Optimisation and Comparison of Three Diplexers Based on a New Slot to Microstrip Junction.

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Abstract — **In this paper, a microstrip to slotline transition using different quarter wavelength stubs is proposed and defined as inhomogeneous. The bandwidth of each stub is separately studied and the microstrip to slotline junction is considered as a band-pass filter controlled by design rules. The DOE optimisation and comparison of three different diplexers using this type of junction is achieved by using new design rules implemented in a new CAD tool. At least, simulations and measurements confirm the theoretical approach of this study.**

I. INTRODUCTION

With the development of more recent communication systems, the interest in higher integration density and low cost microwave packaging increases. The multilayer technologies with the advances in new PCB or ceramic materials offer a good solution to achieve these goals. The use of both microstrip and slot transmission lines is one of the useful applications for multilayer structure ([1-3]) and different coupler structures based on homogeneous transition have been still studied.

The present study highlights comparison and optimisation of multilayer diplexers using a new concept of inhomogeneous slot/microstrip junction. First the homogeneous model of slot/microstrip transition is briefly reminded, and then it is modified to lead to the concept of inhomogeneous junction. Therefore the study, optimisation and design of a three different diplexers using this inhomogeneous junction are proposed. The implementation of CAD tools for this design will complete this study.

II. SLOT/MICROSTRIP JUNCTION

The classical homogeneous slot to microstrip junction can be defined as a transition using quarter wavelength stubs referred to a central frequency ([4-5]) like the following figure:

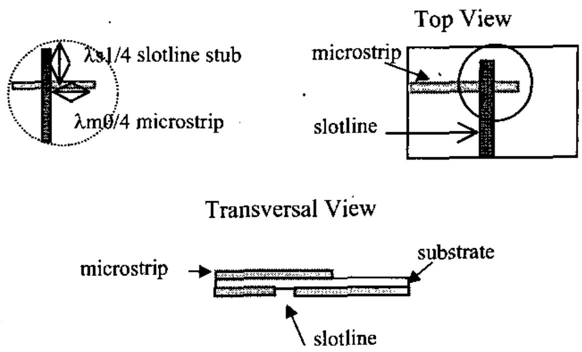

Fig. 1. Junction structure

Previous studies have shown that the electrical model of this structure can be considered as the following:

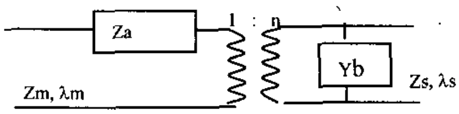

Fig. 2. Electrical model

where the $\lambda_0/4$ stubs can be regarded as brought back impedances and the coupling between the slotline and the microstrip line as a transformer. In this model ([6]):

$$Z_a = -jZ_m \cot g(\theta_{ms}) \text{ with } \theta_{ms} = \frac{2\pi}{\lambda_m}\left(\frac{\lambda_{m0}}{4} + dl\right) \quad (1)$$

$$Y_b = \frac{j(X_s.tg(\theta_{ss}) - Z_s}{Z_s(X_s + Z_s.tg(\theta_{ss}))} \text{ with } \theta_{ss} = \frac{2\pi}{\lambda_s}\frac{\lambda_{s1}}{4} \quad (2)$$

with

Zm or s: characteristic impedance of the microstrip or slot respectively

λm or s: wavelength in the microstrip or slot respectively

λm_0: wavelength in the microstrip stub at the frequency f_0 such as the stub length is equal to $\lambda m_0/4$

λ_{s1}: wavelength in the slot stub at the frequency f1 such as the stub length is equal to $\lambda_{s1}/4$

for the homogeneous junction $f_1=f_0$.

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X_s: end effect of the slotline [7]
dl: end effect of the microstrip.

Considering the equations 1 and 2, the expressions in tangent of Za and Yb indicate the cyclic character of the bandwidth of each stub constituting the junction. Consequently their frequency behaviour can be characterised by a bandwidth and an attenuation in it.

So each element of the transition can be separately detailed. In this case different electric lengths referred to two different frequencies (f1 and f2) can be allotted to the slot and the microstrip stubs constituting the transition. This junction will be defined as an inhomogeneous one.

Taking into account these dimensional modifications for the microstrip and slot stubs, the DAS model ([6]) can be kept and highlights the essential points in terms of frequency pattern for the realization of filters.

III. DESIGN OF DIPLEXERS WITH INHOMOGENEOUS JUNCTIONS

Such inhomogeneous slot/microstrip junctions are now considered to design three different diplexers. Each way of the diplexer is characterised by a central frequency f_i and a bandwidth Δf_i (i=way number).

Like previously shown, the behaviour of each stub (slot or microstrip) leads to several poles at frequencies equal to $(2k+1)*f_{0j}$ (k integer and positive) and a bandwidth of Bw_j. So the desired frequency pattern induces some rules for the design of each stub in the inhomogeneous transition. Consequently for each stub on way number i, f_{0j} and Bw_j must satisfy the following relations ([8]):

$$(2k+1)f_{0j}=f_i+\delta f_i \text{ with } |\delta f_i| \leq \frac{Bw_j-\Delta f_i}{2} \text{ , i=1, 2 or 3 and}$$

$$|\delta fi| \leq \Delta fi/2 \qquad (3)$$

Assuming Bw_j equal to $(1+\eta)f_{0j}$ in first approximation ($\eta \ll 1$), and the Q-factor of the transition considered as a filter, one can also determine the following condition:

$$k \leq \frac{1}{2}\left((1+\eta)\left(Q+\frac{1}{2}\right)-1\right) \qquad (4)$$

Reporting in (3) the k values obtained by (4), several frequency domains are determined for f0j and the relative wavelength λj can be found. For given f_i and Δfi, the highest foj is determined for the smallest k value (zero). In this case, both λj and the associated stub become the smallest and the integration level is increased. But on the other hand, higher k values induce not too large f_{0j} and Bwj, which is better to carry out precisely Δfi.

Three different topologies of diplexers are considered. Port 1 is attributed to the common way, port 2 and 3 are respectively assigned to the low and high frequency ways.

On each diplexer, the same widths for all the microstrip lines and for all the slotlines are fixed. In this case, the only parameters that affect the bandwidth of the structure are the lines lengths.

- The first diplexer topology is an annular slotline coupled with three microstrip lines (see figure 3). This structure is the simplest to optimise because, for each way, the microstrip stub length and its position around the ring are the two only geometrical parameters influencing the bandwidth. The transmitted wave from port 1 is divided in two parts in the slot at the transition J1. The first part courses the ring in the direct direction and the other one in the opposite direction; the two signals are recombined at the junction J2 or J3 depending on their frequencies.

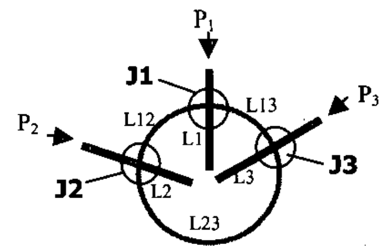

Fig. 3. The Slot Ring diplexer

- The second topology, called "Line diplexer" and shown figure 4, is an opened structure composed by a slotline and three microstrip access lines. In this structure, the wave is transmitted from P1 to the slot through the slot/microstrip transition J1 chosen as a large bandwidth one. Then two inhomogeneous junctions (J2 and J3) permit to recover low and high frequencies respectively.

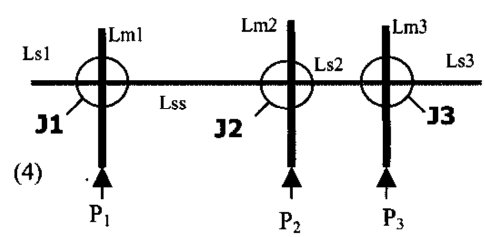

Fig. 4. The Line diplexer

- The third structure is based on a slot T-junction and three microstrip access lines (see figure 5). In that case, the first junction J1 transmits the signal from P1 to the slot Te. The two junctions J2 and J3, placed on each branch of the Te and designed as inhomogeneous, select the frequencies for each way P2 and P3.

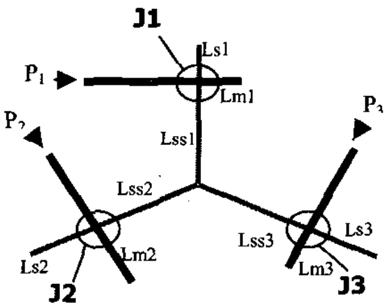

Fig. 5. The Te Slot diplexer

On each structure the more efficient parameters are the stub lengths but the slot transmission lines have to be optimise to reduce the transmission losses.

IV. OPTIMISATION AND REALISATION

To compare the different topologies, the study of three X-band diplexers with the same frequency characteristics is proposed: 2GHz bandwidth around 9.75GHz and 12.25GHz are chosen respectively for the low and high frequency ways.

To limit the number of optimisation parameters, five maximum according to the implemented DOE loop, some parameters that appear less efficient on the diplexer characteristics are fixed.

Diplexer topology	Fixed lengths	Optimised lengths
Ring	The ring size, L1, 123	L2, L3, 112, 113,
Line	Lm1, Ls2	Lm2, Lm3 Ls2, Ls3, Lss
Te	Lm1, Lm2, Lm3, Ls1	Ls2, Ls3, Lss1, Lss2, Lss3

Table 1: Parameter summary

Each structure is designed on MS-QUAD, a CAD tool created at the IXL Laboratory ([9]), including a design of experiment (DOE) algorithm based on Taguchi method ([10]) to optimise each parameter.

As previously seen, the variation domains of the stub lengths are given by the equations (3) and (4).

For the low frequency way (bandwidth Δf_2=2GHz centred on f_2=9.75 GHz), the relationship (4) gives three values for k (0,1,2) and the relationship (3) indicates that the resonance frequencies of each stub constituting the junction are included in the following fields (all frequencies in GHz):

for k=0: $8.75 \leq f_{01} \leq 10.75$, field 1 corresponding at $f_2+\delta f_2=f_{01}$ and $|\delta f_2| \leq \Delta f_2/2$

for k=1: $2.91 \leq f_{02} \leq 3.58$, field 2 corresponding at $f_2+\delta f_2=3f_{02}$ and $|\delta f_1| \leq (Bw_2-\Delta f_2)/2$

for k=2: $1.86 \leq f_{03} \leq 2.04$, field 3 corresponding at $f_2+\delta f_2=5f_{03}$ and $|\delta f_2| \leq (Bw_3-\Delta f_2)/2$

By the same approach, three frequency fields are determined for the resonance frequencies of each stub constituting the junction for the high frequency way (bandwidth Δf_3=2GHz centred on f_3=12.25 GHz, all frequencies in GHz):

$12.25 \leq f'_{01} \leq 14.75$, field 1'

$4.08 \leq f'_{02} \leq 4.075$, field 2'

$2.45 \leq f'_{03} \leq 2.85$, field 3'

As forecast, the field 1 and 1' frequencies lead to low-size circuits, but their associated bandwidth are too high. The field 3 and 3' frequencies support a better approach of selected bandwidth but induce lengths of stubs more significant than those of fields 1 and 2. Ending, the field 2 and 2' give a compromise between the length and the bandwidth of the stubs.

V. SIMULATION AND MEASUREMENT RESULTS

After DOE optimisation of each structure, many simulations are carried on with MS-QUAD, Agilent ADS and Momentum (MoM) tools, before experiment.

The isolation between the low and high frequency ways ant the transmission parameter in the two ways (P1 to P_2 or to P_3) are successively considered and compared for the three structures. Some simulated S21 parameters for low frequency way are proposed on figure 6.

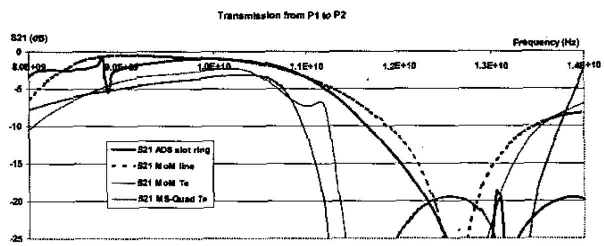

Fig. 6. Simulated transmission parameter at low frequencies

The transmission is satisfactory and better than –3dB for the Line and Slot Ring diplexers, but the slope at the cut-off frequency (11GHz) is too weak. For the third diplexer, the transmission is near from –3dB in each branch because the Te acts as a divider, but there is a good decrease at 11GHz. The Momentum simulations confirm the ADS and MS-QUAD results.

In the third part of the study, the structures are realised in thick film technology on alumina substrate and measured.

First the isolation between P_2 and P_3 is considered (see figure 7)

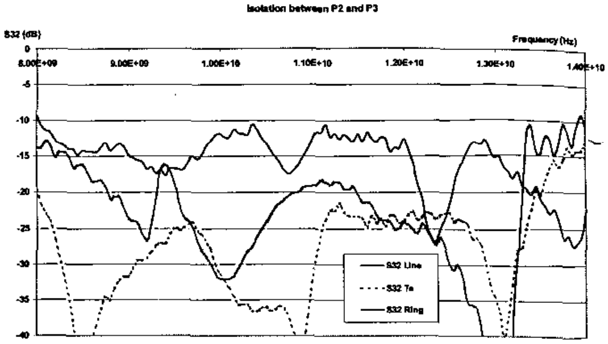

Fig. 7. Measured isolation between low and high frequency way

This isolation is low into the Line diplexer due to the interactions between the junctions J2 and J3 on the two transmission ways. In the Slot Ring diplexer, the isolation is intermediate (less than -15 dB), and the Te Slot diplexer offers the best isolation.

Then the S_{21} parameter for low frequency way is measured as shown in figure 8.

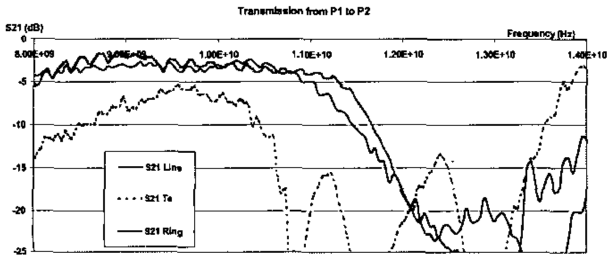

Fig. 8. Measured transmission parameter at low frequencies

Figure 9 shows the measured transmission parameter for the high frequencies.

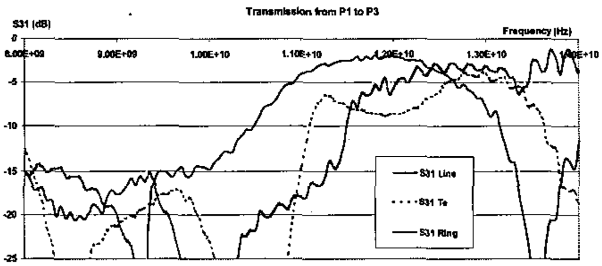

Fig. 9. Measured transmission parameter at high frequencies

A good accordance between the measurements and simulation results is observed.

Finally, the comparison between the three structures leads to the following points:

- The smallest structure is offered by the Line diplexer.
- In terms of losses the Line diplexer and the Slot Ring structure are better than the Te Slot diplexer.
- In terms of isolation between the high and low frequency way, and bandwidth specifications respect, the Te Slot diplexer is better than the other ones.
- The Slot Ring is a good compromise between losses and isolation.

V. CONCLUSION

From a theoretical study of each element of the transition slot/microstrip, a new concept of inhomogeneous junction is introduced. This transition has brought new development on the synthesis of multilayer circuits based on slot/microstrip lines. It is shown that MSQUAD becomes an essential tool for CAD optimisation of such multilayer planar structures. Finally three diplexers were designed, optimised by Taguchi method and compared. The Slot Ring diplexer is the best compromise in terms of losses, isolation and bandwidth. A new design based line diplexer is actually studied to offer better results and higher integration density.

REFERENCES

[1] K. C. Gupta, R. Garg, I.J. Bahl «Microstrip Lines and Slotlines», Artech House, Norwood, MA, 1979

[2] R. K. Hoffmann, J Siegl «Microstrip-Slot Coupler Design-Part I: S-Parameters of Uncompensated and Compensated Couplers", IEEE Transactions on Microwave Theory and Techniques vol MTT-30-n°8 August 1982

[3] M. M. Zinieris, R. Sloan, and L. E. Davis «A Broadband Microstrip-to-Slot-Line Transition» Microwave And Optical Technology Letters Vol. 18, N°5, August 5 1998

[4] J. B. Knorr, «Slotline Transitions, »IEEE Transactions on Microwave Theory and Techniques vol MTT0-22 –1974-p584-554.

[5] N.L. Vandenberg, L.P.B. Katehi "Broadband Vertical Interconnects Using Slot-Coupled Shielded Microstriplines", IEEE Transactions on Microwave Theory and Techniques vol-40-n°1 January 1992

[6] N. Das, «Generalised multiport reciprocity analysis of surface-to-surface transition between multiple printed transmission lines», IEEE Transactions on Microwave Theory and Techniques vol-41-n°6/7 june/july 1993

[7] G. Duchamp, L. Casadebaig, S. Gauffre, J. Pistré, "An Alternative Method for End Effect Characterisation in Shorted Slotlines", IEEE Transactions on Microwave Theory and Techniques vol-MTT 46-n°11 November 1998

[8] G. Duchamp, L. Casadebaig, S. Gauffre, J. Pistré, « Modélisation Quadripolaire de structures planaires mixtes microruban – ligne à fente », *JNM'99*, Arcachon, 5-7 Mai 1999

[9] P. Gouget, G. Duchamp, J. Pistré, « Design of X Band Filter Using Inhomogeneous Microstrip to Slotline» EuMW-2002,Milan,sept. 2002

[10] J. G. Elliott « Statistical and Applications » Allied Signal Corporation 1987