Tunable Ferroelectric Components in LTCC Technology

A. Deleniv*, T. Hu[&], H. Jantunen[&], S. Leppävuori[&], S. Gevorgian*[,#]

* Department of Microelectronics, Chalmers University of Technology
41296 Gothenburg, Sweden
[&] University of Oulu, Microelectronics and Materials Physics Laboratory and EMPART Research Group of Infotech Oulu, P. O. BOX 4500, FIN-90014 Oulu, Finland
Microwave and High Speed Research Center, Ericsson AB
431 84 Moelndal, Sweden

Abstract — **Designs of a tunable matching network and a tunable phase shifter by LTCC ferroelectric technology are presented. The devices are designed for operation in K frequency band. Test structure measurements are presented along with extracted parameters of used ferroelectrics (dielectric permittivity and tunability). These measured parameters are then used to design phase-shifter and matching network using ADS "Momentum". Simulated performance of these components is presented.**

I. INTRODUCTION

Low Temperature Cofired Ceramics (LTCC) technology is widely used to fabricate cost effective and reliable microwave components and devices [1-3]. Today LTCC devices include passive microwave components, such as transmission lines, capacitors, filters etc. The active components based on semiconductors (transistors, varactors ICs) can be used only by assembling them on the surface as discrete components [4]. However, incorporation of ceramics with tunable magnetic or dielectric properties will enhance the possibilities of LTCC technology. Tunable components, such as varactors, filters, phases shifters etc will be possible to integrated monolithically in LTCC based microwave devices.

In this work we present designs of two tunable components based on LTCC thick film ferroelectrics. To design these components we have fabricated and characterized experimentally DC electric field tunability of novel ferrioelectric films suitable for integration in LTCC technology. The measured film parameters are used as input data in simulations of a tunable matching network and a tunable phase shifter. Design issues and performances of these devices are also discussed.

II. FABRICATION AND MICROWAVE CHARACTERISATION OF FERROELECTRIC LTCC FILMS

A. Structure of the substarte and fabrication of ferroelectric films

The commonly used ferroelectric compositions like barium-strontium-titanate (BST) and its low loss version, BST with MgO addition, have sintering temperatures > 1350 °C [5]. The ferroelectric composition used here has sintering temperature in the range of 900-950 °C, which improvement has been achieve by using a mixture of B_2O_3 and Li_2CO_3 as a sintering aid for $Ba_{0.55}Sr_{0.45}TiO_3$+0.6 MgO (prepared by Filtronic Comtek (UK) Ltd.). The total amount of this addition was 4.5 wt-%. The novel composition is labelled as BSTM-BL. The ferroelectric green tape for the test structures was fabricated by tape casting process using B98 (polyvinyl butyral) based slurry system and the casing was done by a single doctor blade with 250 μm wide gap.

The multilayer test structures were prapared by using Al_2O_3 (96 %) as a basic substrate on which a uniform ground electrode layer was screen printed by using Pt paste (Heraeus 5545). After drying, a ferroelectric layer was formed on it by laminating the cast BSTM-BL green tape at 70 °C using 20 MPa pressure and 20 min dwell time. The whole multilayer was then co-fired at 950 °C. Finally, the designed pattering on the top surface was screen printed with silver paste (Heraeus C 1075) and post-fired at 850 °C.

B. Test structure and experimental characterisation

Special test structures are designed and fabricated for microwave measurements. In designing of test structures, and, actual devices, two main limitations are taken into account. The minimum size feature available in our screen printing process used for conductive patterns is 200μm. Thus the test structures and the actual devices need to be designed so that the required DC voltages are i) as small as possible, and ii) the microprobes and network analyser are not damaged by high voltages.

Based on these limitations we developed a test structure and measurement setup for microwave measurements of dielectric properties of LTCC films,

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shown in Fig. 1. The cross section of the test structure is shown in Fig. 2.

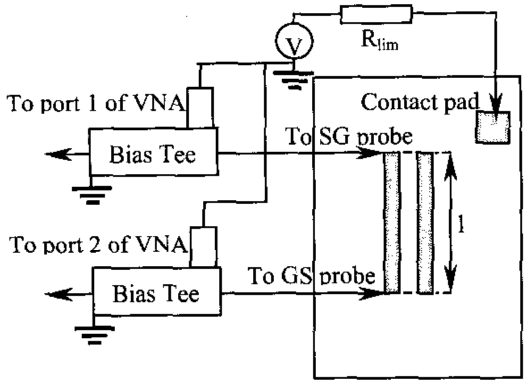

Fig.1 Layout of the test structure and measurement set-up

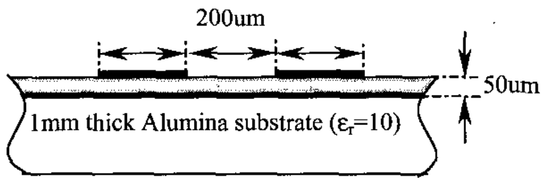

Fig. 2 Cross-section of the test structure

The two coupled microstrip lines on the top of the ferroelectric film are 200 μm wide separated by a 200 μm slot. It is well known that two coupled lines support two independent (odd and even) modes with electric and magnetic wall in the symmetry plane. For on wafer microprobe measurements (using Signal-Ground (SG) 400 μm pitchsize microprobes) only odd mode is excited. For the designed set-up (Fig. 1) that probe tips are under the same DC potential, hence no DC field is applied between them. The high voltage is applied to the ground metallization using a via to the ground plane beneth ferroelectric film. A large resistor is connected in series with DC voltage source to limit the current through the probes.

For specified sizes of the test structure dielectric permittivity of the ferroelectric film is computed form measurements of propagation constant of odd mode. The extraction of propagation constant involves conversion of measured S-parameters to Y (admittance) matrix. The discontinuity of the open ends in the test structure is taken into acount using measurements of two test structures with different lengths. In this case we used two test structures with lengths 2.4 mm and 3.2 mm. A typical measured data are presented in Fig. 3a and b for 100 V and 200 V applied voltages, corresponding to 2 V/μm and 4V/μm DC field. As it can be seen the tunability is more than 15 % over entire frequency band.

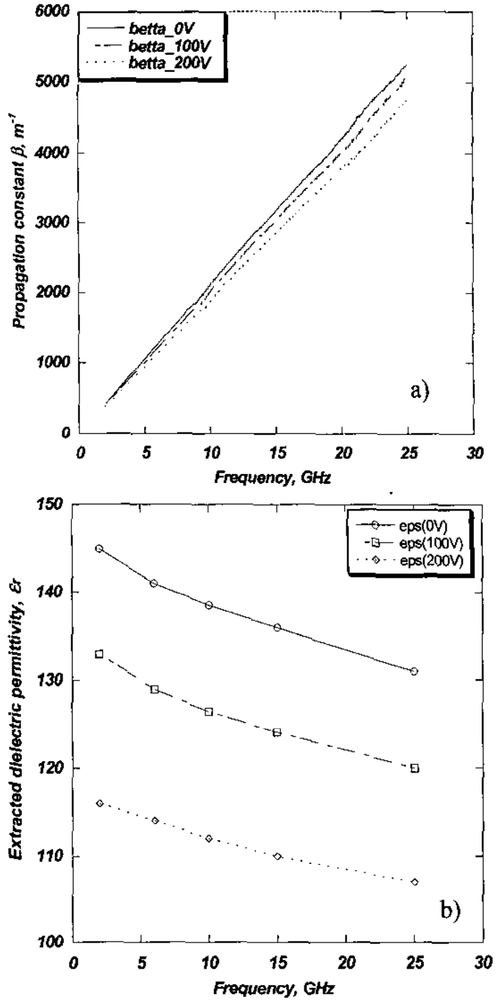

Fig.3 Measured propagation constant (a) and extracted dielectric permittivity (b)

III. Design and Performance of Devices

A. Tunable matching network

The equivalent circuit of a double stub tunable matching circuit is shown in Fig. 4. An arbitrary load is matched by a proper choice of stubs separation θ and their input reactance's *Zin1* and *Zin2* respectively. It can be shown that $\theta=\pi/4$ results in lowest stub input reactance's range, needed. The slot between the strips is small in low impedance stubs, while in the main line it is much larger. Thus, the DC field applied between the strips causes large changes in the permittivity of the ferroelectric film beneath the strips of the stubs changing (tuning) their input impedances, while no changes occur in the main line.

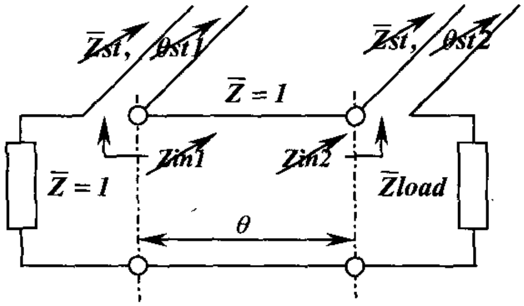

Fig.4 Equivalent circuit of the matching network($\overline{Zload} = 1 \pm 0.1(1 + j)$).

First, we define the required range for input reactance's, which have to be translated to certain stab geometries. In the next step we find a proper stubs length $\theta 1$ and $\theta 2$ for fixed line impedance at zero DC bias. The circuit should provides matching with ~17 % tunability in dielectric constant, what enforce us to add extra half-wavelength section to each stub in order to match specified load impedance. The layout of the matching network, as it was used for modeling the situation with no DC bias, is shown in Fig. 5.

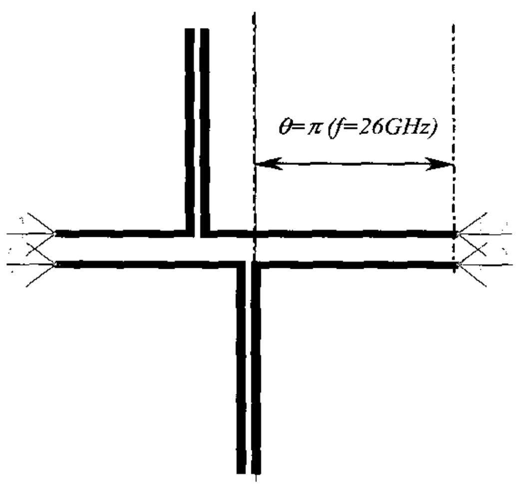

Fig. 5 Layout of the matching network

That case corresponds to matching $\overline{Zload} = 1.1 - j0.1$ and is characterized by electrically longest stubs $\theta 1$ and $\theta 2$ (they will be shortened under DC bias). A port with desired load impedance ($\overline{Zload} = 1.1 - j0.1$) is shifted half-wavelength apart second stub to provide one-to-one impedance transformation at center frequency (center frequency is 26 GHz). Simulated reflection coefficient for the discussed circuit is given in Fig. 6 and it clearly indicates a fact of matching.

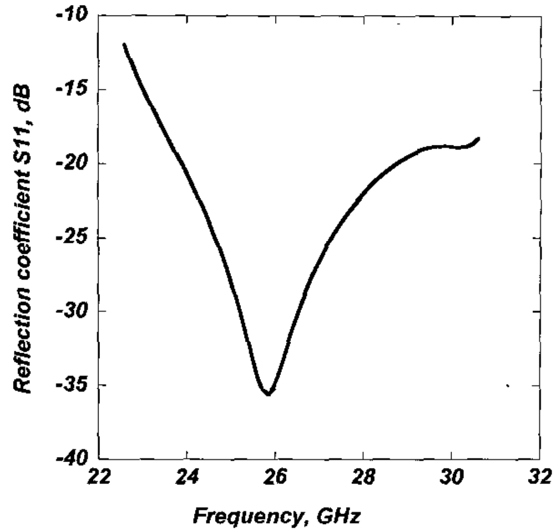

Fig.6 Simulated reflection coefficient for the matching network

B. Phase shifter

A unit cell of a loaded line phase shifter [7] is shown in Fig.7.

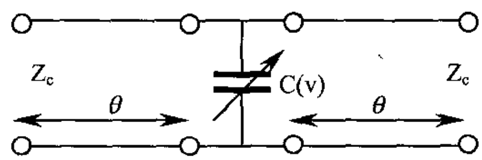

Fig.7 Unit cell of the traveling-wave phase shifter

For example under discussion we choose $Zc=56.5Ohm$, $\theta=\pi/6$ and $C(0)=0.19pF$. Such a unit cell produces about 8° phase shift assuming ~17% tunability in the loading capacitance. It follows from the above measurements that at least 12 unit need to be cascaded to obtain 90° phase shift. The final layout of the developed phase shifter, including quarter-wavelength input/output matching (25Ohm image impedance to standard 50 Ohm input level) sections is shown in Fig.8. The performance under applied DC field, Fig.9, is simulated in "Momentum" by setting different capacitance gap sizes in the sensitive to DC field areas. For the case under discussion the gap widths where set to be 15, 20, 30 and 40μm respectively.

Fig.8 Phase shifters layout

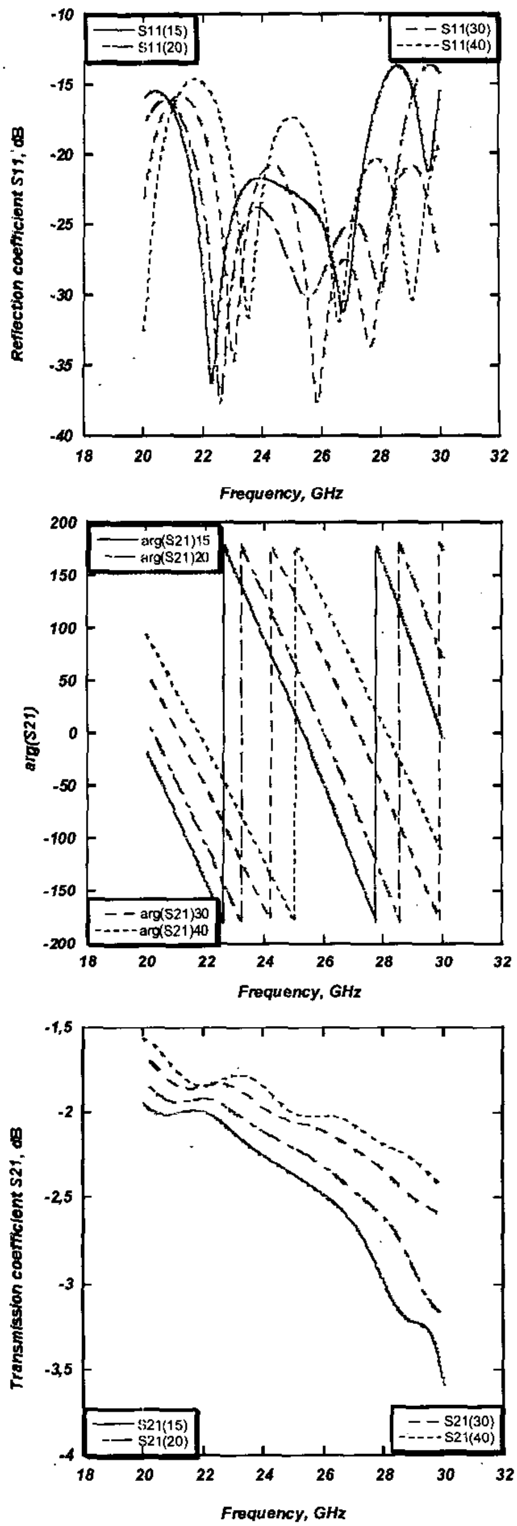

Fig.9 Reflection coefficient (a), phase shift (b) and transmission losses (c) of the phase-shifter.

A rather good matching is observed in wide frequency range.

II. Conclusion

Design of test structure for evaluation of the LTCC ferroelectrics parameters (dielectric permittivity and tunability) is discussed in details. An example of test structure measurement and processing is given followed by a design of two tunable components, which are verified by "Momentum" simulation.

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