X-Band Microstrip Bandpass Filter using Photoimageable Thick-Film Materials

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Abstract — **The rapid growth in commercial microwave technology, particularly for wireless communication, has created a demand for low-cost, high quality microwave fabrication technologies that are also suitable for high volume production. Modern thick-film materials are well placed to meet these requirements, in that they offer low conductor and dielectric losses, with good surface finishes and the ability to realise fine conductor geometries. This paper studies the feasibility of realizing microwave bandpass filters using thick-film photoimaging techniques. This enhanced thick-film technology can realise very narrow line width and spacing, giving performance comparable to the more expensive thin-film techniques. This is an inexpensive and mature technology, which looks set to revolutionize the manufacturing of microwave and mm-wave circuits in the near future. The fabricated filter achieved an insertion loss of only 0.7dB over the frequency range of 9 – 11GHz.**

I. Introduction

Filters play an important role in the operation of a wireless communication system and this is especially so when the frequency spectrum is getting more crowded than ever before. Often, in this type of application, passive filters are employed compared to their active counterparts. Passive filters designed around reactive elements only, using lumped-components such as inductors and capacitors or distributed elements such as cascaded resonators, can operate up to the microwave region. At upper microwave frequencies, such as in the X-band, the parasitics in the inductors and capacitors often proved too much a constraint to use them in the wireless system. Hence, many of the filters used in microwave communication systems employ the distributed elements types.

These filters especially when used in a heterodyne system are often deployed as off-chip circuits due to their excessive size. Whilst there has been a concerted effort to develop new transceiver architectures that minimise the need for filtering, such as direct conversion techniques [1], there is often the need to integrate filtering into an integrated multi-chip module (MCM) transceiver solution [2]. In particular, Ceramic-based MCM technology (MCM-C) is very suitable for low-cost mass volume production. The multiple dielectric layers used allow the realization of innovative printed structures and offers miniaturization through the use of TFMS [3]. A typical MCM-C as shown in Fig. 1, can house high performance MMICs together with high-Q printed passive structures and readily available SMT components onto a common substrate, thus providing a very high-density multi-function module.

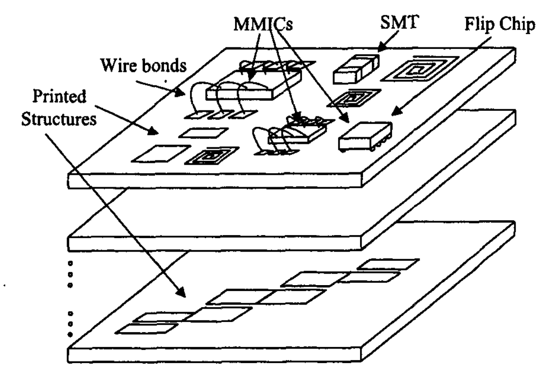

Fig. 1. A typical multi-function MCM-C module.

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Bandpass filters (BPFs) at microwave frequencies often use the parallel-coupled microstrip technique [4]. Two or more resonators are cascaded as such to form the coupled multi-resonator BPF. Each individual resonator is affected by reactive loading from adjacent couplings and open-ended capacitive fringing. However, this structure often requires a very small coupling gap on the outermost resonators, which makes it difficult to realise using low cost methods such as FR-4 type circuit boards and thick-film Alumina processing [5]. With conventional thick-film technology the track and coupling gap widths are limited to approximately 100μm. With photoimageable thick-film techniques, this limitation can be overcome [6-8]. Thick-film processing can then offer a cheap solution for the implementation of circuits in the microwave range.

II. PROCESS

Fig. 2 shows the modified thick-film technology that is used to fabricate the X-band bandpass filter in this study.

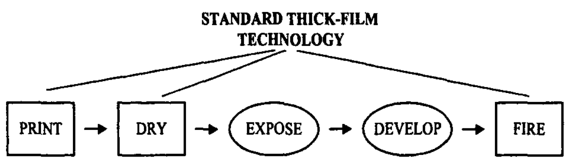

Fig. 2. The photoimageable thick-film process.

The photoimageable process is an extension of the conventional thick film technology, in which standard thick film paste is replaced by a photosensitive material. Photosensitive thick film pastes have been developed by combining a photosensitive vehicle and metal-glass powders, both of which affect the electrical properties and resolution characteristics. As illustrated above, the process steps are as follows: the thick film paste is first blank printed over the total area of the substrate. As the ability to print sharp edge features is not required, the levelling properties of the photosensitive pastes are optimised to provide a uniform thick film with a very smooth and dense surface, free of pinholes and other printing defects. Drying of the printed thick film layer is performed at 100°C for 10 minutes. No special lighting or atmosphere conditions are needed during the printing or subsequent drying stages.

The printed and dried thick film layer is then exposed to a high intensity ultraviolet light through a negative photo mask. The formed photopolymer in the locally exposed areas greatly affects the solubility characteristics of the paste creating a latent image on the substrate. The unexposed regions are removed during a developing procedure of 10 seconds duration using sprayed 0.5% monoethanol amine as the developer. The polymerized exposed regions remain on the substrate without lifting or peeling from the substrate. The firing is performed in a conventional thick film furnace to provide the high density thick film structure. Excellent adhesion of narrow tracks with vertical edges is achieved after firing of developed substrates. It should be noted that the conductor dimensions are defined before the firing step, so some allowance must be made at the layout stage for shrinkage during firing. This is in contrast to the "photoengraveable" process, where chemical etching of the conductor is performed after firing. The relative advantages and disadvantages of the two generic processing methods very much depend on the application. The photoimageable process, for example, is well suited to LTCC technology since multiple conductor layers can be imaged before the final firing step.

The properties of a photoimageable thick film process depend considerably on the photosensitive pastes and equipment used for exposure and developing. Fig. 3 shows a fabricated test structure, with a line width and line spacing of 15μm, which was processed using HIBRIDAS gold paste HC 7900 and dielectric paste HD 1000. Fabrication was performed using the HIBRIDAS standard exposure unit MA3 and developing unit SC4. Also, as observed from the figure, sharp corners and good edge definition can be achieved using this fabrication method.

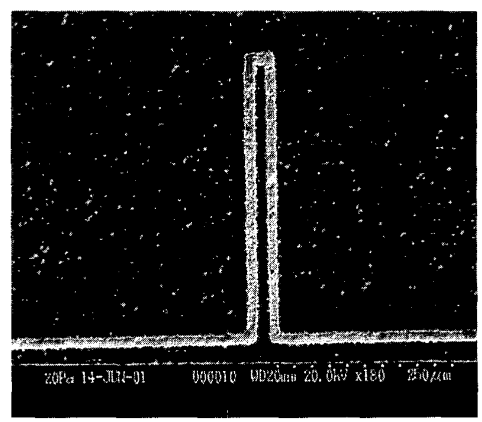

Fig. 3. SEM photograph of a test structure.

III. CIRCUIT DESIGN

For a microstrip bandpass filter implementation, the coupling between resonators decreases with increasing substrate height. Generally, microstrip or stripline bandpass coupled line filters, with bandwidths less than about 20% can be easily fabricated. However, where wider bandwidth filters are desired, very tightly coupled lines are generally needed. This can be achieved by reducing the substrate height used, where the track separation required to realize the coupled line filter becomes smaller [9]. However, this small track separation can present a problem in terms of manufacturability. Also, quite often the characteristic impedances of the stub resonator are in reality difficult to realize as well. Thus the trade-offs between substrate height, minimum coupling gap, realizable characteristic impedances and overall loss must be addressed to gain the required filter performance. The photoimaging process method on the other hand, does not face these problems. Using this technique, filters and other passive components can be fabricated with a line width and a line spacing as small as 15μm, which is unobtainable with a conventional thick-film process.

Coupled line filters can be designed to produce either a maximally flat or equi-ripple response. In this study, a 4^{th}-order bandpass filter has been designed with a center frequency of 10GHz and a 3dB bandwidth of 3GHz using coupled half-wave resonators to give a maximally flat response. The bandpass filter is designed by following the design procedure based on the even- and odd-mode impedances of the coupled lines [4], and is further optimized using *Momentum*^{TM} (by HP ADS^{TM}). The filter is then fabricated on a Alumina substrate (ε_r=9.8) of height 635μm using Hibridas photoimaging metal pastes. With this, the filter requires even- and odd-mode characteristic impedances (Zoe, Zoo) of 92Ω and 26Ω, respectively, for the first coupled line section, which translates to a line width of 350μm and line gap of 30μm on a 25 thou (635μm) Alumina substrate. The next coupled line section requires Zoe and Zoo of 63Ω and 22Ω, respectively, yielding a line width of 700μm and line gap of 30μm. The last two coupled line sections are symmetrical to the first two, thus they have the same dimensions as stated earlier. All the quarter-wave coupled lines have a length of 2700μm at 10GHz. Fig. 4 shows the dimensions of the filter.

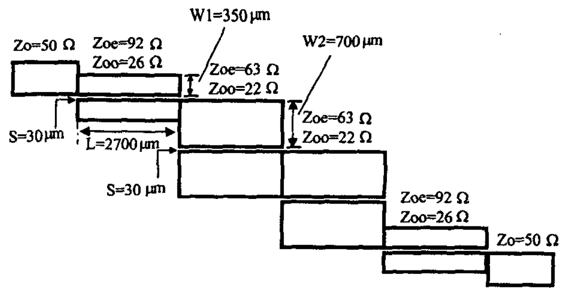

Fig. 4. Dimensions of the designed bandpass filter.

IV. EXPERIMENTAL RESULTS

The fabricated filter as shown in Fig. 5, occupies an intrinsic area of 12.7mm x 3.5mm, was measured using an Anritsu test fixture and HP8510 vector network analyzer (VNA) with a coaxial SOLT calibration.

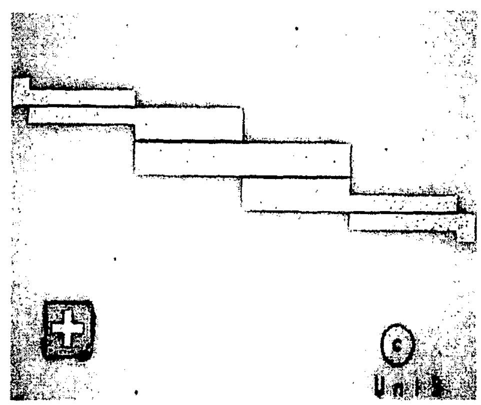

Fig. 5. The fabricated X-band bandpass filter.

Fig. 6 shows the plot of the simulated (dotted line) and measured (solid line) performance of the filter. Very good agreement is obtained between these results, indicating that the modelling of the filter took into account all necessary parasitic effects and that the manufacturing process is well controlled. The fabricated filter has a center frequency of 10GHz with a 3dB bandwidth of 3GHz as desired. Insertion loss of 0.7dB (after subtracting the loss of the coaxial adaptors and coax-to-microstrip transition) and return loss of better than -18dB is achieved over a frequency range of 9 – 11 GHz.

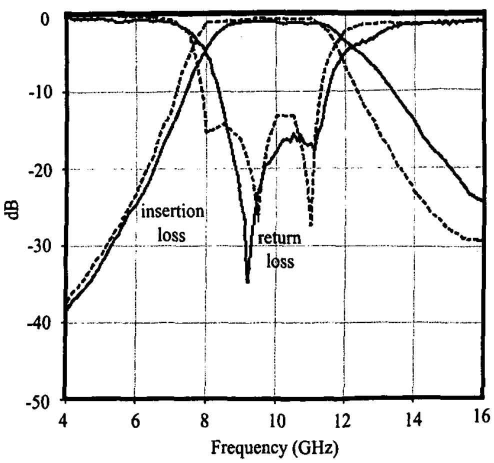

Fig. 6. Simulated (- - - -) and measured (———) performance of the fabricated filter.

V. CONCLUSION

A 10GHz filter has been successfully demonstrated using a thick-film photoimageable technology which is superior to a conventional thick-film technology in terms of producing high definition circuitry. Passive components with narrow line width and tight line spacing requirements as small as 15μm can be comfortably fabricated using this photoimaging technology. The fabricated bandpass filter achieved an insertion loss of 0.7dB over the frequency range of 9 – 11GHz. This can be attributed to the fine-line and space resolution, the well-defined conductor edges and the nearly vertical walls that can be produced by this process. Photoimageable thick-film material is also very well suited for multilayer process, hence making it suitable for MCM implementation, which can offer a quick and cost-effective solution for the wireless system market.

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