

# Parametric Analysis of SiO<sub>2</sub> MOSFET Based Absorber for 5G Massive MIMO Base Station

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**Abstract.** The performance of the SiO<sub>2</sub> MOSFET-based absorber as a solution to arching within transmission lines (used for RF signal transportation) has been realized and analyzed at 28 GHz using the reflected signal from the R<sub>X</sub> branch of 5G massive MIMO base station. The reflected signal from the receiver (R<sub>X</sub>) branch of base stations may lead to interference, thus creating a performance reducing condition (arching) within the transmission lines. For optimum performance in the 5G regime, the SiO<sub>2</sub> MOSFET has been used to solve the problem of arching within the transmission line under large field intensities of a standing wave resulting from the impedance. The SiO<sub>2</sub> MOSFET-based absorber has been observed for a reflectivity of -79.5 dB and a rectification efficiency greater than 17 %

## Introduction

Telecommunication started with the introduction of the First Generation (1G) of technology to Fifth Generation (5G). For maximum efficiency, the massive MIMO technology has been adopted by telecommunication companies for their base station construct, to complement the deficiencies of the SISO technology used in base stations of previous generations [1, 2]. Even though the massive MIMO technology is promising, it has its challenges, and one of such challenges is arching within the transmission line resulting from inconsistency in matching between the T<sub>X</sub> and R<sub>X</sub> branch [3, 4]. Thus, making the line act as an RF storage device instead of transporting device. For this reason, a circulator connected to a MOSFET absorber has been proposed as a solution to the arching within the transmission line used in base station construction.

In this present research work, MOSFET-based absorber has been designed to eliminate arching within transmission lines resulting from the reflected signal in 28 GHz massive MIMO base station. The proposed MOSFET-based model has been analyzed and observed as highly efficient with analysis, based on technical parameters like insertion loss, efficiency, reflection coefficient, reflectivity, permeability, permittivity, and RF propagation (propagating in the absorber). This research paper has been organized as follows. Section II gives an analytical overview of the proposed model. Section III presents the parameter analysis of the rectifier used in the proposed model. Section IV analyses the reflectivity, speed of RF propagating in the absorber, permeability, and permittivity as a performance parameter of the proposed design. Finally, Section V concludes the work and recommends the future aspects.

## Analytical Overview of Proposed Model

One key advantage of 5G technology is process optimisation where 5G is expected to revolutionise areas such as medicine, traffic management, and autonomous vehicles. But with the presence of arching within transmission lines used in base station systems, the overall efficiency of the processes at 5G regime of frequencies will be greatly affected. The proposed model tends to eliminate arching within transmission line thus improving process optimization.

The proposed design for arching effect elimination contains a four-port circulator connected between the  $T_X$ , antenna,  $R_X$ , and MOSFET device (port-1, port-2, port-3, and port-4) as shown in Fig. 1. In this case, the MOSFET is an N-channel improvement MOSFET that absorbs reflected signals from the  $R_X$  branch due to impedance malfunctions that could lead to arching in the transmission line. The modulated RF signal from the  $T_X$  branch of the base station flows through port-1 of the circulator into the circulator. This signal is sent to the reception antenna connected to port-2 of the neighbouring base station's circulator via port-2 [5].

If there is an inconsistency in matching between transmitting base station  $T_X$  and the  $R_X$  branch of the next base station, some signal is reflected in the transmitting base station. The reflected signal from port-3 of the adjacent base station exits the circulator via port-4, which has a rectifier and N-channel MOSFET connected. More details have been discussed in the author's previous work [5, 6].

A sinusoidal voltage source has been used to supply an equivalent source or  $T_X$  branch terminal voltage component of  $44.7\text{ V}$  equivalent to  $20\text{ W}$  at  $43\text{ dBm}$  incident power at  $28\text{ GHz}$  simulation frequency. With the help of a voltage divider, the voltage component of reflected RF power from the  $R_X$  branch connected to the circulator has been generated and applied to the input terminal of the rectifier used in the proposed model.

The values of resistors  $R_1$  and  $R_2$  required to produce a voltage drop equivalent to the voltage component of the reflected RF power from the  $R_X$  branch have been calculated as  $1700\ \Omega$  and  $109\ \Omega$ , respectively. These values have been generated using an electronic device simulator at  $19\text{ dBm}$  reflection from port-4 of the circulator. From the voltage divider's output, the input values have been calculated as  $2.7\text{ V}$  ( $V_{\text{peak}}$ ),  $1.7\text{ V}$  ( $V_{\text{rms}}$ ),  $1.33\text{ mA}$  ( $I_{\text{peak}}$ ), and  $0.566\text{ mA}$  ( $I_{\text{rms}}$ ) at  $19\text{ dBm}$  reflection from port-4 of the circulator. *Cao et al.* [7] have developed a novel rectifying circuit at significant dynamic input power conditions. This rectifying circuit utilizes the circulator in which the microwave is constrained to travel one way. The values of peak voltages and currents pulsate at the output terminal of the rectifier. For the MOSFET device to function effectively, MOSFET input terminal current and voltages must be continuous instead of pulsating.

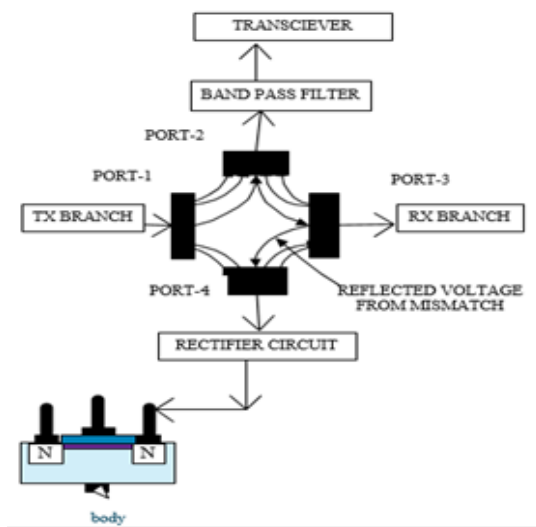


Fig. 1 Proposed model of MOSFET-based absorber [5].

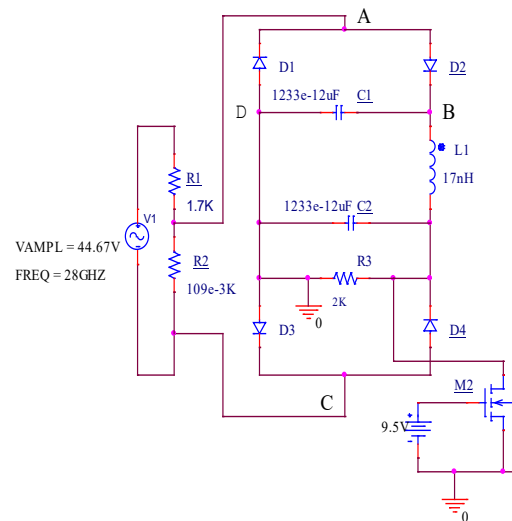


Fig. 2 Circuit for MOSFET based absorber of reflected RF signal [5].

To generate a pure DC, the rectifier's output must be filtered. From the simulation experiment, these values were deduced by the output plot and its equivalent RMS and peak values of current and voltages have been generated. Now  $I_{\text{peak}}$ ,  $I_{\text{dc}}$ ,  $I_{\text{rms}}$ ,  $V_{\text{peak}}$ ,  $V_{\text{rms}}$ , and ripple factor are  $0.9\text{ mA}$ ,  $0.57\text{ mA}$ ,  $0.64\text{ mA}$ ,  $1.8\text{ V}$ ,  $1.27\text{ V}$ , and  $0.33$ , respectively. Also, the values of capacitor and inductor needed for the filter design have been calculated as  $1233e^{-12}\text{ uF}$  and  $17\text{ nH}$ , respectively. After filtration, the DC voltage and current at the output terminal of the rectifier have been observed to be  $1.6\text{ V}$  and  $0.566\text{ mA}$ . The formula for calculating these parameters and values of DC voltages and currents have been generated from the output plots of the rectifier. Since the purpose of this research is to use a MOSFET

to absorb reflected RF power that would have caused arching in transmission lines used in 5G base station. The relationship  $I_S \leq I_D$  and  $V_{DS} = 0$  at the source terminal of the MOSFET must be satisfied at 19 dBm reflection from port-4 of the circulator [8].

The MOSFET is said to have performed its function of absorbing reflected radio frequency signal that would have led to arching within the transmission lines if the relationship  $I_S \leq I_D$  and  $V_{DS} = 0$  at the source terminal is satisfied. From the values of simulation plots,  $I_S$ ,  $I_D$ ,  $V_{DS}$  at source, and  $V_{DS}$  at drain have been observed to be 0.4 mA, 0.4 mA, 0 V, and 1.6 V, respectively. Values from simulation, putting the values of voltages and current into the relationship  $I_S \leq I_D$  and  $V_{DS} = 0$  at the source terminal, at 19 dBm reflected power from port-4 of the circulator, MOSFET's condition for absorption was satisfied for 19 dBm reflection condition from port-4 of the circulator [9]. Even though the value of reflected power is large, it has been used for testing and experimental purposes, which may not be the case in real-life applications. However, the value of current at the output terminal of the rectifier and the value of current at the MOSFET terminal differs by 1.66 mA, this difference is due to MOSFET operating condition.

### Performance Parameters for MOSFET Based Rectifier Used in the Proposed Model

The rectifier used for the proposed model construct have been considered as part of the absorption process of the proposed MOSFET based absorber. Parameters such as crest factor, power factor, harmonic factor form factor, and rectification efficiency of the rectifier have been used to characterize the performance of the rectifier used for the proposed model construct. These parameters have been used previously to determine the performance of rectifiers. In an attempt to improve crest factor and Total Harmonic Distortion (THD), *Chen. et. al* [10] designed a rectifier circuit. The presented design was observed to have a good input current with power factor greater than 0.99, THD less than 5 % and the crest factor was less than 1.6. Considering the rectifier used for the proposed model the proposed model rectifier circuit is better in terms of these performance parameters.

**Crest Factor (CF).** The crest factor is the parameter used in determining the consistency in the waveform of an AC voltage source. The reflected RF signal from Rx branch of the receiving base station has been observed from simulation plots as a sinusoidal waveform with a very short wavelength. The crest factor for current drawn by a non-linear load is generally between 1.41 and 2 [11]. However, this value could be as large as 5 in critical cases. The crest factor of the AC source at the input terminal of the rectifier used for the proposed model can be calculated as:

$$\text{crest factor} = \frac{\text{peak input supply voltage}}{\text{RMS input supply voltage}} \quad (1)$$

From section II,  $V_{\text{peak}}$  and  $V_{\text{rms}}$  have been presented as 2.7 V and 1.8 V. Substituting these into Eq. (1), the crest factor has been calculated as 1.588. Comparing this computed value with the standard requirement for the crest factor for an AC source connected to a non-linear load, it has been observed that this value falls into the range of expected values of the crest factor for an AC voltage source.

**Rectification Efficiency of the Rectifier.** It is the rectifier's DC output power to its AC input power ratio ( $\eta$ ). As an advantage, the higher the rectification efficiency, the higher the DC power output for a given AC input. For a half-wave rectifier, the rectification efficiency is 40.6% . This indicates that the half-wave rectifier can convert a maximum of 40.6 % of AC power into DC power, and the remaining power of 59.4 % is lost in the rectifier circuit. Also, for a full-wave rectifier, the rectification efficiency is 81.2 %. The implication of this is that for an AC input power, 81.2 % will be converted to DC power, while the rectifier circuit will absorb 18.8% of the AC input power. The rectifier circuit used for the proposed model has been observed to be a full-wave rectifier, to calculate the rectification efficiency by [8]:

$$\eta = \frac{AC \text{ input power}}{DC \text{ output power}} \times 100 \quad (2)$$

To calculate AC input power and DC output power:  $P_{AC} = I_{AC}V_{AC}$  and  $P_{DC} = I_{DC}V_{DC}$  have been used. From section II,  $I_{AC}$ ,  $V_{AC}$ ,  $I_{DC}$ , and  $V_{DC}$  have been observed as  $1.33 \text{ mA}$ ,  $2.7 \text{ V}$ ,  $0.4 \text{ mA}$ , and  $1.6 \text{ V}$ , respectively. The  $P_{AC}$  and  $P_{DC}$  have been calculated as  $3.59 \text{ mW}$  and  $0.64 \text{ mW}$ , respectively. Substituting values of  $P_{AC}$  and  $P_{DC}$  into the rectification efficiency formula captured in Eq. (2), the rectification efficiency is  $17.8 \%$ . This indicates that  $17.8 \%$  of power was delivered to the MOSFET while the rectifier circuit has absorbed  $82.2 \%$  of the power supplied.

Comparing this value with the standard requirement of  $81.2 \%$  rectification efficiency for a full-wave rectifier, it has been observed that the difference in efficiency is significant. The reason for this vast variation is the frequency at which the rectifier was used. When frequencies are too high, it becomes difficult for discrete capacitors and inductors to be practical. A combination of Schottky diode and distributed circuit will be employed for the rectification and filtration process during the physical implementation of the proposed model [5, 9].

**Power Factor (PF).** The rectifier extract power from the peak of the reflected sinusoidal wave voltage coming out of port-4 of the circulator, therefore there should be a minimal phase shift, showing a power factor be  $0.95 (\sim 1)$ . The power factor is given by [8, 11]:

$$\text{power factor} = \frac{P_{avg}}{P_{rms}} \quad (3)$$

where  $P_{avg}$  and  $P_{rms}$  are dc and rms value of reflected power, respectively. Therefore, using  $P_{rms} = V_{rms} \times I_{rms}$  and substituting values of  $V_{DC}$ ,  $I_{DC}$ ,  $V_{rms}$ , and  $I_{rms}$  from section II, the  $P_{avg}$  and  $P_{rms}$  can be calculated as  $0.906 \text{ mW}$  and  $0.9622 \text{ mW}$ , respectively. Also, substituting the values of  $P_{avg}$  and  $P_{rms}$  into the power factor formula captured in Eq. (3), the power factor has been calculated as  $0.944$ . this value is nearly equal to the expected value for a non-regulated diode-based rectifier.

**Total Distortion Factor (THD).** A low THD of a power system signifies a system with low peak current and high-power factor. Considering the rectifier system used in the proposed model, there is a change in the current of the reflected power from port-4 of the circulator. The change in current and output voltage of the reflected RF power can be described in terms of harmonic distortion of the current or voltage [8, 12]:

$$\text{Distortion factor} = \frac{1}{\sqrt{1 + THD^2}} \quad (4)$$

Substituting the value of the power factor into the distortion factor formula captured in Eq. (4), THD has been calculated as  $0.36$ . This represents a THD of  $36 \%$  means that the RMS magnitudes of the harmonics are  $36 \%$  of the RMS magnitude of the fundamental frequency of the reflected power from port-4 of the circulator. A perfectly linear signal gives a THD factor of  $0 \%$ .

**Form Factor (FF).** This parameter is a measure of the RMS value to the average value of an alternating signal. For a sinusoidal wave signal, the form factor is  $1.1$  [13]. The form factor can be calculated as:

$$\text{Form factor} = \frac{V_{rms}}{V_{DC}} \quad (5)$$

The  $V_{rms}$  and  $V_{DC}$  have been presented in section II as  $1.7 \text{ V}$  and  $1.6 \text{ V}$ , respectively. Substituting these values into Eq. (5), the form factor has been calculated as  $1.063$ . This value is nearly equal to the standard requirement of  $1.1$  for a pure sinusoidal waveform. Again, the consistency of the rectifier performance parameter can be checked by relating the form factor with the voltage ripple factor.

The relationship between the voltage ripple ( $r_v$ ) factor and the FF is given by  $r_v = \sqrt{FF^2 - 1}$ . Substituting the value FF into this, the voltage ripple factor is 0.35. Comparing this value with the value of voltage ripple factor captured in section II, a difference of 0.02 approximately 6 % error has been observed. However, this value is minimal and negligible. Also, at 19 dBm reflection from port-1 of the circulator used in the proposed model construct, the reflection coefficient, load impedance, return loss, and VSWR were calculated as 0.063, 56.7, 24.024, and 1.134:1, respectively [5, 9].

**Reflectivity of the MOSFET Based Absorber.** Reflectivity can be used to express the performance of an absorber model. In this case, the absorbent material for the proposed model is a combination of the rectifier and the SiO<sub>2</sub> MOSFET. For other absorber models existing in the form of foam absorbers, the thickness of the foam material provides resistance to RF energy. These foam materials allow some of the RF energy to pass through them completely, while others have a metal blocking to contain the radiation [14]. In the case of the proposed model, the channel resistance of the MOSFET and the resistor used in the model have been observed to have the same effect as the thickness of foam absorbers. In other words, the thickness provides resistance in foam absorbers. In contrast, the channel resistance of the MOSFET offers the resistance of the proposed model and the resistor used for the proposed model design. The reflectivity of an absorber can be calculated using:

$$\text{Reflectivity} = 20 \log |\Gamma| \quad (6)$$

The reflection coefficient  $\Gamma$  has been presented in [9] as 0.000179. Substituting this value into Eq. (6), the reflectivity of the proposed absorber model has been calculated as -79.5 dB at 28 GHz. However, a good RF absorber designed at a specified frequency must have a low reflectivity, which is a function of the material used for the absorber design. The proposed MOSFET based absorber design has been observed to have a better reflectivity value compared to the design presented by Rodriguez [15], which has designed an anechoic chamber and used polynomial approximation to compute the RF absorber reflectivity. The designed absorber was observed to have a reflectivity of -34.21 dB after experimentation

## Conclusion and Future Works

The presented model has proven to be a solution to arching within transmission lines used in base stations. The proposed model performance has been analysed using technical parameters like reflectivity, speed of RF propagating in the absorber, distributive, capacitance and permittivity. Also, a complete analysis of the rectifier used for the model has been carried out. The performance of the proposed model has been analyzed with parameters like insertion loss, efficiency, total power absorbed by the MOSFET, total power loss to the rectifier circuit, and reflection coefficient. The values of these parameters have been calculated as 38.3 dB, greater than 90 %, 0.64 mW, 2.95 mW, and 0.000179, respectively.

The future work for this research will provide a co-design of the proposed model, cylindrical surrounding patch antenna, and DG MOSFET amplifier at 28 GHz frequency.

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