Ultra-Wideband Bandpass Low-cost Multilayer Technologies Filter Using Varnish

Hassan Bouazzaoui[1], Kilian Donnart[2], Alexandre Manchec[2], Cédric Quendo[1], Rozenn Allanic[1], Florent Karpus[3], Hugo Bouillaud[3]
[1]Université de Brest ; CNRS, UMR 3192 Lab-STICC, 6 avenue Le Gorgeu, CS93837, 29238 Brest cedex 3
[2] Elliptika(GTID), 2 rue Charles Jourde, 29200 Brest
[3] Protecno(GTID), 2 rue Charles Jourde, 29200 Brest
[1]Cedric.Quendo@univ-brest.fr, [1]Hassan.Bouazzaoui@univ-brest.fr

***Abstract* —In this paper, a new method for ultra-wide band (UWB) bandpass filter design is proposed. This new filter is fabricated using varnish to obtain a multilayer technology, which achieves complex filter structures meeting very hard electrical specifications. Moreover, it has a lower production cost compared to classical multilayer technologies like Low Temperature Co-Fired Ceramic (LTCC) and Organic Substrate Technologies (OST). In first, our objective is to improve the wide band performances and rejection with this new technology. In particular, the coupling between the resonators is increased by superposing resonators or floating metallic patches using varnish. The benefits of the proposed method are also illustrated with simulations and experimental results. The fabricated varnish filter reaches an ultra-wide fractional bandwidth of 100 % and a good level of rejection out of the bandwidth. These proposed filters can be used in communication and radar systems.**

***Keywords* — Broadband communication, Band-pass filters, Coupling circuits, Microstrip filters, Ultra-wideband technology**

I. INTRODUCTION

ULTRA-wideband technology has a crucial role in the development of various transmission systems, such as in-wall imaging, medical imaging, radars and more. However, there has been little scientific interest in this subject, given the lack of regulations allowing the use of IR signals, until the authorization issues by the Federal Communications Commission (FCC) in 2002 [1]. This allows the transmission of signals called "UWB" (Ultra-Wide Band) in the frequency band [3.1 GHz – 10.6 GHz] for communication. The very low energy level (-41.25 dBm / MHz) should permit the joint use of UWB, unlicensed, with existing services in this band. On this occasion, the FCC had to define what the term UWB meant. About communication, it should be noted that the signals must have a band greater than or equal to 500 MHz. It can be noted that according to [2], the term UWB was introduced by the US Department of Defense from 1990 for radar applications. To meet the requirements of the FCC, a UWB filter must not only decrease insertion losses and present a flat group delay on its bandwidth, but also increase the selectivity at both edges of the bandwidth. Indeed, a good out-of-band rejection is also needed to reduce interference from existing wireless communication systems. Developing a UWB that responds well to innovative requirements can be a difficult task, thus, interesting research in the microwave field have recently been sparked on the development of UWB bandpass filters [3-5], these researches cover the majority of the UWB bandwidth with the fractional bandwidth of 109.5 % at the center frequency of 6.85 GHz. The synthesis of the filters was established under the assumption of a narrow bandwidth, and it proved to be very powerful in the design of the filters with a wide bandwidth. In [6], a three-line coupling filter originally shows its ability to achieve a wide bandwidth of 40 % to 70 %. In [7], a 49.3 % broadband bandwidth was achieved in terms of stopping bands of a filter block with both tuning ends on a resonator ring. Nevertheless, this filter configuration remains complicated for the design of UWB filters with a bandwidth of approximately 110.0 %. All these filters have many drawbacks, such as unexpected bandwidths, narrow upper/lower stop bands, a large footprint, and a complex configuration. Following to this disadvantage, a compact UWB bandpass filter using a microstrip-line where varnish is stacked to achieve a multilayer technology and to make ultra-broadband filters is presented here.

II. THE PROPOSED VARNISH TECHNOLOGY

The varnish in the microwave field is usually used for the protection of the electronic circuits, however, it can be used for multilayer circuits manufacturing. Therefore, a technological test has been made to laminate a copper foil on top of the varnish and prove the possibility to obtain a multilayer technology starting from a single layer substrate and varnish. Fig. 1 shows some examples of the technological steps using varnish in microwave circuits fabrication, additionally, in this case, the first step was just to laminate a copper foil on the varnish, following to this success, the generalization is accepted, it is possible to deposit several layers of varnish followed by laminate copper foil, to have the multilayer appearance. Furthermore, the varnish allows us to superpose resonators, to make the multilayer metalized via-hole, and also to protect the final circuit.

Before using the varnish, it is essential to characterize it, therefore, we have used a basic method of characterization with the help of an open-circuited stub, this stub was designed without and with varnish, later we found that the permittivity of the varnish is 5.4, also its dielectric loss tangent equal to 0.02 at 1 GHz and 0.04 at 10 GHz.

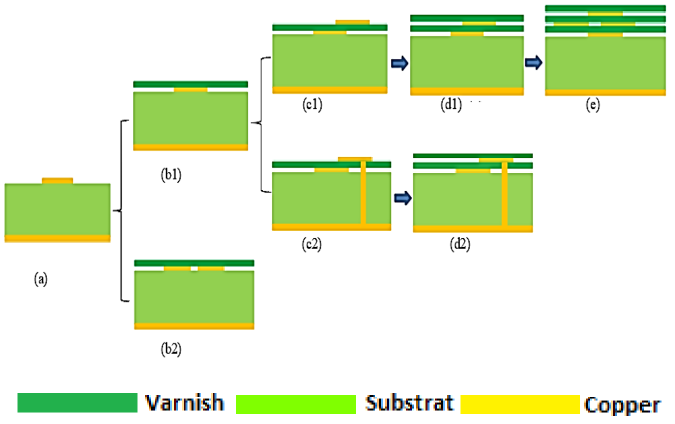

Fig. 1. Some examples of the technological steps using varnish in microwave circuits fabrication. (a) RF devices in microstrip technology. (b) Addition of a layer of varnish on the copper. (c) – Deposition of a copper layer on varnish. (d) Deposition of a third layer of varnish.

III. Coupled line filter on a single microstrip layer on FR4

A. Synthesis and design

Considering a first reference such as a coupled line filter in a classical microstrip technology shows the interest of this work. This one is a 3rd order Chebyshev filter with a Ripple of 0.5 dB and a bandwidth of 50%, The first step is to calculate the J parameters with the equations (1)-(6) required in the tabulated coefficients [8]. These coefficients represent normalized element values of an equivalent LC filter: g0 = 1, g1 = 1.5963, g2 = 1.0967, g3 = 1.5963, g4 = 1.

$$Z_0J_{0,1} = \sqrt{\frac{\pi(BW)}{2g_0g_1}} = 0.7014 \quad (1)$$

$$Z_0J_{1,2} = \frac{\pi(BW)}{2\sqrt{g_1g_2}} = 0.5935 \quad (2)$$

$$Z_0J_{2,3} = \frac{\pi(BW)}{2\sqrt{g_2g_3}} = 0.5935 \quad (3)$$

$$Z_0J_{3,4} = \sqrt{\frac{\pi(BW)}{2g_3g_4}} = 0.7014 \quad (4)$$

Next, the impedances are calculated for each stage Z_{0e}, Z_{0o} with the equations (5), (6) [8], and are summarized in Table I.

$$Z_{0O}\,|_{i,i+1} = Z_0[1 - Z_{0Ji,i+1} + (Z_{0Ji,i+1})^2] \quad (5)$$

$$Z_{0e}\,|_{i,i+1} = Z_0[1 + Z_{0Ji,i+1} + (Z_{0Ji,i+1})^2] \quad (6)$$

TABLE I
THEORETICAL VALUE FOUND FOR EVEN AND ODD IMPEDANCE FOR THIS FILTER

i , i+1	Zoo [Ω]	Zoe [Ω]
0,1	39.25	109.66
1,2	37.93	97.28
2,3	37.93	97.28
3,4	39.25	109.66

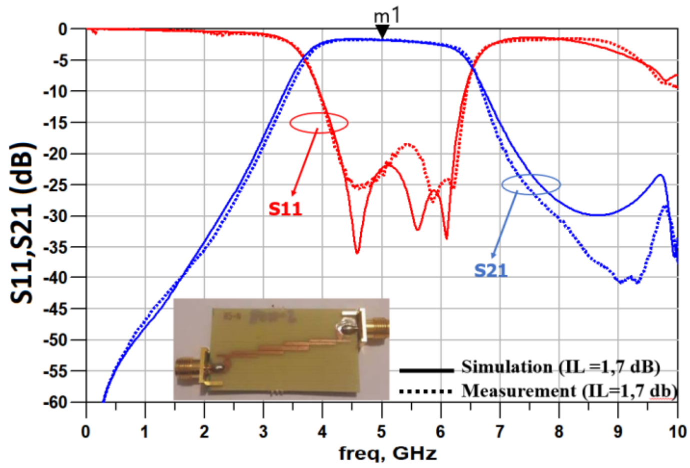

Fig. 2. Comparison between the simulation and the measurement of the fabricated filter on single layer technology (reference filter). Inset: Photograph of the reference filter.

The bandpass filter is designed on a FR4 substrate (ε_r = 4.4, h = 1.2 mm). To work at 5 GHz, this filter was defined with a circuit simulator and electromagnetic simulations was performed with Momentum (Keysight technologies). The filter has a coupling slot access of 150 µm. It corresponds to the technological limit in Printed Circuit Board manufacturing. It is also important to note that in this technological configuration the bandwidth of this bandpass filter can never exceed 50%.

Fig. 2 shows that this electromagnetic simulation filter presents an ultrawide bandwidth and insertion losses of 1.7 dB, it should be noted that measurements are in a good agreement with the electromagnetic simulations.

IV. Coupled line filter on multilayer technology using varnish

In this part, the goal is to improve significantly the bandwidth of the filter thanks to an additional varnish layer with a thickness of 30 µm above the filter. Thus, a low-cost multilayer technology is obtained and that allows the deposition of metal floating patches and the superposition of resonators to enhance couplings and consequently to enlarge the bandwidth.

A. Varnish and floating metallic patches filter results

Fig. 3 presents the results of experimental and electromagnetic simulations and illustrates their good agreement with 1.7 dB of insertion losses. Fig. 4 presents a comparison between the reference filter and the same one with varnish and floating patches. As expected, this new configuration of multilayer filter increases the coupling between resonators and subsequently enlarge the filter bandwidth. Indeed, the relative bandwidth becomes 64 % instead of 51 % for the classical microstrip structure.

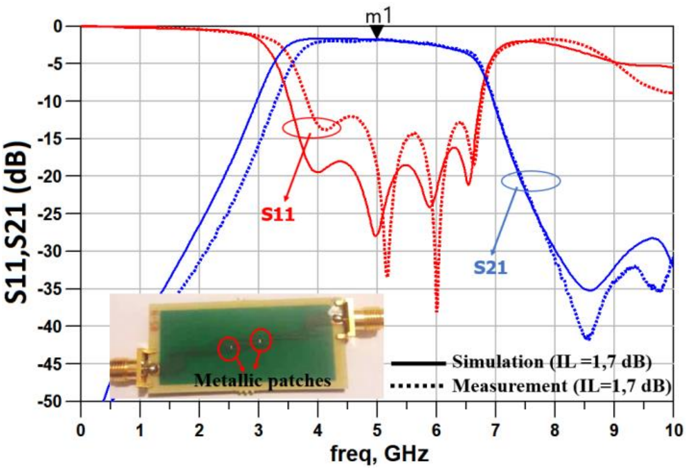

Fig. 3. Measured vs simulated S-parameter for the fabricated varnish & floating metallic patches filter. Inset: Photograph.

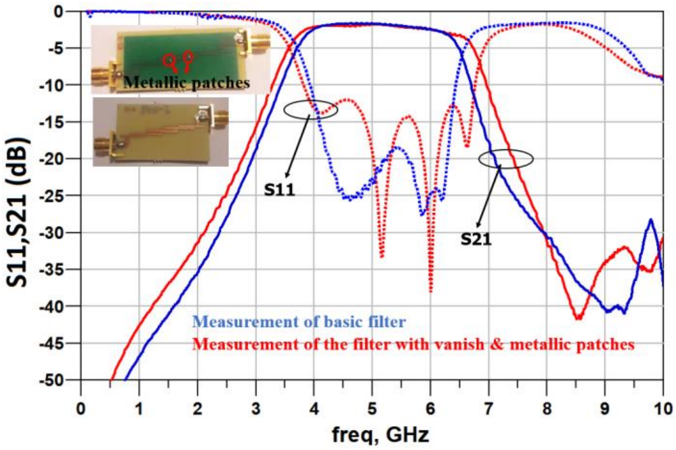

Fig. 4. S-parameters measurement of the reference filter & the first new configuration filter.

B. Design of the filter with varnish, with superposition of the resonators

According to the synthesis presented in part III, an even mode impedance that exceed 110 Ω is required to have an ultra-wideband coupled line filter, i.e., 100% bandwidth, (see Table II). This implies a strong coupling with a slot thinner than 50 µm between the lines of this filter. So, we use our low-cost PCB multilayer technology with a thin layer of varnish to superpose two microstrip lines. By this way, the filter presents strong couplings between resonators.

TABLE II
THEORETICAL VALUE FOUND FOR EVEN AND ODD IMPEDANCE FOR THE FILTER WITH VARNISH

i , i+1	**Zoo [Ω]**	**Zoe [Ω]**
0,1	49.59	148.78
1,2	61.10	179.81
2,3	61.10	179.81
3,4	49.59	148.78

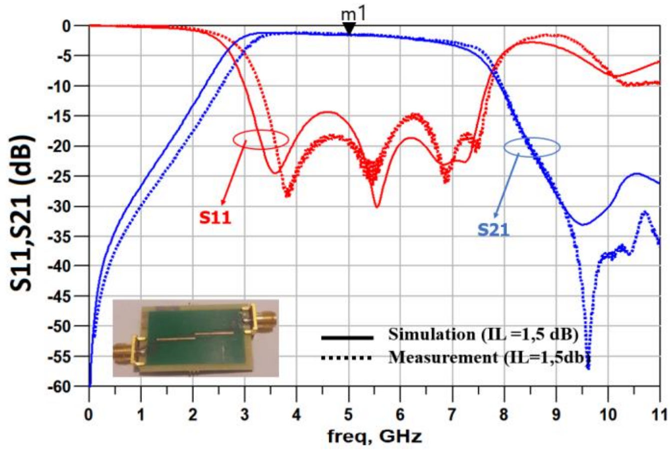

Fig. 5. Measured vs simulated S-parameters for the fabricated varnish and superimposition of resonators. Inset: Photograph of the advanced filter.

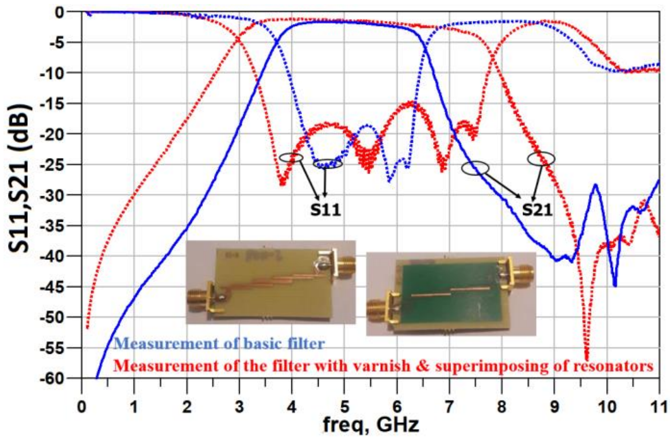

Fig.6. Measured S-parameters of the reference filter & varnish and superimposition of resonators

C. Varnish with superposition of the resonators filter result

Fig. 5 presents the measured and the electromagnetic simulated responses, which shows the mastery of study and the fabrication of the developed filter. The filter has a central frequency of 5 GHz, the insertion losses are lower than 1.5 dB (Marker 1) and a 100 % bandwidth.

V. Comparison between the reference filter & varnish with superimposing of resonators filter

Fig. 6 shows the measured results of the reference filter and the second multilayer low-cost filter, the latter having numerous advantages such as the ultra-wide bandwidth, with a low insertion loss level (IL = 1.5 dB) and an equivalent bulk size.

Table III compares the performances of the three filters studied, developed and fabricated. The last filter presents interesting results compared to the reference filter as twice the bandwidth of the reference filter is obtained. The losses remain unchanged. This quality factor degradation is due to the losses of the varnish but still acceptable.

TABLE III
BANDWIDTH MEASUREMENTS, INSERTION LOSS & Q-FACTOR COMPARISON OF EACH MANUFACTURED FILTER

	Bandwidth (%)	**Insertion loss (dB)**	**Filter size(mm)**
Reference filter	51	-1.7	4.5*2.3
Varnish and floating metallic patches	64	-1.7	4.5*2.3
Varnish with superposed resonators	100	-1.5	4.3*2.2

VI. TEST & VALIDATION

A. Variation influence of the varnish thickness on the filter response

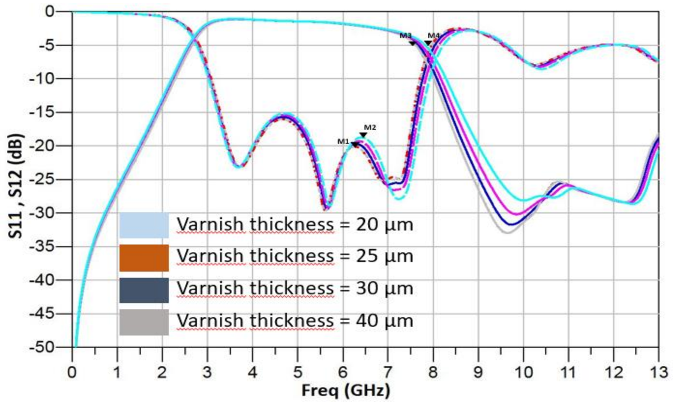

Fig. 7. Simulation of the filter with varnish and superimposition resonators depending on thickness.

Due to the manufacturing tolerance, the impact of the varnish layer thickness has been analysed to predict the filter response sensitivity. This study has been done on the filter with varnish and superimposed resonators.

Fig.7 shows that the filter response is not affected by the thickness tolerance of the varnish layer, indeed the frequency shift according to this variation remains very weak, it is around 0.1GHz.

B. Temperature measurements

Space objects evolve in a very hostile environment. For example, past the difficult launch, they are exposed to space vacuum, strong temperature variations, particle flows and harmful radiation.

As part of the proposed study, the thermal behaviour of the multilayer varnish technology has been evaluated on the advanced fabricated filters.

Fig.8 describes the responses of this filter exposed to the following temperature: 20 °C, 50 °C, 100 °C and 150 °C. Between 20 °C and 150 °C, the insertion losses and the return loss increase by less than 1dB. Moreover, the frequency variation as a function of the temperature is relatively insignificant. Consequently, the behaviour of the multilayer varnish technology is very satisfactory.

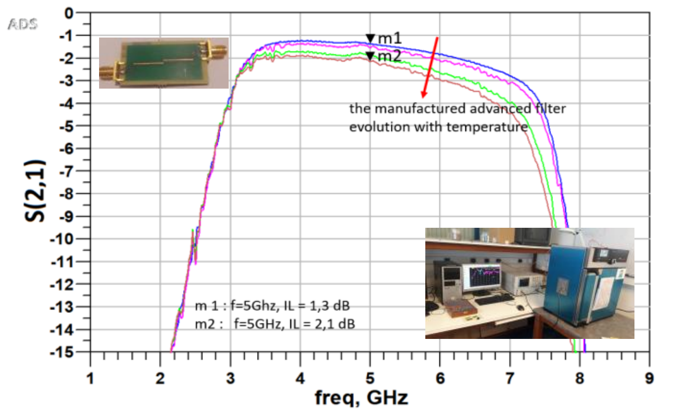

Fig. 8. Temperature influence on the varnish and superimposition of resonators filter. Inset: Photograph of the used stove.

VII. CONCLUSION

This paper presents a new method of circuits manufacturing in multilayer Printed Circuit Board technology with metallized varnish. This method offers a lot of advantages (low cost, bulk size, and electrical performances). Thanks to the superposition of resonators, a 100 % bandwidth filter has been developed, fabricated and measured compared to a 50 % bandwidth with a classical Printed Circuit Board technology.

Moreover, this multilayer low-cost technology offers a lot of possibilities for innovative filters topologies including cross-couplings configurations.

The goal would be to improve the rejection close to the bandwidth, or the group delay. In addition, it is possible to use the varnish on a low-loss substrate in order to further improve the quality factor of the filters.

ACKNOWLEDGMENT

The authors want to acknowledge “Meredit” for it financial support.

REFERENCES

[1] FEDERAL COMMUNICATIONS COMMISSION, « Revision of part 15 of the commission’s rules regarding ultra-wideband transmission systems, first report and order ». FCC, fév. 2002.
[2] R. J. FONTANA, « Recent system applications of short-pulse ultra-wideband (UWB) technology », IEEE Trans. on Microwave and Techniques, vol. 52, sept. 2004.
[3] H. Ishida and K. Araki, “Design and analysis of UWB bandpass filter with ring filter,” in IEEE MTT-S Int. Dig., vol. 3, Jun. 2004, pp.
[4] H. Ishida and K. Araki, “A design of tunable UWB filters,” in Proc. Int. Workshop Ultra-Wideband Systems, 2004, pp. 424–428.
[5] A. Saito, H. Harada, and A. Nishikata, “Development of band pass filter for ultra-wideband (UWB) communication,” in Proc. IEEE Conf. Ultra-Wideband Systems Technology, 2003, pp. 76–80.
[6] J. T. Kuo and E. Shih, “Wideband bandpass filter design with three-line microstrip structures,” Proc. Inst. Elect. Eng., vol. 149, no. 5/6, pp.243–247, Oct./Dec. 2002.
[7] L. H hsieh and k. Chang, “Compact, Low Insertion-loss, Sharp-Rejection, and Wide-Bande microstrip bandpass filter”, IEEE Trans. on Microwave Theory and Techniques, vol 51, no.4, April 2003.
[8] R. Ludwig and P. Bretchko, RF Circuit Design: Theory and Applications. Upper Saddle River, NJ: Prentice-Hall, 2000, chapters 2 and 5.