Effect of CSDG MOSFET based High Pass Filter on Signaling

Llewellyn Naidoo, Viranjay M. Srivastava

***Abstract*: This research work looks at the design of active high pass filter that can be used in mobile communication systems. These systems make use of trans-receiver system. This type of system is commonly used in handsets. In this research work the proposed filter has been designed with a Cylindrical Surrounding Double-Gate (CSDG) MOSFET and operates at cutoff frequency of 100 GHz (0.1 THz). A CSDG MOSFET is an extension of DG MOSFET technology. It is structured by rotation of DG MOSFET with respect to its reference point to form a hollow cylinder. It consists of two gates, one drain and one source. The gain, phase, and return loss of the high pass filter has been analyzed with and without CSDG MOSFET using electronic device simulator. Finally, it has been demonstrated that the third order high pass filters performs better with the CSDG MOSFET.**

***Index Terms*: Active High Pass Filter, CSDG MOSFET, Gain, Phase, Return Loss, Microelectronics, VLSI.**

I. INTRODUCTION

The telecommunication sector has evolved from the simple telegraph which was first commercially developed in 1837 by Sir William Fothergill Cooke and Charles Wheatstone [1]. It reduced communication time during the early 1800's from days to hour's just as modern technology as reduced the communication of large amounts of information from hours to seconds [2]. This is due to the rapid changing of technology which has allowed businesses to operate more efficiently and helps keep people connected to one another. One of the largest and thriving segments in telecommunications is wireless communications [3, 4]. Mobile technology is the most common type of wireless communication and is used in cellular communication [5, 6]. This form of communication consists of both consumer part (handset) and infrastructure part (radio base stations). The handset is made up of transmitter and receiver and is known as transceiver system [7]. Receiver is a device that modifies the received signal from transmitter into a desired signal. Figure 1 shows a superheterodyne receiver which was designed by Edwin Armstrong in 1918 is the most widely used today in communication systems. Superheterodyne receivers emit low-power radio signals during normal operation [8]. The incoming signal that is collected by the antenna enters the RF stage where it passes through an RF filter and then an amplifier to provide the initial filtration and amplification of the signal.

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This research work looks at designing an RF filter that can be used in a communications network. This proposed filter builds on the basic filter configuration which has been documented various times in literatures. Compared to these existing works, this proposed filter is designed to operate within the upper ends of the RF spectrum. The advantage of operating at these higher frequencies will allow the filter to work within a greater bandwidth which eventually leads to more information being filtered. Authors first simulated the designed filter and observed the parameters and thereafter looked at the effects adding an additional capacitive model viz. a CSDG MOSFET as on those parameters.

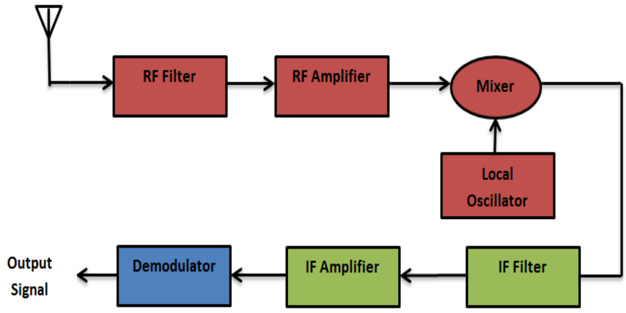

Fig. 1: Superheterodyne receiver [9].

For the RF filter section of this research the aim is to design a filter that can operate at extremely high frequencies. This can be achieved by using capacitor components that have values that are less than *0.002pF*. By using these components the overall capacitance of the filter will be reduced and thus a frequency of *100GHz* can be achieved more efficiently.

II. BASIC MODEL OF RF FILTER AND CSDG MOSFET

A. RF Filter

The RF filter performs the function of frequency selection by passing signals whose frequencies lie within a specified range whilst preventing the passing of those that fall outside this region [10]. These components are common but critical components in the RF front-end [11]. The two most common types are high and low pass filters. In addition to having low and high pass filters there are variations of these types of filters. Some of these include RC, RL, RLC, LC, and LR filters [12, 13].

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Each of the five mentioned filters consists of either a combination of a resistor, inductor or capacitor network and is driven by a voltage or a current source and is referred to as passive filters.

Over the past few decades, passive filters have given rise to active filters [14]. There have been a number of designs in the field of active filters and these filters make use of active components such as an operational amplifier and other electronic components like resistors and capacitors [15]. The advantage of using an active component is that it provides a filter circuit with amplification and gain control. For this design an active high pass filter is considered and is designed to operate at a cutoff frequency of 100 GHz. The following equation is relevant for the design of the op-amp based circuit [16, 17]. The value for C_1 (input capacitance) was chosen as 0.001*pF*. So, using $f_c = 1/(2\pi R_2 C_1)$, we get the value of $R_1 = 1k\Omega$ (input resistor). $R_2 = 1k\Omega$ (feedback resistor).

The following equations are relevant for the design of the transistor based circuit:

The value for C_3 was chosen has 0.001*pF* and $C_2 = 2C_3$, so $C_2 = 0.002\ pf$. Hence using $f_c = 1.414/(4\pi R_3 C_3)$, we get the value of $R_3 = 1.2\ k\Omega$.

The value for R_4 has been chosen has 1.8*k* Ω. So, using $R_3 = R_4 R_5/(R_4 + R_5)$, we get $R_5 = 3.9k\Omega$. Resistors R_4 and R_5 are responsible for setting up the bias point for the transistor base. Also, $R_e(\beta+1) > R_2$, where β is the forward current gain of the transistor and has a value of 60. So, $R_e(60+1) > 1.2k\ \Omega$. Therefore achieved $R_e = 22\ \Omega$ (emitter resistor). The transfer function of the filter is given as:

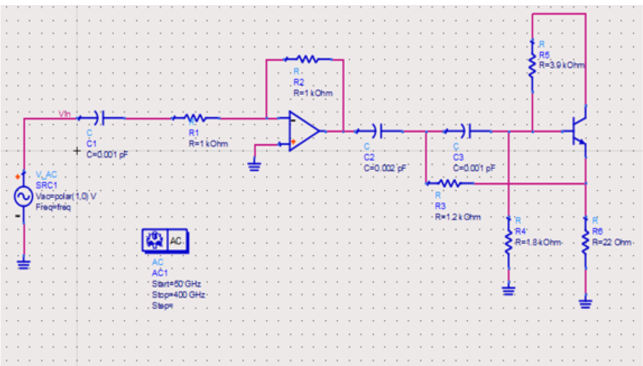

Fig. 2: Circuit design of active high pass filter.

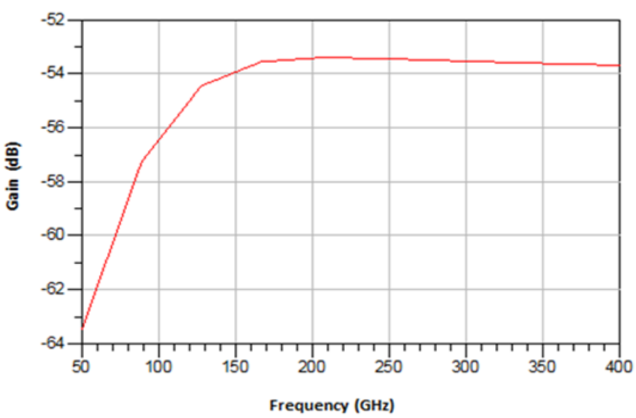

Fig. 3: Frequency response of active high pass filter.

$$T(s) = \frac{R_2 C_1 R_e s^3}{s^3 (R_1 C_1) + s^2\left(1 + \frac{R_1 C_1}{R_3 C_2} + \frac{R_1 C_1}{R_3 C_3}\right)} + \frac{R_2 C_1 R_e s^3}{s\left(\frac{1}{R_3 C_2} + \frac{1}{R_3 C_3} + \frac{R_1 C_1 (R_4 + R_5)}{R_3 C_2 R_4 R_5 C_3}\right)} + \frac{R_2 C_1 R_e s^3}{\left(\frac{R_4 + R_5}{R_3 C_2 R_4 R_5 C_3}\right)}$$

B. CSDG MOSFET

To further improve the gain of the designed active high pass filter, this section looks at implementing a CSDG MOSFET that can be added at the output of the filter. Since capacitance plays such an important role in the selectivity of frequencies, by using a CSDG MOSFET to act as an additional capacitor not only will the frequency selection be better but also improvements in gain will be observed. The CSDG MOSFET is an extension of a DG MOSFET with numerous benefits [18]. It is formed by rotation of a DG MOSFET with respect to its reference point to form a hollow cylinder [19, 20]. The basic concept of a CSDG MOSFET is to control the *Si* channel width so there is a smaller contact point at both sides of the channel.

A metal electrode called the Gate is kept apart from the semiconductor by a thin layer of SiO_2. This thin layer acts as an electrical insulator and occupies the space between the Source and Drain which makes the Gate electrically insulated from the Body [21, 22].

This newer concept of MOSFET design aids in suppressing the Short Channel Effects (SCE) and leads to higher currents as compared with MOSFET using a single gate. It is at the forefront of MOSFET technology and research within this field is consistently growing. Fig. 4 shows the cross sectional area of the CSDG MOSFET.

For this design we have selected $a = 5\ nm$, $b = 12\ nm$, $L = 20\ nm$, $t = 10\ nm$, and $d = 10\ nm$, where a, b, L, t and d are the MOSFET's inner radius, outer radius, length of cylinder, junction depth and depth of source respectively. The designed CSDG MOSFET is illustrated in Fig. 5.

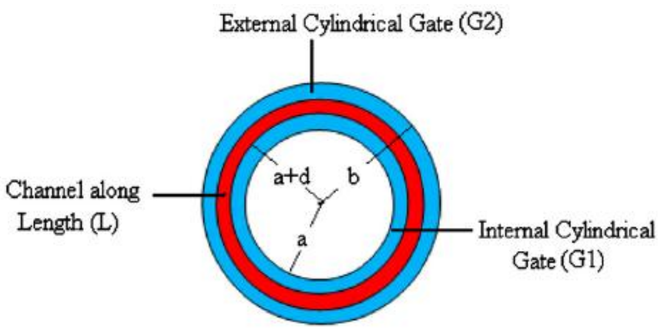

Fig. 4: Cross section of CSDG MOSFET [23].

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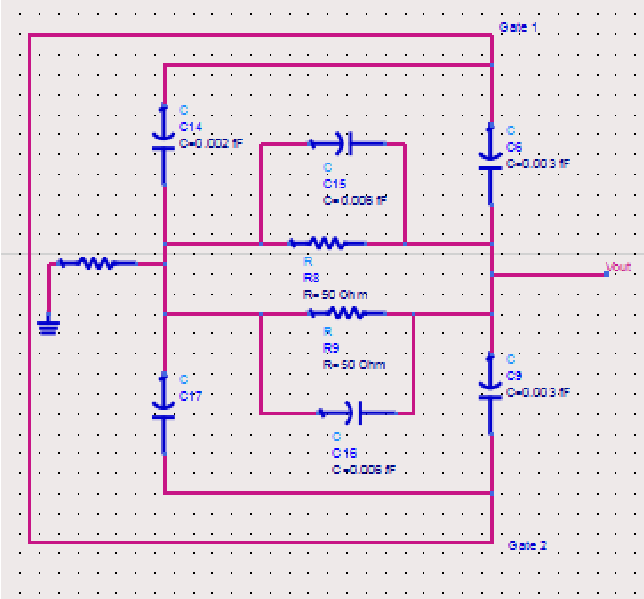

Fig. 5: Basic small signal model of CSDG MOSFET.

C. Filter Suitability in Mobile Communications

A mobile phone operates efficiently by using a highly selective filter. These filters are placed between the antenna and preamplifier and ensure that only signals of the appropriate frequency band will be amplified and the correct signals are received during important functions such as incoming calls and navigation services [24]. If filters are not designed properly it will lead to network problems during these calls.

The proposed filter is designed to operate at frequencies around *100 GHz*. This will allow mobile devices to complete multiple functions at once as there is a greater bandwidth to operate. With a greater demand from consumers for their handsets to be more function rich, mobile device manufacturers need their devices to work in the Extremely High Frequency (EHF) Band [25-27].

III. MODELING OF PROPOSED FILTER WITH CSDG MOSFET

The proposed design has merging of active high pass filter and CSDG MOSFET circuits as shown in Fig. 6. The transistor consists of a pair of resistors which create a bias point for the base of transistor whilst the transistor current is set by resistor R_e [23]. By connecting the MOSFET to the output of transistor to act as an additional capacitor, the benefits of the various parameters such as phase, return loss, and gain have been analysed. The later parameter is one of the most important parameters when designing a filter.

The designed MOSFET has been developed with a specification that allows minimal capacitance to be within the circuit. From theory that relates capacitance with frequency, a decrease in capacitance will increase the frequency and will allow the filter to operate at the upper regions of RF spectrum [28].

IV. SIMULATION RESULTS AND ANALYSIS

The designed third order active high pass filter with CSDG MOSFET as shown in Fig. 6 has been simulated using an electronic device simulator. The gain and phase of the circuit has been observed and are shown in Fig. 7 and Fig. 8, respectively. Since MOSFET is a capacitive model and one of the components that contributes the most to the working of an active filter is a capacitor, the results achieved during simulations is as expected.

From Fig. 7 it can be observe that the frequency increases, the gain of the filter approaches closer to *0 dB*. At the cutoff frequency of *0.1 THz* we observe a gain of *-55.54 dB*. Between this point and the frequency where maximum gain is reached we observe *-9 dB*. This agrees with the theory of how this type of high pass filter should behave since each order of filter will produce *-3 dB* drop in frequency [29].

Fig. 8 shows the phase response of the filter. Filter has effect on both the amplitude and phase of the signal. From Fourier analysis theory a square wave is made up of a fundamental frequency and odd order harmonics [30, 31]. The phase responses of these harmonics are accurately characterized. If there is a change in the phase relationship the sum of these harmonics will not be equivalent to the square wave. This will result in overshoot has the wave is seen has being distorted.

The proposed filter has a phase shift of *270°* at the cutoff frequency. This result also agrees with filter theory behavior and thus we can say that the proposed filter solution has been designed correctly [29].

Fig. 9 shows the improvements in terms of gain and it has been tabled in Table 1. At the cutoff frequency of *100 GHz* the difference in gain is *0.63 dB* and as the frequency increases, the difference in gains only gets larger, until it reaches its maximum gain. In this case this frequency is approximately *500 GHz*. The differences in gain at the cut-off frequency may only be a mere *0.63 dB* but considering the frequency domain this active high pass filter is designed for, the newly designed filter will ensure that a considerable amount of additional information is able to be transmitted.

Looking at Fig. 9 we observe that there is a steeper slope for the filter that made use of the CSDG MOSFET compared to the simple filter that didn't. From theory it is known that the steeper the slope of a frequency response graph the greater its ability to provide effective filtering. This means the frequencies below the cut-off frequency will be rejected faster and will thus allow the pass-band signals to be received more efficiently.

Return loss is defined as the ratio of reflected signal ($P_{reflected}$) to input signal (P_{in}). Often return loss is expressed has a positive integer such as *20 dBm*. But it's really meant to be a negative integer because return loss is always lower than the input signal. The return loss is given by the following equation [32, 33]:

$$RL = 10\log\left(\frac{P_{reflected}}{P_{in}}\right)$$

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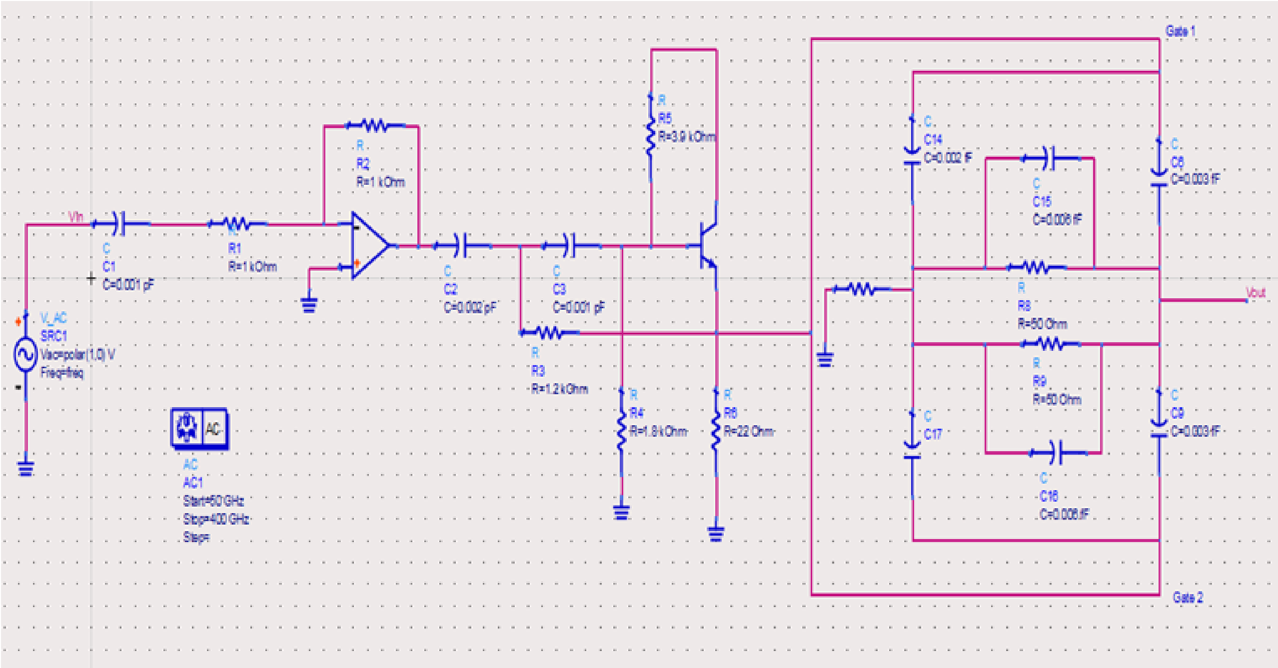

Fig. 6: MOSFET active high pass filter.

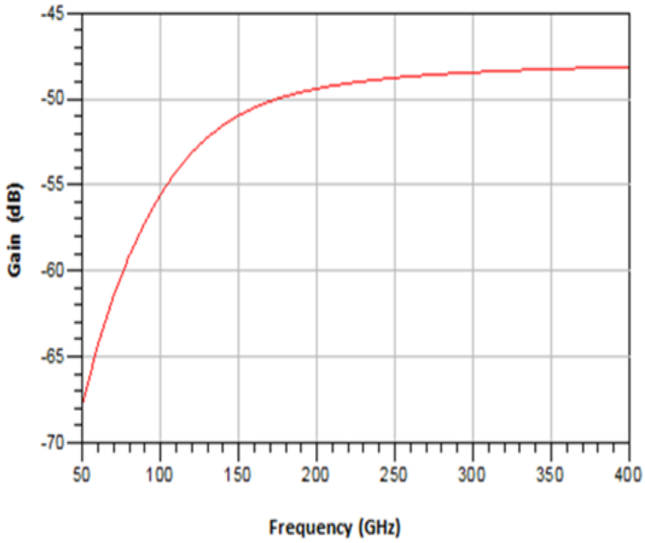

Fig. 7: Gain of proposed filter.

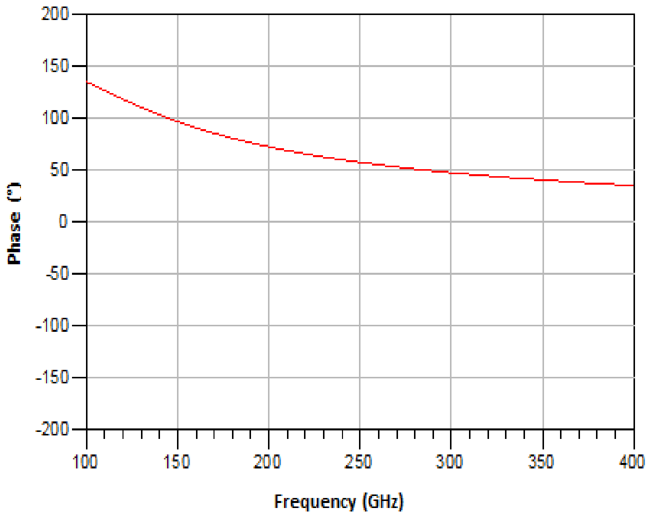

Fig. 8: Phase of proposed filter.

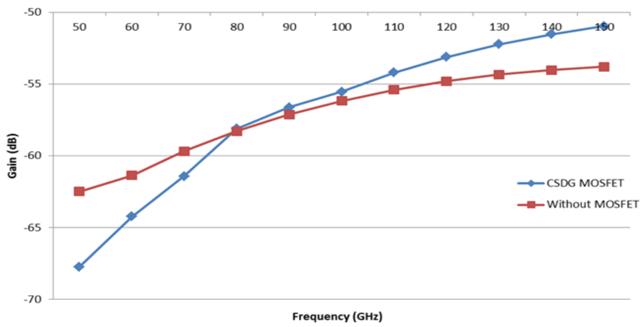

Fig. 9: Comparison of gains.

Table 1: Comparison of Gains of Filters

Frequency (GHz)	Gain (dB)		
	With CSDG MOSFET	Without CSDG MOSFET	Difference
50	-67.74	-63.48	-4.26
60	-64.23	-61.37	-2.36
70	-61.42	-59.68	-1.74
80	-58.10	-58.29	0.19
90	-56.62	-57.13	0.51
100	-55.54	-56.17	0.63
110	-54.20	-55.40	1.2
120	-53.11	-54.80	1.69
130	-52.23	-54.34	2.11
140	-51.52	-54.02	2.50
150	-50.96	-53.79	2.83

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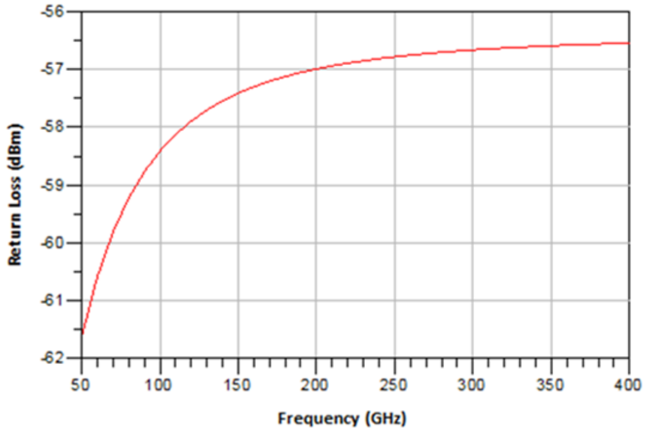

Fig. 10: Return loss.

Fig. 10 shows the return loss of the designed filter that can be implemented in a remote controlled device. Return loss of *-58.4 dBm* has been observed. This is the power ratio which is in decibels (dB) of the measured power and is then associated with 1 mW. The closer the value is to *0 dBm* the stronger the signal will be.

This result may be far from the desired result of *0 dBm* but with technology and components rapidly improving we can achieve results that are closer to the desired result and thus ensuring that the signal delivered is of a more considerable strength. However, considering the frequency domain the designed active high pass filter is operating in this is a good start to research work relating return loss to cut-off frequency.

V. CONCLUSIONS AND FUTURE WORKS

This work analysed the design and simulation of active high pass filter with CSDG MOSFET that could be used in mobile communication systems. An active filter has been chosen to be designed over a passive filter since it is efficient, costs and its weight is kept to a minimum and one can control the overall gain of the filter. The design of the active filter made use of two active components viz. operational amplifier and transistor. The transistor was implemented in this design as we require to achieve frequencies that are higher of the RF spectrum whilst providing the levels of gain that are required for a filter to deliver it's information efficiently and an operational amplifier helped with this aspect of the design.

In addition a CSDG MOSFET was added to the output of the circuit to see what effect it had on the gain of the designed filter. The newly designed filter offers better gain compared to a filter that made use of an operational amplifier and transistor that formed an active filter. It was also found that the return loss was improved.

Future work will involve achieving a better gain which is closer to unity which will ensure that more information is received. This will be achieved with technology improvements and further research can be carry forward in the field of CSDG MOSFET's and various types of gate oxides that could be a potential replacement for the SiO_2 layer.

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