PACKAGED SINGLE POLE DOUBLE THRU (SPDT) AND TRUE TIME DELAY LINES (TTDL) BASED ON RF MEMS SWITCHES

Giorgio De Angelis[1], Andrea Lucibello[1], Romolo Marcelli[1], Simone Catoni[1], Antonio Lanciano[2], Roberta Buttiglione[2], Massimiliano Dispenza[2] Flavio Giacomozzi[3], Benno Margesin[3] Alfredo Maglione[4], Mirko Erspan[4], Chantal Combi[5]

[1]CNR-IMM Roma, via del Fosso del Cavaliere 100, 00133 Roma, ITALY
giorgio.deangelis@imm.cnr.it, andrea.lucibello@imm.cnr.it, romolo.marcelli@imm.cnr.it, simone.catoni@altran.it

[2]SELEX-SI, via Tiburtina km 12.400, 00131 Roma, ITALY
alanciano@selex-si.com. rbuttiglione@selex-si.com, mdispenza@selelx-si.com

[3]FBK-irst, via Sommarive 18, I-38100, Povo (TN), ITALY
giaco@fbk.eu, margesin@fbk.eu

[4]OPTOI, Via Vienna 8, I-38100 Gardolo (TN), ITALY
alfredo.maglione@optoi.com, front_end@optoi.com

[5]ST Microelectronics, Milano, ITALY
chantal.combi@st.com

Abstract–*Packaged MEMS devices for RF applications have been modelled, realized and tested. In particular, RF MEMS single ohmic series switches (SPST) have been obtained on silicon high resistivity substrates and they have been integrated in alumina packages to get single-pole-double-thru (SPDT) and true-time-delay-line (TTDL) configurations. As a result, TTDLs for wide band operation, designed for the (6-18) GHz band, have been obtained, with predicted insertion losses less than 2 dB up to 14 GHz for the short path and 3 dB for the long path, and delay times in the order of 0.3-0.4 ns for the short path and 0.5-0.6 ns for the long path. The maximum differential delay time is in the order of 0.2 ns.*

Keywords: *RF MEMS, SPST, SPDT, TTDL, packaging.*

1. INTRODUCTION

RF MEMS devices are currently considered a winning solution for many applications where mainly pin diodes have been utilized up to now [1]. True-time-delay-line (TTDL) as well as matrices or phase shifters can take advantage from the MEMS technology because of the extremely low loss, linear behaviour and virtually no current consumption in electro-statically actuated devices [2-6]. A number of issues are presently considered as mandatory for releasing the reliability of MEMS devices and configurations, including the mechanical performances and charging characteristics. One of the main items in considering RF MEMS switches reliable devices is the packaging. There are several examples in literature on how to solve efficiently such an issue, trying to protect the device for decreasing the contribution of different effects: (i) the increase in the insertion loss because of the additional transitions, (ii) the inert atmosphere needed for avoiding the sticking due to residual humidity and related leakage control, (iii) temperature contributions, (iv) radiation in case of special applications like space devices.

In this paper we present a possible packaging solution for MEMS switches in a TTDL configuration. It is based on individual RF MEMS switches embedded in an alumina package. Such a hybrid configuration is promising as it concerns with the optimization of a quite established technology on silicon or quartz for MEMS switches, to be married with technologies already developed on the usual substrates for high frequency applications, where feeding lines and packaging can be easily realized.

2. SPST AND SPDT TECHNOLOGY AND TEST

MEMS single switches (SPST) have been obtained by means of an eight-mask process involving photo-lithography, and deposition techniques of metal and dielectric films. A 525 μm thick, high resistivity silicon substrate has been used as a support for the successive technological steps, ended with the removal of a photo-resist sacrificial layer to get a suspended gold membrane as a double clamped bridge. Such a device is actuated by means of an electrostatic potential provided by external pads and poly-silicon, highly resistive feeding lines. The photo of the single switch (SPST) to be used for the TTDL configuration is given in the following Fig. 1. Actuation voltages in the order of 45 volt have been measured on the SPST, and reliable response over several cycles in hot switching conditions has been proved.

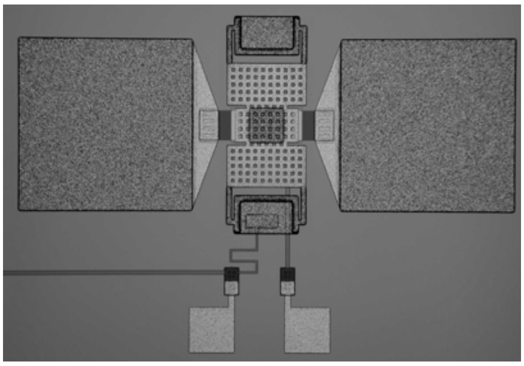

Fig. 1. Photo of the SPST developed for the TTDL structure.

In Fig. 2 is presented the scheme used for realizing the SPDT configuration. Actually, an alumina substrate has been worked out for obtaining holes where to place the SPST previously cut from the silicon wafer. Three bonding wires connect the I/O lines of the SPST to the matched microstrip on the alumina substrate.

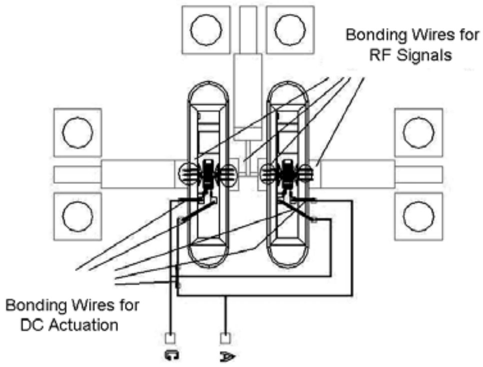

Fig. 2. Detail of the SPDT device. The bonding wires connections are also evidenced.

Of course, several sources of electrical mismatch have to be considered, as also investigated by means of preliminary simulations: (i) the passage from one substrate to another one using bonding wires, (ii) the length of the wires and the relative height between the two substrates, (iii) the shape and possible related resonant effects of the location for the SPST, (iv) the necessity to have both SPST quite close each other, in order to optimize the SPDT electrical response, (v) the microstrip to CPW transition for measurement purposes. An additional loss will be caused by the presence of the cover for the fully packaged structure. On the other hand, the above defined contributions are unavoidable for any final structure, and they are the major source of insertion loss, while the MEMS devices, not exceeding 0.4 dB of loss, are for sure less important; it helps in an effective decrease of the total insertion loss when configurations like TTDL with several bits are considered.

First of all, to have a correct feeling of the SPDT expected best performances, ideal single switches have been realized by means of reference structures, simulating a device technologically actuated (bridge DOWN) or in the UP position. Since we have a series ohmic switch, the UP position of the bridge corresponds to the OFF state, while the DOWN position will correspond to the ON state. In particular, the OFF state has been obtained as a capacitive gap in the plane, without realizing the bridge in the central area of the single device, while the ON state has been obtained by using a geometry including a technologically actuated device, i.e. the switch without the sacrificial layer used for obtaining the real structure. A detailed photo of the ideal SPDT device and its connections is given in Fig. 3, while in Fig. 4 and in Fig. 5 the isolation, return loss and transmission electrical performances are shown.

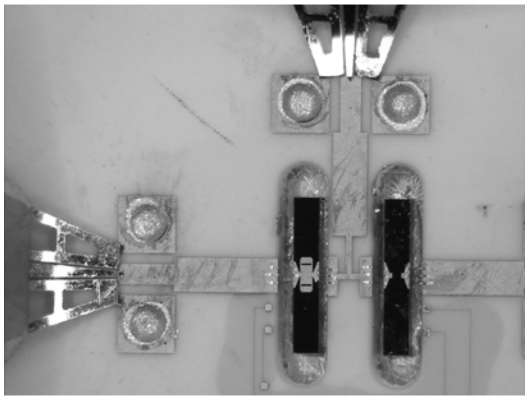

Fig. 3. Setup for measuring the ideal SPDT made by the OPEN and DOWN devices. The CPW probes positioning at the transition microstrip to CPW are also evidenced.

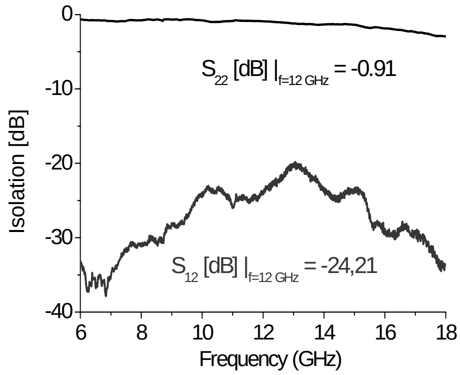

Fig. 4. Isolation of the ideal SPDT.

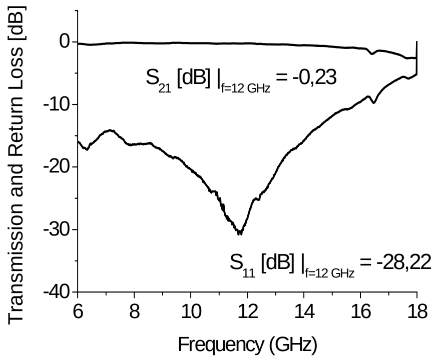

Fig. 5. Return Loss and Transmission characteristics of the ideal SPDT

3. ALUMINA TECHNOLOGY AND TRUE TIME DELAY LINE MODULES CHARACTERIZATION

The TTDL has been designed to be realized by a metallisation pattern on an alumina substrate 630 μm thick. Along the path, holes have been opened by laser to allow the positioning of the RF MEMS switches cut from the processed silicon wafer. The thickness for alumina has been chosen to be as close as possible to the commercial silicon substrate used for manufacturing the single switches. In fact, by means of this solution, short wires have been used for connecting the switches.

In the following figures, the assembling procedure for obtaining the TTDL structure (Fig. 6) and details on the wire bonding needed to connect the RF MEMS switches to the TTDL layout (Fig. 7) are shown.

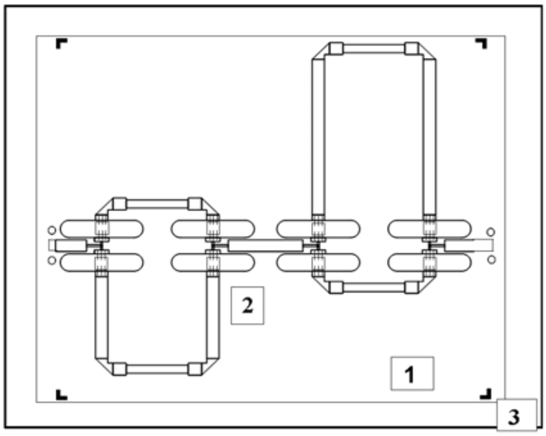

Fig. 6. General assembly of the TTDL module to be packaged. In particular, 1 is the alumina substrate, 2 are the places for MEMS positioning (8 all together) and 3 the metal support for the alumina package. The cover has to be placed on the four corners indicated in the figure. To provide the proper ground connection for the SPST a conductive epoxy on the back side has been used.

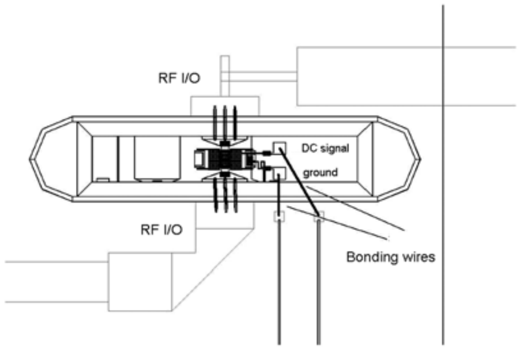

Fig. 7. Detail of one of the wire bonding connection from the DC pads of the MEMS in the cavities with the feeding lines on alumina.

In the following Fig. 8 and Fig. 9 the measured electrical performances of the TTDL, namely the reflection and the transmission response, are plotted. In particular, the short path for the structure and the long one have been measured, actuating the RF MEMS switches following the scheme given in Fig. 6, i.e.: (i) the upper left and bottom right pattern for the short path, and (ii) the bottom left and the upper right pattern for the long path. Losses are comparable in both configurations and close to 5 dB at 12 GHz, also if the short path should present lower contributions. Less than 2 dB at 12 GHz have been measured in the almost ideal short path configuration made by technologically actuated switches, while 3 dB have been measured for the ideal long path at the same frequency. Actually, the packaging technique needs further optimization, as well as the feeding system for the switches, to solve this problem. The Scattering Parameters measurements have been used for the evaluation of the delay times for the TTDL. Specifically, the delay time T_d has been calculated as:

$$T_d = -\frac{1}{360}\frac{\partial\phi[\deg]}{\partial f} \qquad (1)$$

and it has been plotted in the following Fig. 10 for the absolute short and long paths. It is worth noting that the differential delay, which can be obtained by the absolute delay time characteristics plotted in Fig. 10, is coherent with previous findings on the ideal structures, i.e. almost 0.2 ns over the entire frequency range.

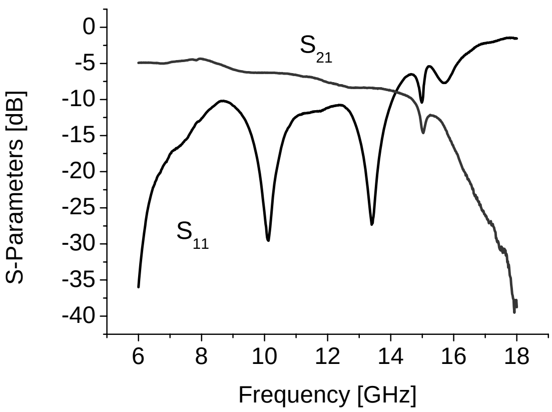

Fig. 8. Electrical response of the TTDL short path.

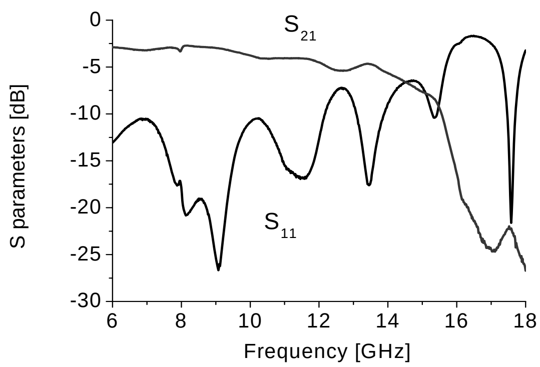

Fig. 9. Electrical response of the TTDL long path.

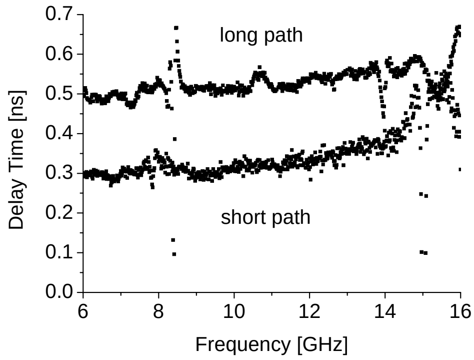

Fig. 10. Delay Time measured for the long and short path of TTDL.

4. CONCLUSIONS

SPDT and TTDL structures based on RF MEMS switches have been designed, realized and tested in packaged configurations obtained by embedding the SPST in an alumina structure, where the paths have been properly defined. Differential delay times within 0.2 ns have been obtained in the frequency range (6-18) GHz.

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