

## Actuation command circuit for 60GHz RF MEMS phase shifters

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**Keywords** : RF MEMS, 60GHz, low power command, boost converter, charge pump

**Abstract.** *This paper presents the design and realization of a low power, high speed circuit used to actuate RF MEMS (Radio Frequency MicroElectroMechanical Systems) based phase shifters at 60GHz. The phase shifter are used to realize beam forming reconfigurable antenna for high data rate WPAN (Wireless Personal Area Network) applications. RF MEMS commonly have high actuation voltages usually obtained with charge pumps. In this paper we presents boost converters as an alternative to the use of charge pumps for actuating RF MEMS in the field of Systems on Chip (SoC).*

### INTRODUCTION

Wireless links at 60GHz are characterized by a very high free space loss. This loss is above 68dB at one meter range, and 88dB at 10m range. Transmission distances are then often shorter than 15m, and show interesting possibilities for short range high data rate communication. Owing to this particularity, regulating authorities have declared a wide frequency band around 60GHz (57GHz - 64GHz) unlicensed for emission levels up to 43dBm in North America. Europe and Asia also possess an unlicensed band around 60GHz, thus opening the opportunity to develop products using this frequency band for global market.

Typical applications for 60GHz data transmission are high data rate and short range links. This can allow, for example, full non-compressed High Definition (HD) video streaming over short distances using Orthogonal Frequency Division Multiplexing (OFDM) based modulations [1]. Goals are there to replace High Definition Multimedia Interface (HDMI) cables by wireless links, or simply to increase download speed for kiosk download applications.

Considering that 60GHz signal is highly attenuated over distance, it is necessary to concentrate as much energy as possible in the

direction of the targeted node. Such needs make it impossible to use directional antennas in the case of moving network nodes. This necessity to obtain a beam pointed as precisely as possible at the receiving node leads to the use of reconfigurable antenna arrays.

A reconfigurable antenna array uses phase shifting to make emitted signals to add up in a particular direction, thus allowing pointing at a specific node in the neighborhood.

In the case of 60GHz communications, the width of the used band favors the use of RF MEMS based phase shifters instead of usual CMOS, FET or bipolar transistors based phase shifters. RF MEMS have recently reached performances that allow their use with medium actuation voltages around 30V [2].

This paper proposes an actuation solution using a boost DC-DC converter. The first section describes the RF MEMS and their application in the case of a 60GHz phase shifter. The second part explains the electronic circuit developed and its specificities. The digital circuit used to control the voltage provided to the MEMS is also described. In the conclusion we give an overview of the integration perspectives for this circuit in the near future.

### 1. RF MEMS PHASE SHIFTER

RF MEMS are a new kind of passive circuit components, used in broad-band communications. Common applications for RF MEMS are varactors and switches.

The RF MEMS micro-switches show better performances concerning isolation, loss and power than those of conventional diodes or CMOS transistors. The long term goal is to replace the active circuits currently used in systems such as switches by passive circuits based on RF MEMS.

We developed a new technology at LAAS-CNRS which allow fabricating RF MEMS up to 94GHz [2]. Our RF MEMS show exceptionally low insertion loss when switched ON, along with a good attenuation of the signal when switched OFF [2]. Figure 1 shows one of our RF MEMS working at 60GHz and the measured insertion loss.

These MEMS, although qualified as “low actuation voltage” need 30V actuation voltage to switch.

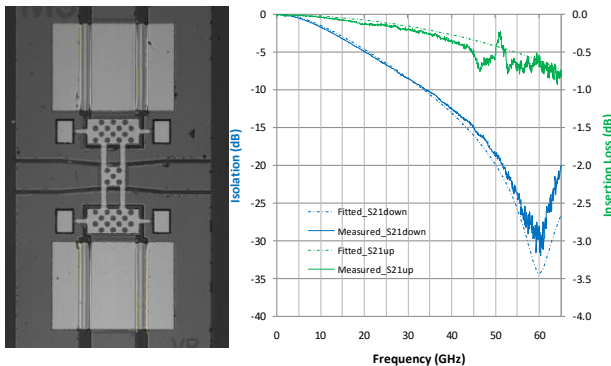


FIG 1. 60GHz RF MEMS

RF MEMS phase shifters exhibit low insertion loss together with very low phase error. 60-GHz phase shifters have been recently designed and fabricated at LAAS CNRS, using a specific process on a microelectronic compatible silicon substrate. Figure 2 shows a complete RF MEMS 1bit phase shifter [10]. The work is in progress for the characterization of our phase shifters at 60GHz.

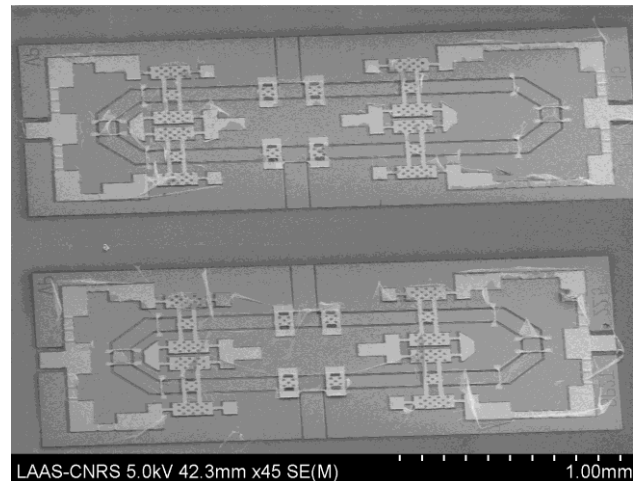


FIG 2. 60GHz 1bit phase shifter

Table 1 shows the state-of-the-art of integrated phase shifters.

TABLE 1. State of the art of phase shifters

ref	Frequency (GHz)	Type/bits	Phase error	Insertion loss (dB)	Bulk	Area (mm <sup>2</sup> )
[5]	75-110	MEMS/3	3°	-2.7	Glass	5x1.9
[6]	50-70	MEMS/2	5°	-4.6	Quartz	2.1x1.5
[7]	30-38	0.12u bicmos/4	7°	+1	Si	0.9x0.4
[8]	18-26	0.13u cmos/4	9.7°	-3.8	Si	0.8x0.6
[9]	55-65	65nm cmos/4	9.2°	-9.4	Si	/
[10]	27-94	MEMS /1	TBD	TBD	Si+BCB	2 x 0.7

### 2. ACTUATION COMMAND CIRCUIT

As shown before, even for “low voltage actuation” RF MEMS we need a 30V actuation voltage. Yet, these improvements in performances cannot overcome the problems caused by low supply voltages in Wireless Personal Area Network (WPAN) and Wireless Sensor Network, which are our main application. Actually, CMOS technology functions with power supply ranging from 0.8V<sub>DC</sub> to 5V<sub>DC</sub> whereas RF MEMS often require 30V or more to actuate. This gap in supply voltages makes it necessary to develop DC-DC converters with converting ratios in excess of 10.

Such DC-DC converters are currently built using charge pumps [3][4]. Those charge pumps are characterized by a constant output current, necessary to maintain proper functioning. However, charge pumps do not adapt to the

extremely low capacitance of RF MEMS coupled with literally no current leaks [2]. We then propose a solution using boost DC-DC converter. Moreover, Boost converters, despite relatively high current peaks, allow shorter settling times compared to charge pumps.

The command circuit has two parts: digital command part and DC-DC conversion part.

**2.1. Digital switching command**

The digital part will perform a conversion from 4 state 2 bit input representing the desired phase-shift (in our case: 0°, 22.5°, 45°, 67.5°) into outputs supplying either 0V or 30V efficiently. The digital integrated part of the command circuit is prototyped on a Xilinx FPGA Spartan-3 Board. Xilinx ISE is used to develop VHDL code.

The digital command circuit is divided in 2 modules. The first one converts a binary input representing an angle into “on/off” signal for the MEMS. The second module avoids overlapping of the output signals, thus avoiding short circuits resulting from switching both 0V and 30V to the outputs.

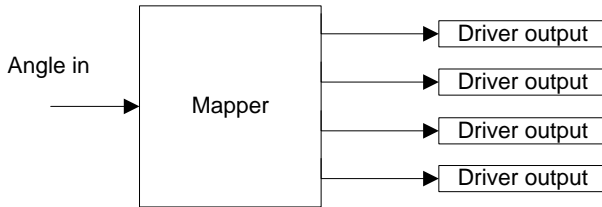


FIG 3. Block diagram of the program for FPGA

**2.2. DC-DC conversion and 30V s switching**

According to the needs for capacitive RF MEMS, the whole system has to be dimensioned to provide output voltage of 0V or 30V to a 500fF equivalent capacitance. This circuit contains MOS transistors to perform a push-pull operation. These MOSFET possess parasitic capacitances which are usually much higher than 500fF. The output load is then negligible compared to these parasitic.

This circuit is divided into two blocks, a 3V<sub>DC</sub>→30V<sub>DC</sub> voltage converter, and a half-bridge driving 30V<sub>DC</sub> with control input levels of 0V-3V.

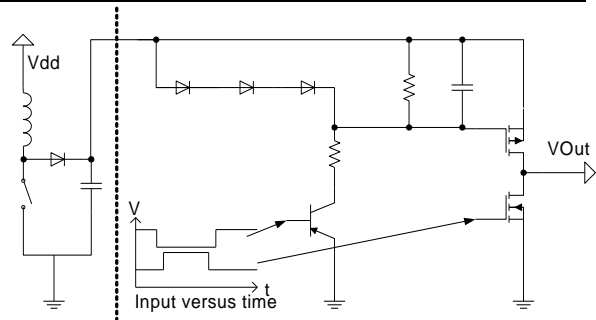


FIG4. Boost DC-DC converter and push-pull circuit

The first stage is a DC-DC boost converter, which provides a 30V DC level from a 3Vdc supply. This stage is dimensioned to reduce power consumption while keeping a sufficient fan-out.

The second stage uses 2 MOSFET. A P-MOS is used to drive 30V voltage to the output and is controlled using a bipolar transistor to obtain 30VDC / 27VDC voltages on the grid. This bipolar transistor will be replaced by a MOSFET during the integration of the circuit. The other MOSFET, a N-MOS is directly controlled using the 0V–3V output of the FPGA.

**3. SIMULATIONS AND RESULTS**

Simulations are performed using a modified version of Spice, LTSpice which includes models for components manufactured by Linear Technology. Control inputs are designed for input levels compatible with levels at the outputs of Xilinx Spartan and Virtex FPGAs.

Figure 5 shows the output of the circuit cycling between 0V<sub>DC</sub> and 33V<sub>DC</sub> with a rise time of 10 us, and an average power consumption of 3 mW in cycling mode.

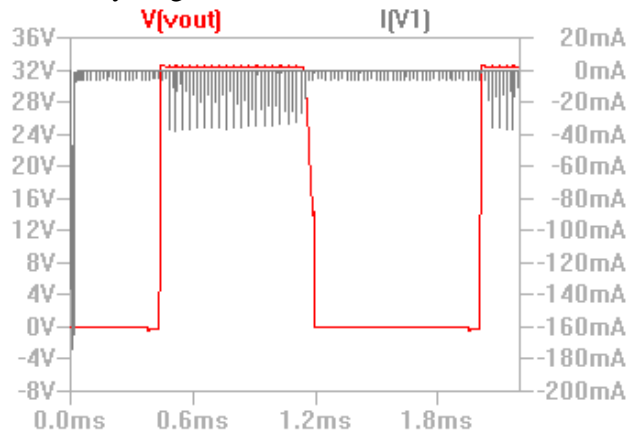


FIG 5. Simulated output voltage ( $V_{out}$ ) and power supply current ( $I(V1)$ )

We fabricated the prototype (Fig.6) and it is currently under test. First measurements show a 36VDC “ON” level and a 0VDC “OFF” level. The voltages attained by this prototype allow driving ON / OFF states of the RF MEMS based phase shifters built at LAAS CNRS.

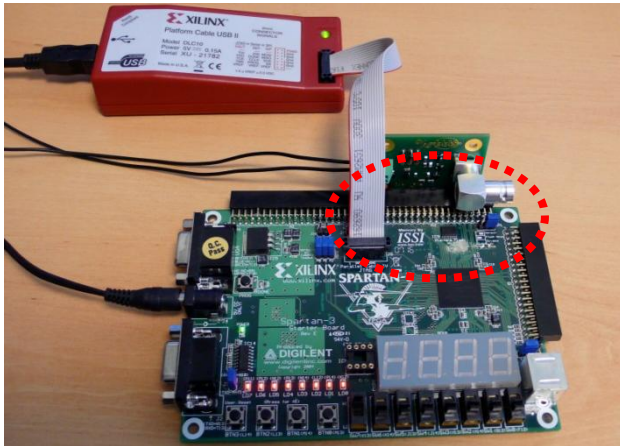


FIG 6. Fabricated prototype (dotted circle) connected to Xilinx Spartan3 FPGA with digital command circuit

## CONCLUSION

We presented a new actuation command circuit for RF MEMS using digital circuits and DC-DC boost converter. The advantage of boost converter is its fast rise time. Simulations showed 3mW average power consumption per MEMS actuated when switched at 100KHz. The fabricated prototype shows promising results in terms of power consumption. The measurements will be done by the time of the conference. In long term perspective, we plan to integrate this actuation command circuit with the RF MEMS. The digital command circuit can be integrated along with the baseband part of the communicating system into ASIC circuits in ST Microelectronics CMOS 65nm technology. The DC-DC converter can be developed in LAAS CNRS technology [11].

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