

# Integrated Variable Resistor using Switched Capacitor Circuit and Voltage-Controlled Capacitor

Nishant Sharma<sup>1</sup>

<sup>1</sup>Undergraduate Student, Electronics and Telecommunication Engineering, Thadomal Shahani Engineering College, Maharashtra, India

**Abstract** – Propose a method to fabricate voltage controlled variable resistor in integrated circuits using switched capacitor circuit and varactor tuning circuit. Simulate switched capacitor circuit with variable capacitor on LTSPICE.

**Key Words:** MOSFET, pn junction, diode, characteristics, clock.

## 1. INTRODUCTION

Integrated circuits today work largely on MOSFET technologies. Different regions of operations of a MOSFET is exploited, the different nature of a MOS characteristic graph allows it to simulate several devices. Fabricating devices like passive resistors and inductors are especially hard. These are bulky devices and introduce a lot of parasitic impedances when fabricated, resulting in inaccurate and undesired behaviour. Switched capacitor is a method used to simulate resistances in an integrated circuit. A varactor diode is a pn junction diode that acts as a variable capacitor under reverse bias having a large dynamic capacitance range. Typically ranging from 15pF to 60pF.

### 1.1 Switched Capacitor Circuit

Switched Capacitor circuits are used to simulate resistance in an integrated circuit. In switched capacitor, the combination of ideal switches and a capacitor are assumed equivalent to a resistor. However, this equivalence is exact only when the terminal voltages of the capacitor are piecewise constant [1].

Switched capacitor is a technology that can be easily fabricated as all of its elements can be implemented using MOS transistors hence making it efficient to fabricate.

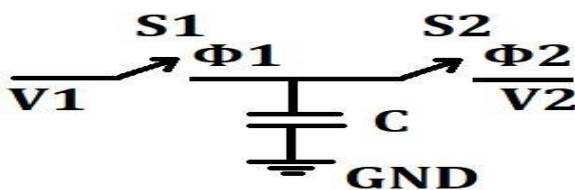


Fig -1: Simple Switched Capacitor

The switches S1 and S2 operate at the sampling frequency of  $\Phi_1$  and  $\Phi_2$  respectively.  $\Phi_1$  and  $\Phi_2$  are two non-

overlapping clock signals. These switches are voltage-controlled switches. C is a capacitor.

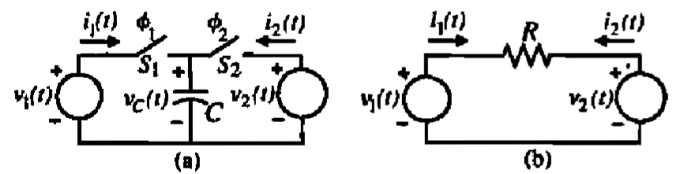


Fig -2: (a) Simple Switched Capacitor equivalent circuit (b) equivalent resistor network [9]

Resistance in an electrical circuit is obstruction offered to the flow of current in the network. That is if both the circuits have equal current flowing through them, we can say they have equal resistance. Hence to simulate equivalent resistance we equate the average current flowing through both the networks.

$$i_1(\text{average}) = \frac{1}{T} \int_0^T i_1(t) dt$$

Fig -3: Definition of average current [9]

After equating the average current of both the circuits we end up with the relation R is equal to T divided by C capacitance.

$R = T/C$ , where R is the desired resistance to be simulated, T is the time period of the clock, and C is the equivalent capacitance value to be fabricated.

It is clear from the equation that resistance value is dependent on two parameters, the clock frequency and the capacitance value.

The switches in the circuit are MOS transistor switches. MOS transistor operated in the saturation region can be used as voltage-controlled switches. MOS transistor also provides capacitance between its gate and bulk terminal where the oxide layer acts as the dielectric.

### 1.2 MOS transistor as voltage-controlled switch

MOS transistors can replace the voltage-controlled switches in the switch capacitor circuit. The control voltage or clock signal are fed to the gate terminal of the MOS. The

input voltage is given to the drain terminal. When the clock goes high, this turns the MOS transistor ON and lets the voltage at drain pass through, otherwise blocking it.

### control voltage/clock $\Phi$

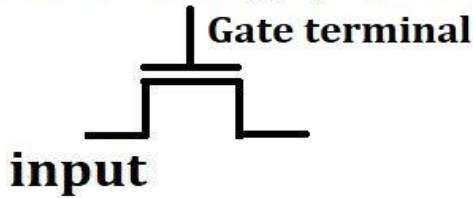


Fig -4: MOS transistor as switch

### 1.3 MOS transistor as capacitor

MOS transistors can replace the voltage-controlled switches in the switch capacitor circuit. The control voltage or clock signal are fed to the gate terminal of the MOS. The input voltage is given to the drain terminal. When the clock goes high, this turns the MOS transistor ON and lets the voltage at drain pass through, otherwise blocking it.

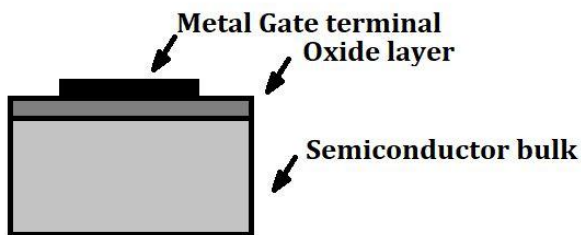


Fig -5: MOS Capacitance

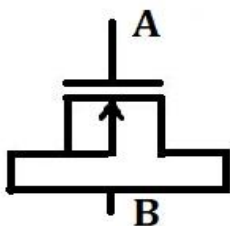


Fig -6: MOS as a capacitor

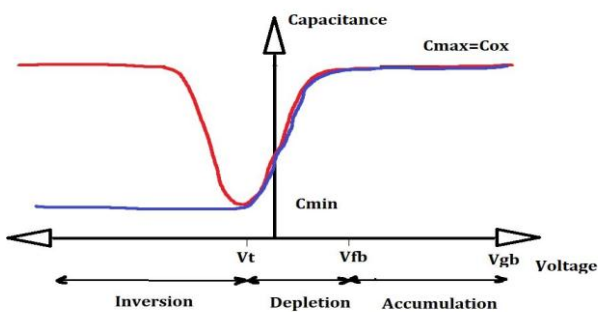


Fig -7: MOS capacitor characteristics

Here the capacitance is the function of voltage applied across the gate and the bulk or substrate. The capacitance for the purpose of simulating a fixed resistor value is kept at the region of the characteristic graph where the capacitance is constant with respect to voltage.

There are different topologies to implement capacitance using MOS transistors in an integrated circuit but MOSCAPs are designed in such a way that the relative change in capacitance is very less with change in voltage.

### 1.4 Varactor Diode

Varactor diode or varicap diode is a semiconductor pn junction device. Varactor diode uses the depletion region of the pn junction device as a dielectric and the two semiconductor layers as conducting plates to form a capacitor. By applying a reverse bias voltage, the region of charge depletion can be varied and hence varying the distance between the conducting plate which affects the capacitance of the device.



Fig -8: Varactor diode symbol

Fabricated varactor diode has a larger dynamic range of capacitance compared to MOS capacitor and also has a wider linear range, and hence allows us to more precisely control the capacitance of the network.

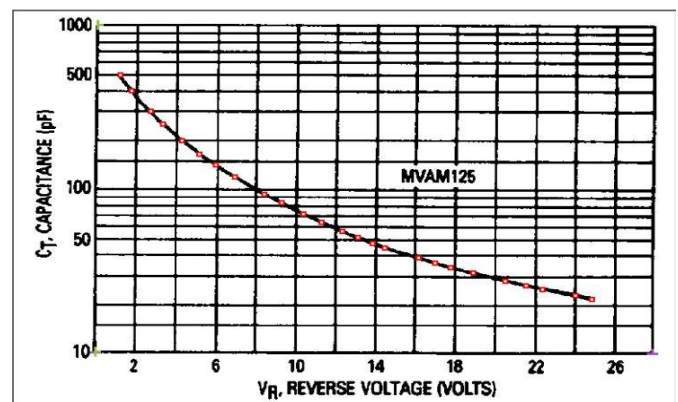


Fig -9: Varactor characteristic [7]

### 1.5 Tuning network

The tuning circuit consist of two equivalent capacitors, one of them being a varactor diode. As mentioned earlier, varactor diode has a larger linearity range and larger dynamic range, which is both needed for a good tuning circuit. A control voltage is applied at the anode of the varactor diode and varactor diode is made to work in

reverse bias. Changing the reverse bias voltage, changes the equivalent capacitance of the network of the two series capacitors. Different topologies of varactor diode provide improvement in linearity with voltage change[6].

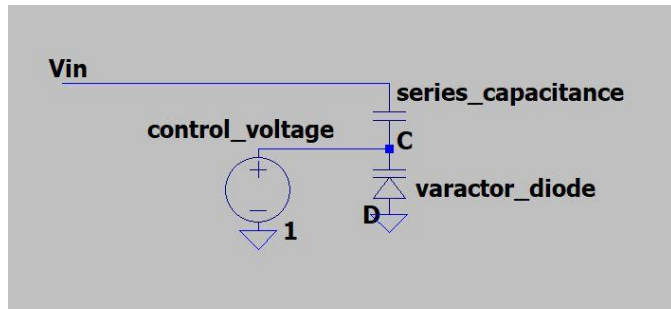


Fig -10: Tuning network

### 2. PROPOSED CIRCUIT

The proposed circuit is to be able to fabricate a voltage controlled variable resistor. Fabricating bulky components has always been a challenge, hence the proposed circuit make use of semiconductor devices which are easy to fabricate.

As the established relation of the capacitance used in switch capacitor circuit and the equivalent resistor is as  $R_{eq} = T/C$ . that is resistance and capacitance are inversely proportional and that change in resistance is dependent on change in capacitance, operating frequency or clock frequency being constant.

The capacitor in the switched capacitor circuit can be replaced by a voltage-controlled capacitance tuning circuit to vary the capacitance of the network and hence achieving voltage-controlled resistance.

Here[Fig -13], V1 and V2 are two DC voltage sources, S1 and S2 are voltage-controlled switches, V4 and V5 are clock sources. V3 is the control voltage for the tuning circuit. Capacitor C1 and varactor diode D2 make up the tuning circuit.

### 3. SIMULATIONS AND RESULTS

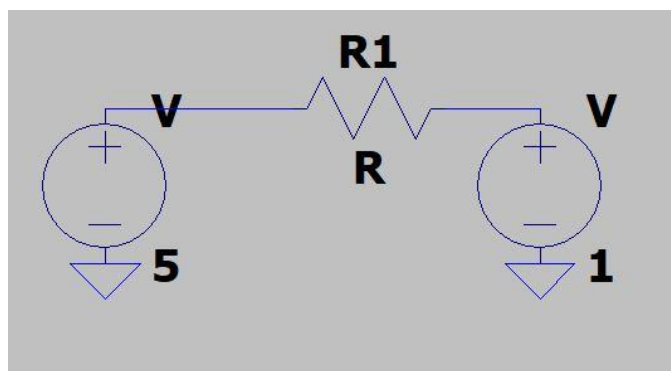


Fig -11: Reference circuit

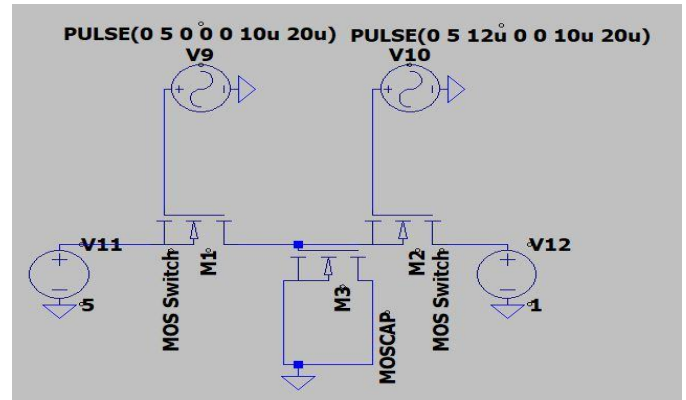


Fig -12: switched capacitor using MOS devices

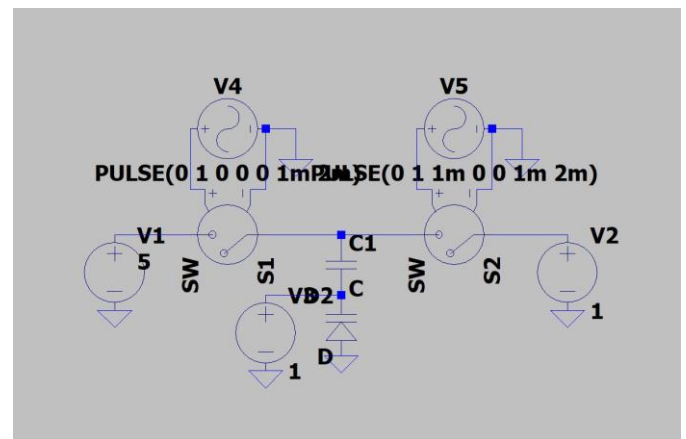
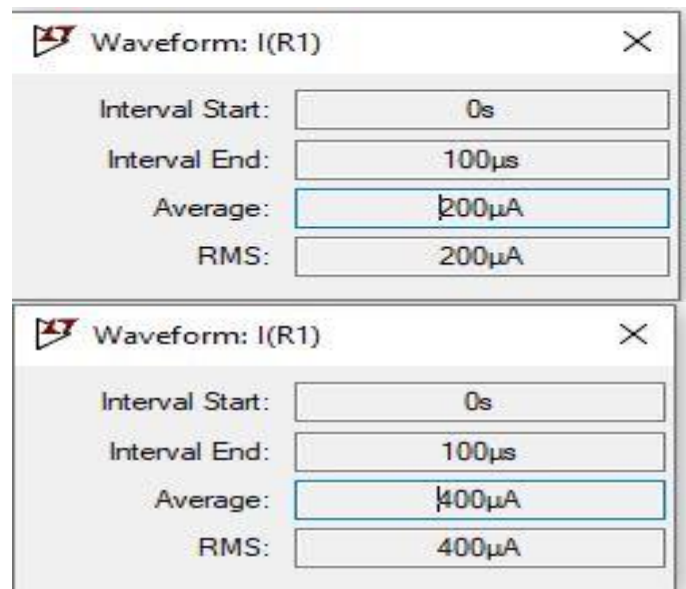


Fig -13: proposed circuit



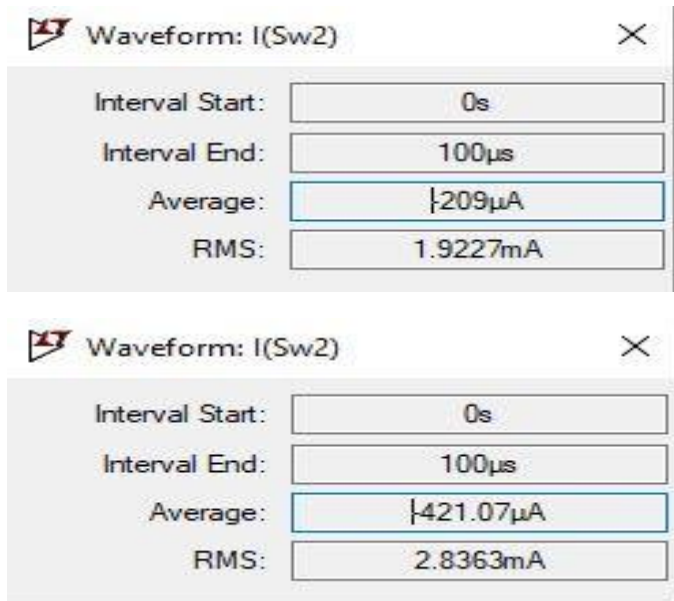


Fig -14: simulation output

A network with desired resistor value is simulated for reference and a switched capacitor circuit with equivalent capacitance value is designed. The current flowing through the output node is measured and compared. Resistance is nothing but opposition offered to the flow of current, if equal current flows for equal input voltage, from ohm's law, we can conclude that the circuits have equal resistance to offer to the flow of current.

MOS capacitor was simulated for different design parameters to get the desired range of capacitance for the sake of simulation of the complete proposed circuit. [8]

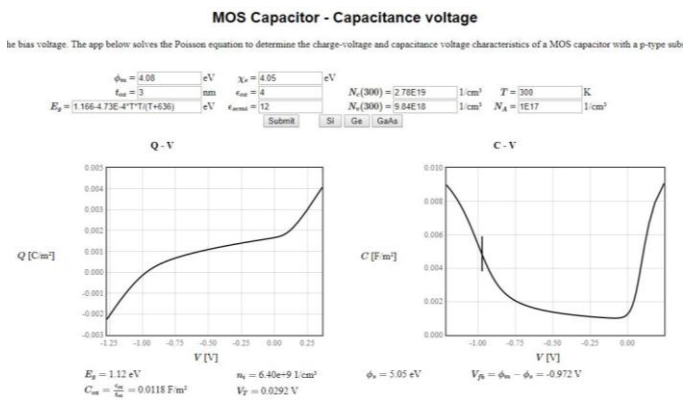


Fig -15: simulated MOSCAP

### 3. CONCLUSION

For equal input voltages, we can see that equal current flows through both the circuits. Current through R1 resistor and current through second switch are equal. Variable resistor was fabricated, and tested, first designed for the resistance of 20K ohms and then for the resistance of 20K ohms. We can see that in both the cases, keeping input voltage constant, the current changes equally in both the circuits. And the average current is the same.

### REFERENCES

- [1] M. L. Liou, Y.-L. Kuo, and C. F. Lee, "A tutorial on computer-aided analysis of switched-capacitor circuits," *Proc. IEEE*, Aug. 1983.
- [2] Richard J. Trihy and Ronald A. Rohrer, *A Switched Capacitor circuit Simulator: AWESwit*, *IEEE journal of solid state circuits*, VOL 29, NO. 3, March 1994.
- [3] Shanthi Pawan, Yannis Tsvividis, Krishnaswamy Nagraj, Modelling of accumulation MOS capacitors for Analog design in digital VLSI processes, *IEEE*
- [4] Li, S. and Zhang, T. (2012). Simulation and Realization of MOS Varactors. *Procedia Engineering*, 29, pp.1645-1650.
- [5] P. Andreani, S. Matinson, Use of MOS varactor in VCO, *IEEE*
- [6] Buisman, K. & Vreede, L.C.N. & Larson, L.E. & Spirito, M. & Akhnoukh, A. & Scholtes, T.L.M. & Nanver, Lis. (2005). Distortion-free varactor diode topologies for RF adaptivity. 4 pp.. 10.1109/MWSYM.2005.1516547.
- [7] Qsl.net. (2019). *Varactor capacitance vs. voltage curve fitting*. [online] Available at: [https://www.qsl.net/in3otd/electronics/varactor\\_mode1/varactor\\_fitting.html](https://www.qsl.net/in3otd/electronics/varactor_mode1/varactor_fitting.html).
- [8] Lampx.tugraz.at. (2019). *MOS Capacitor - Capacitance voltage*. [online] Available at: [http://lampx.tugraz.at/~hadley/psd/L10/moscap\\_cv.php](http://lampx.tugraz.at/~hadley/psd/L10/moscap_cv.php).
- [9] Philip E. Allen, Douglas R. Holdberg, *Analog CMOS circuit design second edition*, chapter 9, switched capacitors.