallizations are neither wirebondable nor solderable and therefore require subsequent plating.

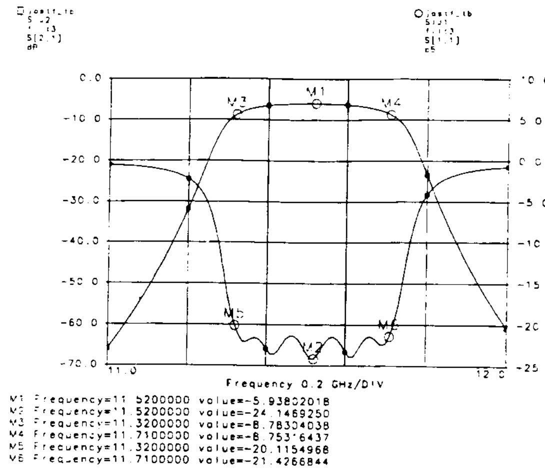

Fig. 3. Simulation results for the 11.52 GHz filter

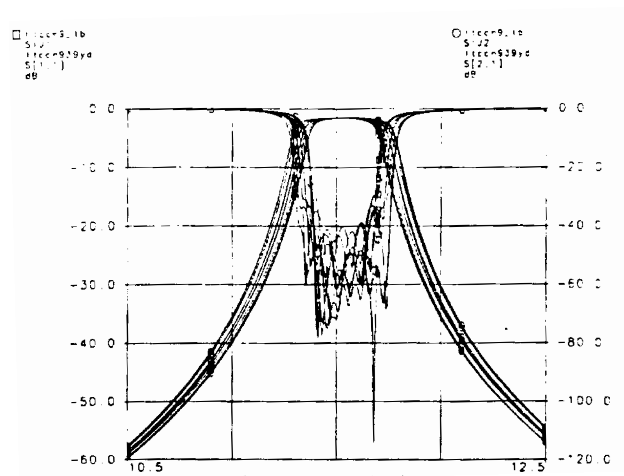

Fig. 4. Yield analysis for the 11.52 GHz filter

Unlike thick film process where successive lamination and firing steps cause bowing and line degradation the single step lamination and firing of LTCC produces a flat substrate with fine, high quality line definition. In addition, the elimination of costly repeated firings greatly increases the number of conductive layers achievable. The current state of the LTCC technology allows high density circuitry (as fine as .0035″ lines and spaces) interconnected with conductive vias (as fine as .0035″ diameter). Fig. 2 shows how LTCC compares in terms of circuit density to other packaging technologies. The wide range in available relative di-

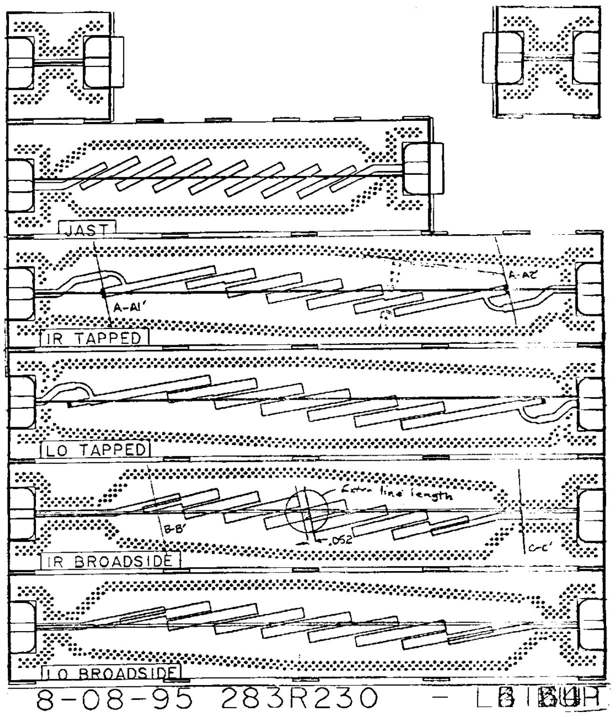

Fig. 5. LTCC buried stripline filter artwork

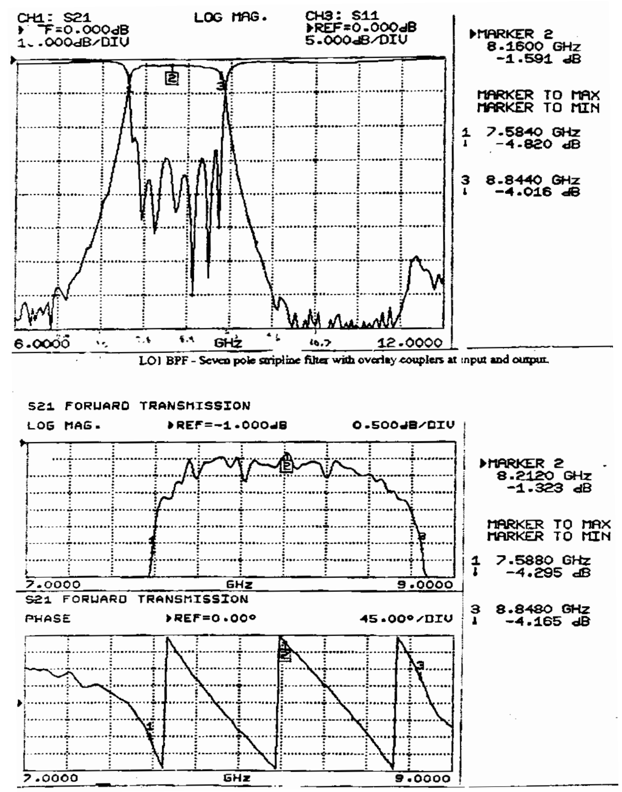

Fig. 6. Measured results on seven pole stripline filter with overlay coupler at input and output

electric constants in LTCC increases design flexibility. Relative dielectric constants as low as 3.8 are particularly well suited for high speed digital applications. Moderate ϵ_r ranging from 6 to 80 are well suited for high frequency applications. Availability of high ϵ_r up to 20,000 allows integration of capacitor devices into the multilayer structure. Resistor pastes are available which can be printed on internal layers of circuitry and cofired into the structure. This integration of passive components [3],[4] reduces the number of surface mount components, reducing the number of solder and wirebond connections, thereby, increases reliability.

III. LTCC FILTER DESIGN, SIMULATION AND YIELD ANALYSIS

Typical filters requirements used in the low power R.F. subsystems, are given in Table 1.

These requirements and the yield analysis described below, dictated a 7 -pole, .05 dB ripple Tchebycheff filter. Because LTCC is used as the technology for the transmission medium, stripline design is chosen as the appropriate method of the resonator structure, since it allows full advantage to be taken of the three dimensional structures possible with the LTCC. Standard designs of parallel coupled stripline resonators realization ation [5] of filters was used as the initial step in the design. Then simulations and optimization of the design was performed using commercial software packages (HP EESOF and HP HFSS) to simulate the various non ideal conditions, (e.g. line width changes, open line effects, via holes, and transitions from stripline to microstrip test fixtures). A typical result of an optimized simulated filter response is shown in Fig. 3.

Table 1. Typical Filter Requirements

Center frequencies	8.16GHz to 14.08GHz
3dB Bandwidth:	300 MHz (minimum)
Insertion Loss:	(To be minimized) 8 dB maximum over Bandwidth
Insertion loss variation:	2 dB max.
Return Loss:	15 dB minimum over passband
Out of band rejection:	>55 dB (at f_0 ±400 MHz and beyond)

After the optimization process was completed, the estimated yield analysis is performed. The yield analysis accounts for all the manufacturing tolerances. The model dimensions are randomly varied according to the tolerances and large number of the filter performances are generated. Each response is checked against the specifications, and if the specifications are not met, the run is reported as a failure. The yield analysis on the designs achieved 100% yield with respect to the toler-

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TABLE 2. COMMERCIAL LTCC TAPE PROPERTIES

	851	951	901	966	A6
Green Thickness	AT-4.5±7% A2-6.6±7% AX-10±7%	AT-4.5±7% A2-6.6±7% AX-10±7%	A5-5 ±7%	A5-5±7%	5 ±0.8%
Fired Thickness	AT -3.7 A2 -5.5 AX -8.3	AT -3.8 A2-5.6 AX -8.5	A5-4.2	A5-4.2	3.9
Dielectric constant	7.3 @1 Mhz	7.85 @10Ghz	5.45 @10Ghz	6.8 @10Ghz	5.9 ±0.15 @10Ghz
Dissipation Factor	.003 .007(WEC)	.004 .006(WEC)	.004 .004(WEC)	.0011	.0012
X-Y Shrinkage	12%±2%	12.9% ±.3%	16%±.03%	13.5%±.05%	15.25% ±.15%
Z Shrinkage	17%	15%	15%	14.1%	22.825% ±1.13%a
TEC	7ppm/C	5.8ppm/C	3ppm/C	6.5ppm/C	6.2ppm/C
Temperature Sensitivity on ϵ_r		1.21 MHz/C			.548 MHz/C

ances listed in Table 2, for various LTCC materials and processes. Fig. 4 is a typical plot showing yield analysis for 11.52 GHz filter. The art work for the LTCC filters is shown in Fig. 5. The via holds around the filters are included for shielding and preventing spurious coupling to other circuitry on the same LTCC structure.

IV. TEST RESULTS

Measured results on an 8.16 GHz filter is shown in Fig. 6. The measured data was taken without de-embeding the effects of two SMA connectors and microstrip to stripline transition. The loss of these fixture interfaces is about 0.4 dB, which is estimated based on the measurements of two back to back transitions, shown in Fig. 7. Temperature cycling of the filter over -55°C to 85 °C is shown in Fig. 8. Maximum frequency shift is about 20 MHz over the 140 °C temperature range.

V. CONCLUSION

Several stripline filters were designed and fabricated in the new Northrop Grumman low-K 96 LTCC tape. The measured results indicate that this type of filters have great promise for miniaturization of advanced receivers and signal sources. The results of this development provided conclusive proof that buried microwave LTCC filter technology can be successfully applied in the Miniature Digital receiver program to drastically reduce the volume allocated to these filters, to eliminate all touch labor for filter tuning, to increase reliability by eliminating several interconnections and to reduce the receiver production cost.

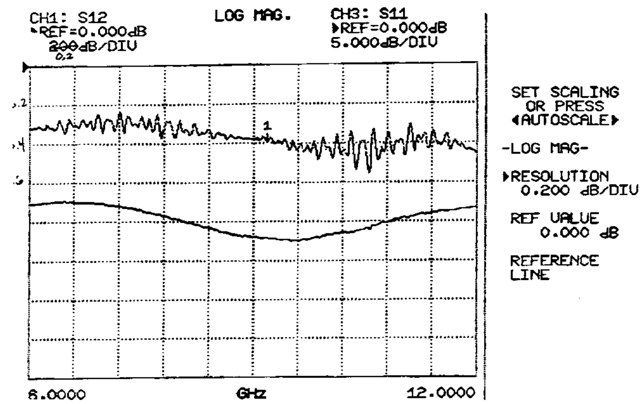

Fig. 7. Loss of transmission line plus SMA connectors

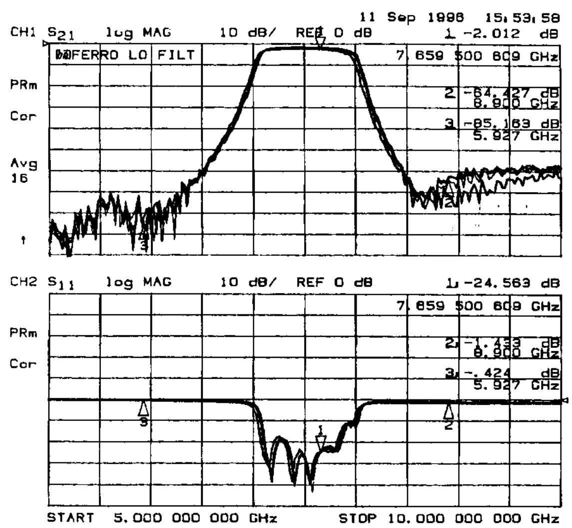

Fig. 8. Temperature Cycling Of The Filter over -55°C to 85 °C

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