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RF CIRCUIT REALISATION USING THICK FILM TECHNOLOGY

Jitendra Kumar[1], Harsh Dashora[2], Kamaljeet Singh[3], P. Palani[4], Ajay Andhiwal[5]
[1,2]Systems Engineering Group, U R Rao Satellite Centre, India
[3,4,5]HMC and Indigenization Group, U R Rao Satellite Centre, India

Abstract

Thick film technology is mostly employed at lower frequency circuits such as hybrid micro circuits due to the associated losses of the paste. The characterisation and implementation of the conductive paste at higher frequencies is important so as to employ this technique at higher frequencies. Also the role of ceramic substrate due to higher dielectric losses needs detailed measurement to deduce the useful range of this technique with the selected paste. In this article simple transmission line using the thick film technology is fabricated, characterised and result of the thick and thin film technologies are compared. Subsequently RF circuits such as filter are fabricated using both thick and thin film fabrication technology and comparative analysis carried out. The line losses of 0.01 dB/cm up till 5 GHz is achieved using the standard gold paste. This article details the fabrication process, implementation methodology, design aspects, simulation and comparative analysis of the microstrip circuits such as transmission line and band pass filter.

Keywords:

Thick Film, Microstrip, Band Pass Filter, Transmission Line

1. INTRODUCTION

Planar transmission line based passive circuits are mostly realized on alumina substrate at higher radio frequencies. Printed circuit techniques such as thin film technology based fabrication are used to implement the circuit; this technique employs metalized alumina substrate with higher tolerances of metal thickness, surface smoothness and dielectric purity apart from controlled etching technique. The main bottle neck associated with the above technique is the low throughput and expensive process. As reported [1-3] the performance at low end of microwave frequencies can be achieved by employing thick film technology. The added advantage of thick film technology is faster result and comparatively inexpensive.

In this article simple transmission line using the thick film technology is fabricated, characterised and result of the thick and thin film technology are compared. Subsequently a planar band pass filter is designed, fabricated using both thick and thin film process and comparative analysis of the outcomes is carried out. Because any system which is used for space application has to meet stringent quality levels mainly with respect to extreme temperature conditions and vibration levels of the launch vehicle, hence the specimens of the filters are undergone with temperature cycles and outcomes of the same is detailed in this article which provide the basis of using thick film technology for microwave frequency circuit realization. A simple 50 Ohm transmission line is fabricated using thick film paste. The characterization of the line carried out and comparative analysis of losses with thin film technology is carried out. Further this approach is extended for realization of band pass filter at S-band frequency.

In order to realise a filter which has minimum insertion loss and sharp cut off, there are various microstrip based filter topologies devised for example Hairpin-Line Filters, Inter-digital Filters, Comb-line Filters, Stub Band pass Filters, Coupled Resonator filter, DGS based filter, Meta-material-based filter etc. The microstrip transmission line has a thin conducting layer on one side of the dielectric; the other side of dielectric is metalized acting as ground plane [4]. This type of transmission line is broadly used for RF/microwave circuit realization such as filters, couplers, dividers, diplexers etc. as it results in repeatable and reproducible structure.

The filter topologies can be realised using MIC fabrication processes and the processes are broadly divided into two types such as Thick film process and Thin film process. Thin film technology commonly known for realization of MICs for RF/Microwave applications wherein high purity alumina about 99.6% substrates with different metallization schemes are used and this process is preferred as it is less lossy but in recent advent of pastes, thick film technology also showed excellent results for MIC fabrication up to X-band frequency. The advent of new fritless and low frit thick film conductor pastes has made possible great improvements in the loss characteristics of screen-printed thick film microwave integrated circuits [3].

Thin film processes require large number processing steps hence their turnaround time and production costs are more. Thick film technology based on photo-image-able dielectric and conductor composites provide a quick solution that is comparable with thin film and similar performance can be achieved at reduced time, effort and is inexpensive.

This article demonstrates the implementation of low frequency gold paste at higher frequencies by reducing the porosity of the transmission lines. Further 50 Ohm transmission line and S-band filter are implemented using the same approach and characterized. The comparative analysis of the transmission line and filter implemented using thick film and thin film technology is presented in this article.

2. FABRICATION TECHNIQUE

There are two types of fabrication techniques employed for MIC realization namely thin film process and thick film process. Both of the processes use Alumina as substrate but the purity of the dielectric, surface smoothness and loss tangent are different. The flow of each technique is detailed below [5]-[7]:

The process of thick and thin film technology is based on the contact mask technique. The difference of the technology is based on the metallization where thick film is based on paste and thin film metallization employs sputtering.

In order to remove porosity in the deposited paste due to low frequency of applications, double coating is employed. The Fig.2 shows the quality of film before and after re-deposition. This also results in the achieving the dimensional accuracies.

Generally thick film process is used for low frequency applications which employed alumina substrate with 96% purity and 99.99% pure gold thick film composition. In this work the same process is used for fabricating circuits at microwave frequencies by employing advanced process techniques such as double printing to reduce the porosity, achieve better line resolution and surface smoothness.

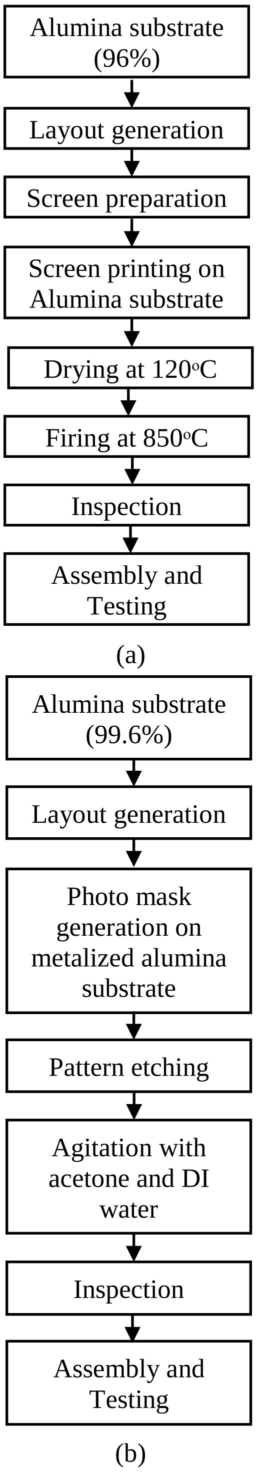
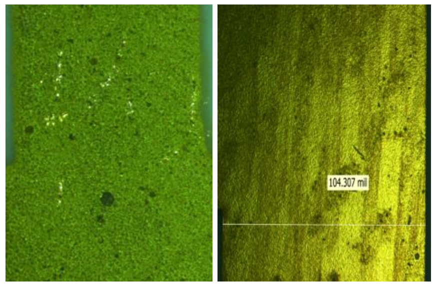


Fig.1. Flow chart of (a) Thick film process (b) Thin film process



(a) (b)

Fig.2. Quality of the film (a) single layer thick film process (b) double layer thick film process

3. MICROSTRIP LINE

Microstrip line is an inhomogeneous transmission line due to distribution of the field between the strip and the ground plane. The Fig.3 shows the general schematic of a microstrip line having conductor width *w*, height *h*.

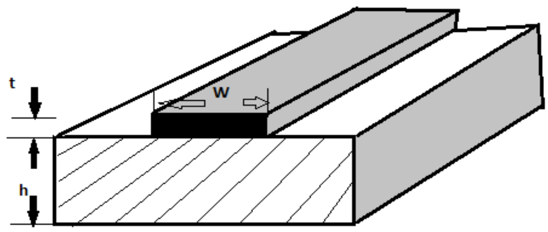


Fig.3. Cross section-view of microstrip line

Signal attenuation is one of the major parameters in microstrip passive circuit design. The finite conductivity of metal and lossy dielectric substrates is responsible for signal attenuation in microstrip line [8]-[9]. The attenuation constant of the dominant microstrip mode depends on geometric factors, electrical properties of the substrate, conductors and on the operating frequency range. Further microstrip line is capable of radiating from any line discontinuity as well as introduction of other modes that are guided by the air-dielectric interface without requiring metal strips. Considering nonmagnetic materials, losses associated with microstrip lines are dielectric loss, conductor loss and radiation loss. Radiation loss can be reduced by the use of thin and high-dielectric materials. Various loss mechanisms encountered during signal propagation in planar lines are:

- Conductor losses of the metallization
- Substrate losses
- Interface losses
- Radiation losses

Thin film technology having the metallization thickness of 5-6μm consists of Cr-Cu-Au layer which is around 5-6 times of the skin depth [10]. The surface nearest to the metal surface propagates the electromagnetic wave. In case of thin film, wave propagation is concentrated in the copper layer whereas in thick film the wave propagation takes place solely in the gold paste. The choice of gold paste is important for achieving the low loss in the thin substrate.

4. TRANSMISSION LINE

Microstrip transmission line of 50 Ohm impedance is fabricated using both thick and thin film technology [12]. The fabricated specimen in the thick film is shown in Fig.4.

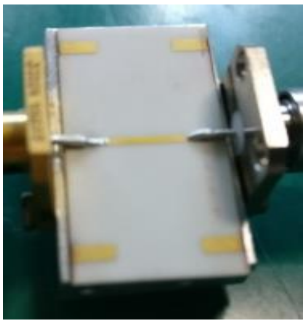


Fig.4. Realized 50-ohm microstrip transmission line

The fabricated line is characterized using vector network analyzer for return loss and insertion loss, same is plotted in Fig.4 [13]-[15].

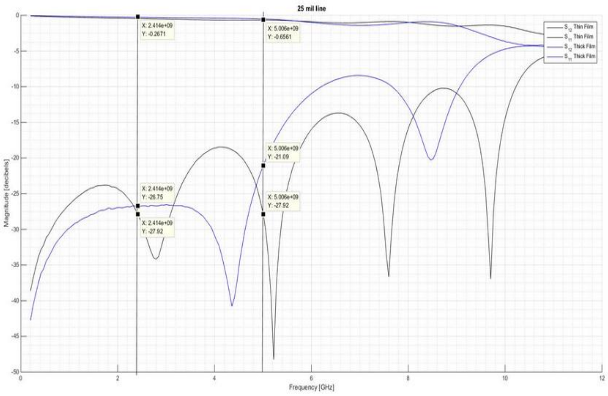


Fig.5. Comparison of thick and thin film transmission lines

Response is tabulated in Table.1 which clearly shows that parameters are comparable and up to 5 GHz frequency, the parameters are exactly matching with thin film process.

Table.1. Comparative Analysis of Microstrip Line

Parameter	Thick film line	Thin film line
DC resistance (Ω)	0.2	0.2
Attenuation (dB/cm)	-0.013	-0.012
Return loss (dB)	-25	-27

From the Fig.3 and Table.1 it is concluded that the performance of both transmission lines is similar up to 5 GHz of frequency and further also losses in thick film produced line is minimal. Hence thick film fabrication technology can be used equally for microwave circuit realization up to certain frequency and same can be improved further if the particle size of lithography paste is even smaller.

5. FILTER DESIGN

In order to demonstrate Thick film technology for RF circuit realization, an S-band band pass filter is proposed to be designed using microstrip structure. The proposed filter is loop resonator filter where a square loop resonator is used as filtering element and Stepped impedance resonator (SIR) pattering is carried out in order to achieve high Q with reduced dimension and suppressed high order harmonics [1]. SIR can be considered as two transmission lines of different lengths and characteristic impedance. Design parameters of SIR are controlled by both length and impedance ratio [16]-[18]. SIR is constructed by cascading a high-impedance section and low impedance section [19]-[20] and the impedance ratio K is defined as Z_2/Z_1. For $0<K<1$, we get the minimum line length of the resonator. Proper choice of the above parameters leads to an optimal reduction of circuit dimension and extension of upper rejection bandwidth [2].

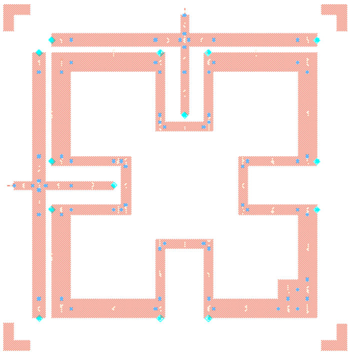


Fig.6. Schematic of dual mode resonator filter

The designed filter is centred at 2250MHz frequency and is fractional bandwidth of 4%. The impedance ratio K which is Z2/Z1 is considered as 0.6 which gives minimum length for SIR. To achieve transmission zero in both sides of pass band, input and output ports are placed orthogonally adjacent arm of the square ring SIR and for achieving dual mode characteristic a perturbation element [4] is located on the corner of the SIR.

6. MICROSTRIP FILTER IMPLEMENTATION

The simulated dual mode resonator filter is fabricated by using two different process namely thick film process and thin film process [11]. The fabricated circuit is shown in Fig.6.

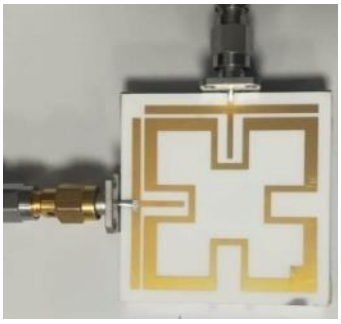


Fig.7. Fabricated dual mode resonator filter

The prototype is fabricated using alumina 99.6% and 96% and finishing of both the specimen is similar. The fabricated models are characterized at ambient as well as cold (-30^{o}C) and hot (60^{o}C) temperatures, to ensure reproducibility of test parameter at extreme temperatures in both the prototypes.

7. SIMULATED/MEASURED RESULTS

Two Dual mode resonator band pass filters are realised on Alumina substrate using two different fabrication processes and insertion loss and return loss were measured in vector network analyzer as shown in Fig.7.

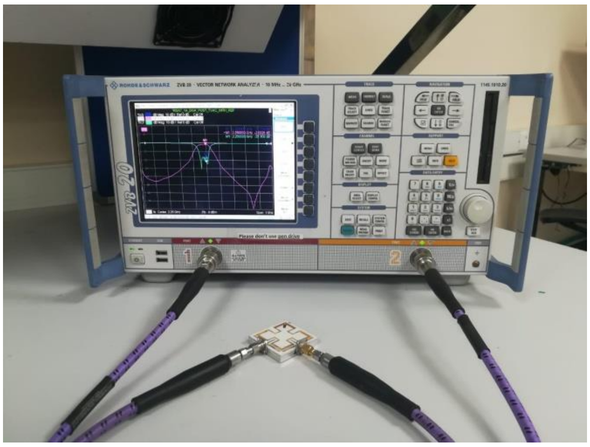


Fig.8. Measurement of fabricated circuit

Both the fabricated filters based on thin and thick film processes are characterized and same is plotted in Fig.8 and Fig.9.

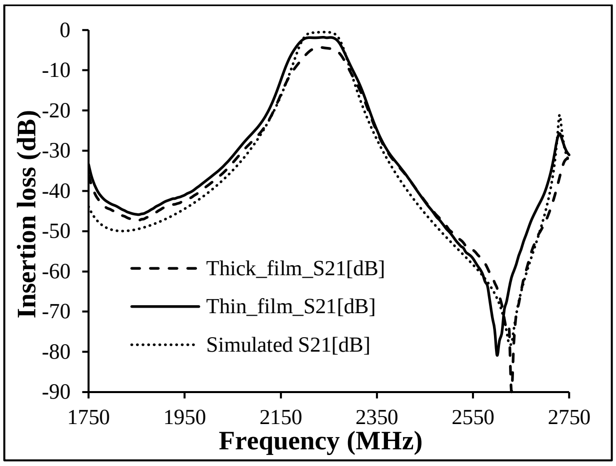


Fig.9. Insertion loss plot for dual mode resonator filter

The above response shows that characteristic of realised filters is exactly following the pattern of simulated response with slight change in insertion loss.

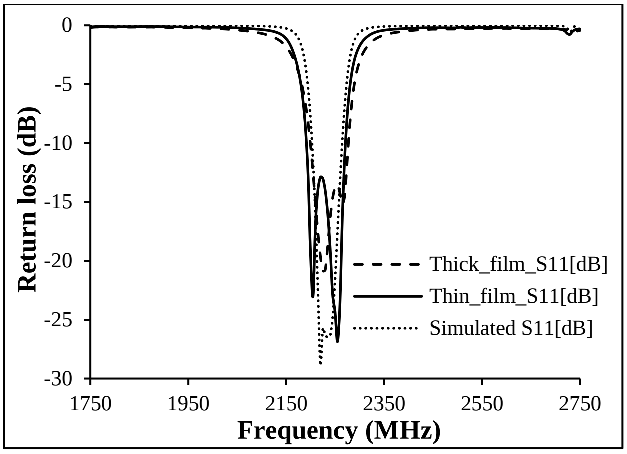


Fig.10. Return loss plot for dual mode resonator filter

Similarly return loss is also follows simulation results and a symmetric response is seen around the centre frequency.

Filter performance is observed in wide frequency band (Fig.11) shows that pass band is very narrow which provide 4% of bandwidth and steep roll off at stop band.

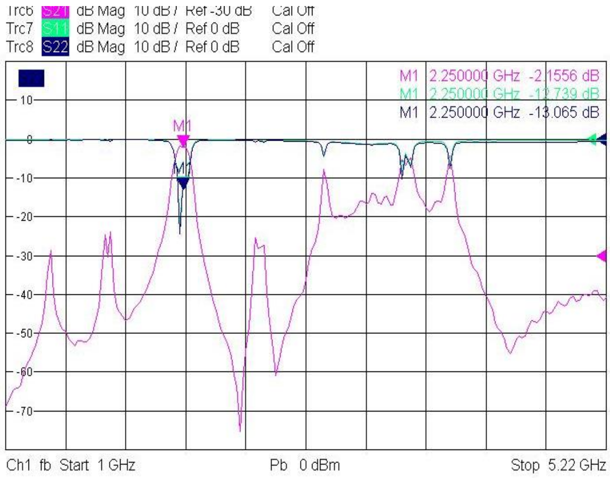


Fig.11. Wide band response

It is also displayed in above Fig.11 that designed filter is having suppressed second harmonic response which is because of the limitation of thick film fabrication technology and it is desired for designing transmitter at microwave frequency.

8. PERFORMANCE OVER TEMPERATURE

In order to evaluate the performance of RF circuit to be used for space-based application, one needs to characterise these circuit across the specified temperature range. In this case cold (-35^{O}C), ambient (+25^{O}C) and hot (+60^{O}C) temperatures are considered.

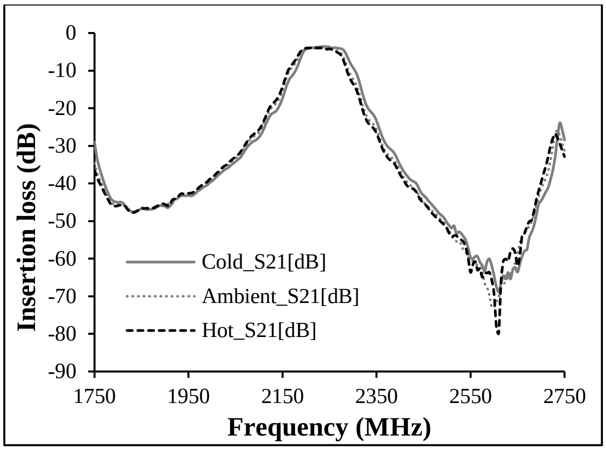


Fig.12. Thin film performance across temperature

The Fig.12 shows that band pass filter performance across temperature is consistent and same can be used for space applications effectively where extreme temperature is experienced by RF circuits.

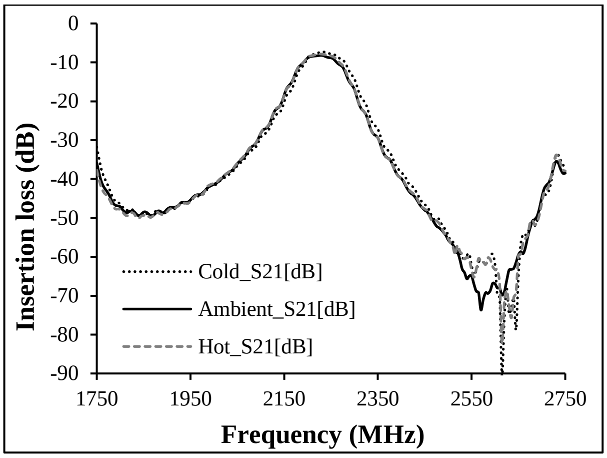


Fig.13. Thick film performance across temperature

Performance of thick film-based band pass filter is also found consistent across temperature and same is equally suitable for space applications as shown in Fig.13.

9. DISCUSSION

The test results are detailed in following Table.2, which is focused on insertion loss, return loss, bandwidth and Q-factor. Insertion loss is affected by permittivity and insulation property of the substrate, simultaneously conductor losses also have major contribution due conductivity of top metallic surface ($\alpha=\sqrt{(\omega\mu\sigma/2)}$).

Due to impurities in the substrate, substrate losses increases and due to particle size and surface smoothness conductor loss will increase. Which is reflected in the result where insertion loss increases significantly.

All the parameters are comparable with each other and meeting the required specifications.

Table.2. Comparative Analysis of Thick and Thin Film Process

Parameters	Thick film	Thin film
Centre frequency (MHz)	2250	2250
Return loss (dB)	-14.5	-14.5
Q-factor	24.7	22.0
Bandwidth (MHz)	90.5	101.3

As the above table shows all the filter parameters are of same order but insertion loss in thick film produced filter is double which may be because of substrate purity and the solder paste used is having bigger particle size, hence microstrip surface on top side is not smooth enough and same is attributed to higher grain size. The same can be replaced with low grain size paste resulting in lesser insertion loss.

10. CONCLUSION

Dual mode resonator filter realisation at S-band frequency is demonstrated using two different fabrication processes such as thin film and thick film processes. The response of the filter realised through both fabrication processes is satisfactory and it is understood that thick film process is also equally capable of producing RF planar circuits on alumina substrate and there is added advantage that turnaround time and fabrication cost is also less in thick film process.

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