A Complete Integrated TX/RX Front-End Combining 3D Topologies And Global Synthesis.

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***Abstract* — We propose an original procedure for integrating a RX/TX front-end. A dual operating mode function (mixer/modulator), based upon a CPW magic-Te a, is developed. A global synthesis technique is then considered in combination with 3D integration techniques for achieving bandwidth requirements and design flexibility. The complete RX/TX module is presented.**

I. INTRODUCTION

Cost and electrical constraints related to new telecommunications systems and proposals (MMDS, LMDS, Wireless Local Loop, ...) must absolutely be simultaneously considered today for designing efficient RF front-ends, with performances in accordance with on-board or base station equipment.
Technological orientations, as well as design methodologies, really contribute to reach such challenge. In this way, RF modules can not be individually considered, and global synthesis techniques must be involved. We have previously reported about such approach which is really well-suited for meeting cost, size and electrical requirements, especially about radiating elements. As a consequence, the technology has to be improved so as to provide to the designers a great design flexibility necessarily implied with such global synthesis. We have proposed a 3D multi-technologies approach, then offering various transmission line topologies and a number of available technological combination.

In this paper, we first present results about efficient filter-antenna modules, underlying the numerous advantages related to a global synthesis under a 3D integration technique.

The method is then extended to the implementation of a complete integrated dual operating mode RF front-end. We discuss about the great interest of a 3D technology for improving hybrid interconnections between passive and active components. Then, we emphasize on the design task, based upon the association of electromagnetic and "circuit" simulations. The dual operating mode function (modulator/mixer module) is especially described and validate through comparisons between experiments and simulations.

The complete integrated RX/TX module is presented and characterized in both emitting (BPSK modulation) and receiving (homodyne mixer) modes.

II. A GLOBAL SYSNTHESIS METHOD FOR IMPROVING ANTENNA PERFORMANCES

The figure 1 describes a microstrip patch antenna reported on a foam substrate ($\varepsilon r = 1.07/\tan \delta = 0.001$), electromagneticaly coupled to a back-side microstrip filter on alumina substrate. A global synthesis procedure is proposed for introducing the antenna as the last resonator of the filter [1] [2] [3].

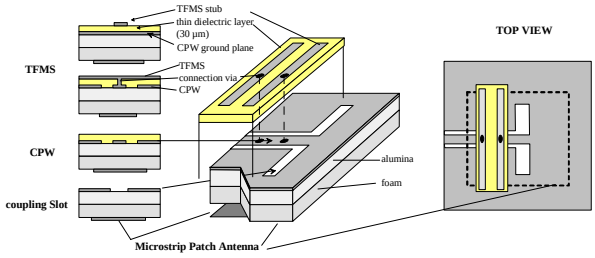
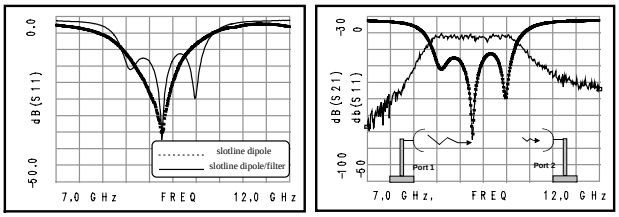


Fig. 1. Filter-antenna module on a composite substrate

This antenna is modeled as a RLC resonator, R being the equivalent radiating resistance. This way, the filter synthesis procedure can be performed at Fo, assuming the output port loaded by the equivalent R resistance of the patch.

The figure 2 describes the return loss parameter measured for such antenna-filter structure. An operating bandwidth of about 20% centered at 10 GHz is reached (ρ < -10 dB) while the radiating performances are also notified on this wide band (fig. 2b) [4].

Notes that 3D topologies have been used for integrating the filter, regarding the required characteristic impedance, especially for the parallel stubs of the filter (Zc # 5 Ω). TFMS (Thin Film MicroStrip lines) and 3D CPW (Coplanar Waveguide) have been implemented on an alumina substrate with intermediary (εr =4/30µm) dielectric sheets.



a) return Loss *b) transmission losses*

Fig. 2. Antenna-filter module – Characterization

If the global synthesis technique brings interesting perspectives in terms of electrical behaviour, it also induces drastic constraints on the technology to be associated. This contributes to the 3D technological orientation

III. Design and Implementation of 3D Multi-Technology RF front-ends.

Following the same idea, we extend the global synthesis technique, in relation with a 3D integration process, to the design of complete RF integrated front-end modules. The corresponding schematic is mentioned on figure 3.

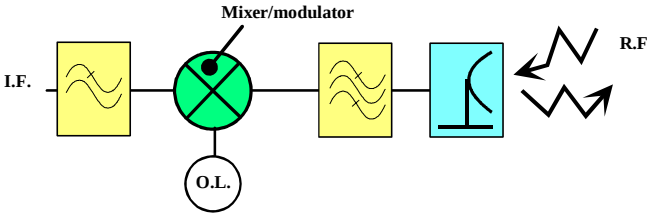


Fig. 3. Dual mode RX/TX module : schematic

This device is made of the previous described antenna-filter module, cascaded with a dual mode mixer/modulator function and corresponding filtering sub-circuits, and a local oscillator.

The critical mixer/modulator function is composed of an annular slotline Magic Te structure with schottky diodes, and required filters and transitions to external feeding access.

- In TX mode, the diodes are alternatively switched Off and On depending on the incident binary signal injected through the low-pass IF-filter (Intermediate Frequency), then modifying the phase of the Local Oscillator signal (LO with a 0-180 phase shift).

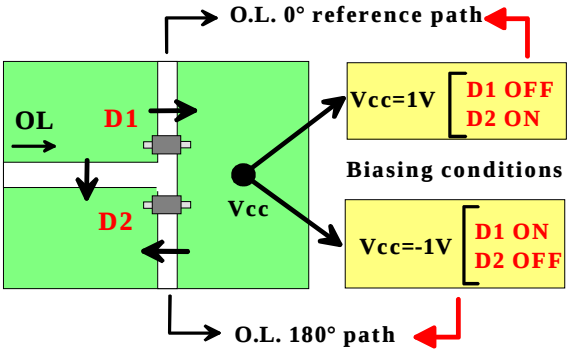


Fig. 4. magic TE in Modulator operating configuration

- In RX mode, the incident RF signal is mixed with the LO signal. The beam-lead diodes generate harmonic frequencies, and especially the I.F. frequency.

The corresponding architecture is described on figure 5 for a CPW modulator/mixer module. Great difficulties are encountered with such a technology, concerning the parasitic mode filters and also the diodes mounting operations (reproducibility, alignment,..).

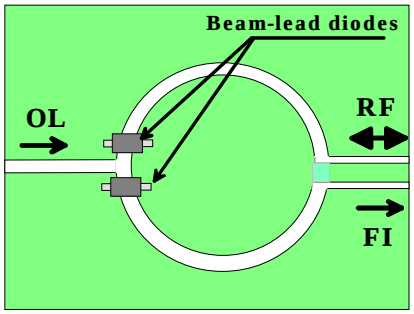
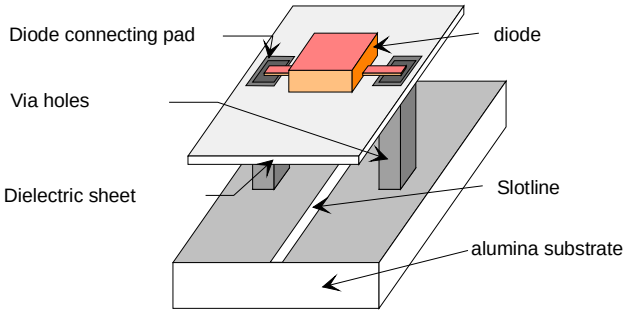


Fig. 5. Description of the magic TE in Mixer operating mode

We have modified such classical architecture along a 3D multitechnology process, taking into account the numerous benefits of such multilayer integration. This way, the diode are connected to both annular slotline conductors through a protective dielectric sheet, by means of discrete vias holes – see fig. 6. The diodes mounting operation is really made easier because the alignment and positioning with respect to the magic Te is now perfectly controled (accurate connecting area).



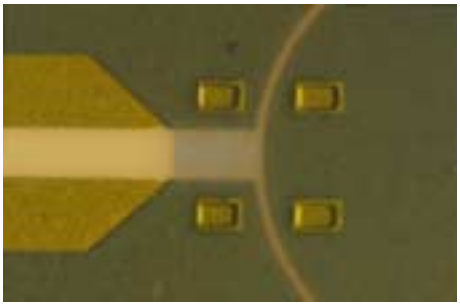


Fig. 6. Beam-lead diode mounted on the modified magic Te feeding ports – 3D Pads location.

The design procedure is made harder because of the multileveled configurations to be considered. We develop an hybrid approach, by using electromagnetic simulator (HP-MoMentum) for properly describing the diodes access regions, and "circuit" simulator (HP-MDS) for modeling the complete structure.

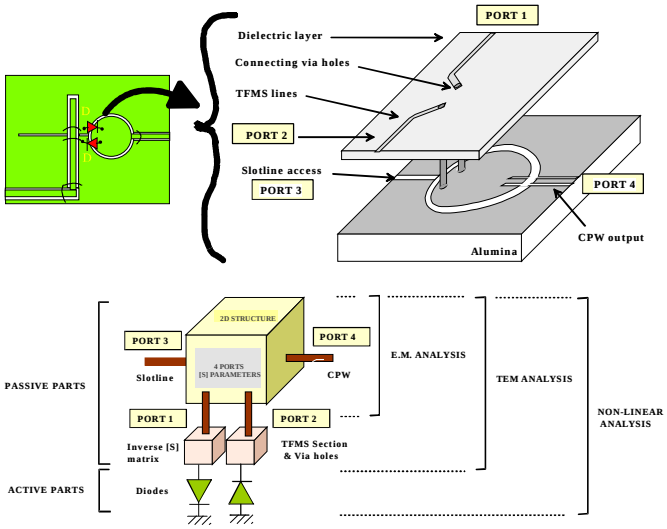


Fig. 7. Hybrid design procedure. Analysis: Procedure

Notes that the diodes feeding points are considered as standard feeding ports. The non-linear analysis task can be engaged for optimizing the matching conditions at RF, FI and OL frequencies nearby these mixing discrete components.

We have implemented such module on an alumina substrate (εr =9.5 / 635µm), with intermediary dielectric sheet (εr =4 / 30µm), for a center RF frequency of 10GHz.

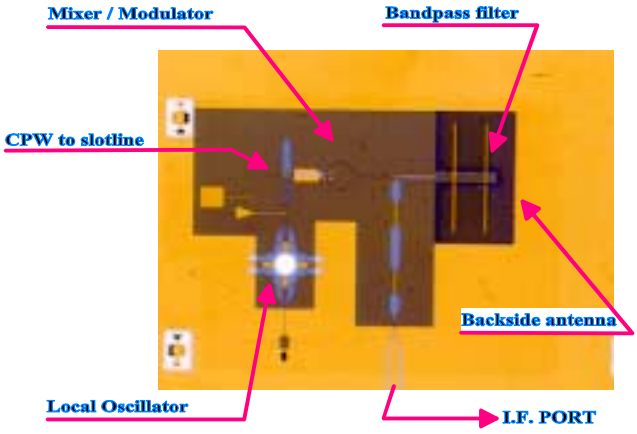


Fig. 8. Photography of the complete integrated module.

Previous experimental characterizations were performed for evaluating the performances of the mixer. As mentioned on figure 9, we obtain quite good results (conversion losses of about 7dB, mainly due to the diodes resistance), comparable with the ones obtained by a standard uniplanar approach.

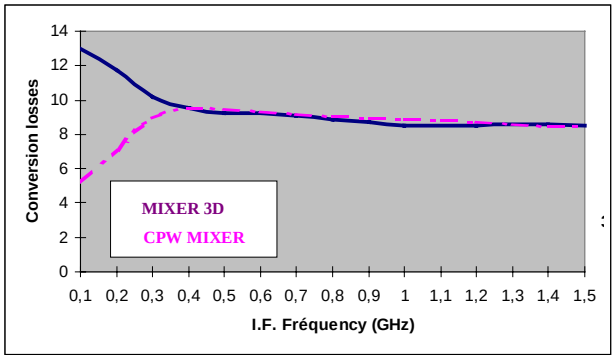


Fig. 9. Uniplanar/multitechnology mixer : Comparisons

Nevertheless, the mounting and tuning operations are really made easier here because of the implicit integration of dielectric bridges (parasitic mode filters) and well-controled diode access ports .

IV. RX/TX Module -Characterization

The figure 10 describes the experimental test-bench defined for characterizing the RX/TX module.

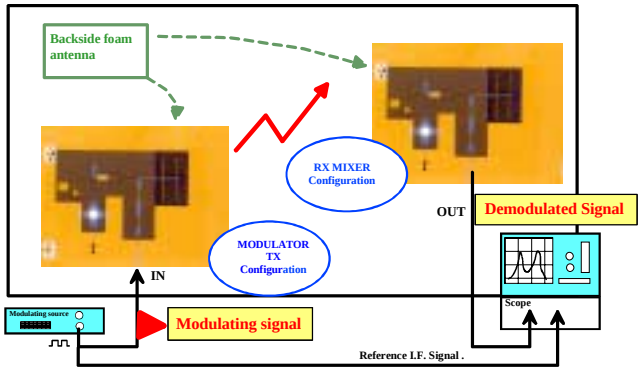
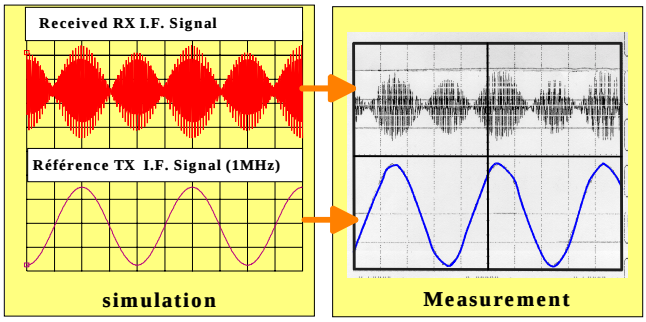
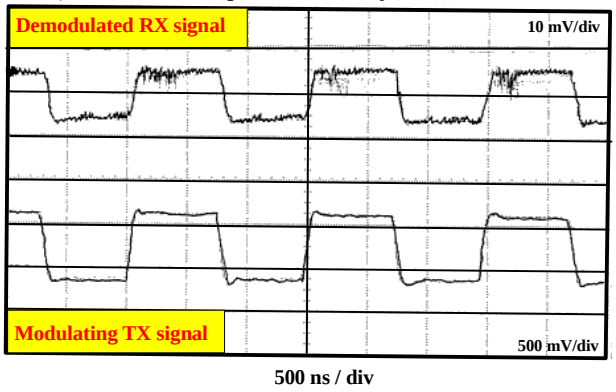


Fig.10 Test-bench with dual operating mode modules

The module 1 is used as a up-converter mixer – see fig. 11a – or as a BPSK modulator (1Mbits/s modulating signal) - cf fig. 11b.



a) Module 1 = Up-converter Injected



b) Module 1 = Modulator

Fig.11 Time domain experiments and simulations

The received RF signal is demodulated through a second hybrid module configure as an homodyne down-converter, and compare to the reference TX I.F. information on a scope

The experimental verification has been done at 10 GHz in the far-field region. One can observe the good correspondence between the radio-transmitted signal and the reference one. This reference binary signal can be easily recovered regarding its amplitude, and the spectrum purity obtained through the efficient RF and FI filtering structures engaged.

V. Conclusion

In this paper, we demonstrate that global synthesis techniques, combined with appropriate and flexible 3D technologies can be efficiently used simultaneously for implementing completely integrated RX/TX modules. The dual operating mode structure is quite original and attractive at once for future generations of RF equipment. It could be quite a good solution for simplifying the individual set top box which will be necessarily placed for each subscriber for decoding received RF signal from LEO satellites, fibre or base stations in a near future. The technology appears also as a key-issue for size and cost motivations, offering either a better design flexibility or minimizing technological drawbacks.

References

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[4] Ch. Person et al., "Original Techniques for Designing Wideband 3D Integrated Couplers", IEEE MTT-S 1998, Baltimore, Vol. 3, June 1998, pp. 119-122.