

Directed high-energy radio wave exposure detection

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Abstract—We present a directed high-energy radio wave exposure detection sensor using radio frequency (RF) energy harvesting techniques. The sensor comprises a small dipole antenna and a tunable rectifier circuit. Reverse biasing the diode allows high levels of RF radiation to be detected by the sensor. We also demonstrate how the frequency-dependent nature of the rectifier can be alleviated. The proposed sensor performance is experimentally evaluated in the 5-10 GHz range.

Index Terms—RF exposure, directed energy weapon, wearable antenna, energy harvesting, rectifier

I. INTRODUCTION

In recent years, there have been several reports of American diplomats and intelligence personnel exposed to directed high-energy radio frequency (RF) radiation. Soldiers on the battlefield are often at risk of RF weapon exposure [1]. Besides military operations, accidental exposure can occur in industrial, manufacturing, and medical facilities. Since the symptoms of high-energy RF exposure might not be instantaneous, real-time detection is of paramount importance.

Frey *et al.* discussed the design considerations of a potential high-power microwave-directed energy exposure detection system using thermoacoustic wave generation as the field interaction mechanism [2]. In conjunction with energy harvesting rectifiers, we leverage the radiation efficiency reduction of omnidirectional on-body antennas [3], [4] for designing a directed high-energy RF exposure detection sensor (Fig. 1). To our knowledge, this is the first energy-harvesting high-energy RF exposure detector. While the proximity of the antenna to the human body reduces the incident RF power level, a reverse bias mechanism allows us to set the activation threshold of the rectifier. Consequently, the proposed detector can detect very high levels of incident RF power. Although the proposed sensor is an active device (requiring a battery), the diode stays in reverse bias in its normal operating condition. In other words, the diode (and the circuit) remains open unless there is an incident high-energy RF wave. As a result, only a negligible amount (500 nA maximum for the diode in use) of reverse leakage current flows through the diode. Therefore, the proposed sensor will have a long battery life. Furthermore, the compact size of the antenna and the rectifier circuit will allow the fabrication of a credit card-sized high-energy RF exposure sensor. The performance of the sensor is evaluated in the 5-10 GHz range.

II. DESIGN AND EXPERIMENTAL SETUP

A. Antenna Design

The antenna is a dipole made with copper tape on a thin paper substrate (Fig. 2). Each arm of the dipole is 13 mm

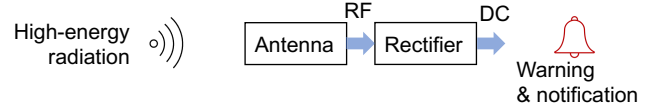


Fig. 1: Proposed high-energy RF exposure detection system.

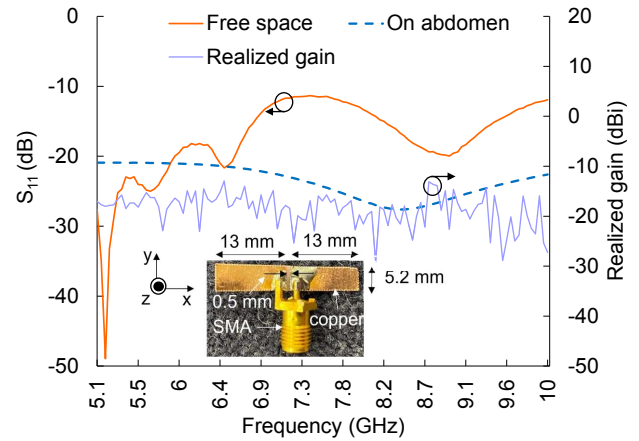


Fig. 2: Reflection coefficient and realized gain vs. frequency plot of the antenna on the water container.

long and 5.2 mm wide. There is a 0.5 mm gap between the dipole arms. The dipole is resonant around 5.2 GHz in free space (Fig. 2). The reflection coefficient (S_{11}) of the antenna changes as the antenna is placed on a human abdomen (Fig. 2). The S_{11} curve is relatively flat compared to the free space scenario.

The realized gain (G_R) of an antenna is defined as follows:

$$G_R = G + 10 \log_{10}(1 - |S_{11}|^2) \quad (1)$$

where G is the antenna gain in dB. Fig. 2 shows the on-body realized gain (5-10 GHz) of the antenna along the z-axis ($\theta = 0^\circ$). The antenna was placed on a human abdomen during the gain measurement. The average realized gain is around -20 dB. The purpose of the low realized gain is to reduce the power level of the incident RF wave.

B. Rectifier and Bias

The rectifier (Fig. 3) converts the RF signal (P_{in}) captured by the antenna into DC (V_{out}). The rectifier consists of an inductor (L_1), a resistor (R_L), a Schottky diode (D , model: MA4E20541-1141T), capacitors (C_2 , C_3 , and C_L), and a DC

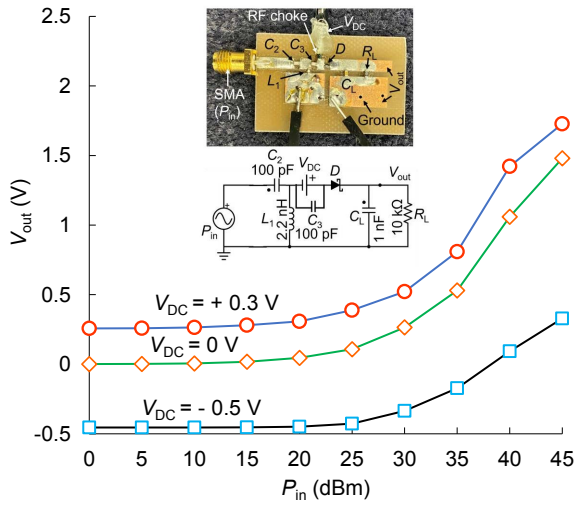


Fig. 3: Rectified DC voltage vs. input RF power plot (5 GHz) for different bias conditions (V_{DC}).

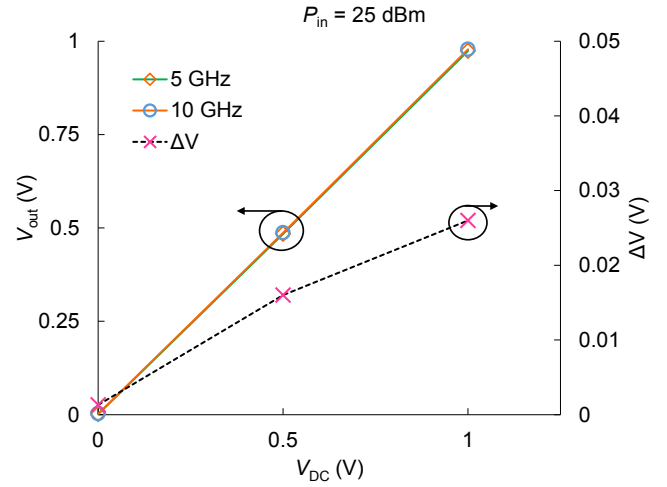


Fig. 5: Rectified DC voltage (V_{out}) vs. bias voltage (V_{DC}) plot at a fixed input power level (25 dBm).

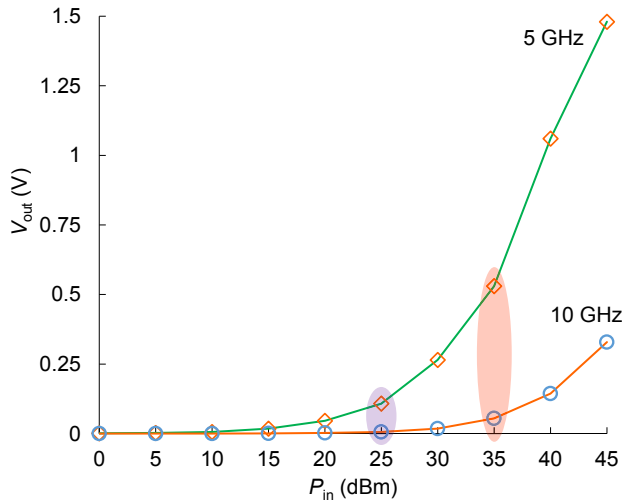


Fig. 4: Rectified DC voltage vs. input RF power plot ($V_{DC} = 0$ V) at different frequencies. The output DC voltage level shows strong frequency dependence at higher input power levels.

source (V_{DC}) for biasing. The diode starts carrying current when the input voltage is 0.35 V or higher. V_{DC} helps us tune the bias point (or activation threshold) of the diode (and the rectifier). Fig. 3 shows V_{out} vs. P_{in} in different bias conditions. In forward bias conditions ($V_{DC} > 0$ V), a certain level of V_{out} is attained with lower input RF power P_{in} compared to the unbiased condition ($V_{DC} = 0$ V). On the other hand, if the diode is reverse biased ($V_{DC} < 0$ V), a higher level of P_{in} is required. We capitalize on this feature of the diode (and the rectifier) to design the high-energy RF exposure sensor by reverse biasing the diode so that only higher levels of RF input power are required to activate the rectifier.

III. RESULTS AND DISCUSSION

Fig. 4 shows that V_{out} vs. P_{in} is dependent on frequency. In the unbiased condition, the difference between the V_{out} values

is higher at high P_{in} levels. The frequency-dependence of V_{out} will make it difficult to define a P_{in} threshold for high-energy exposure detection. For both frequencies, the V_{out} levels are close at low P_{in} values. The bias voltage V_{DC} can move the V_{out} vs. P_{in} upward or downward. As a result, we can pick a P_{in} value from the unbiased condition and tune V_{DC} so that the sensor reaches a V_{out} threshold for a dangerous P_{in} level. We chose 25 dBm input power where V_{out} values are close for both frequencies. A sweep of the bias voltage V_{DC} (from 0 V to 1 V) shows that V_{out} values for both frequencies are very close with minimal difference (Δ) (Fig. 5). The tunability of the rectifier will allow the sensor to be used in different RF exposure scenarios.

IV. CONCLUSION

In summary, we demonstrated a high-energy RF wave exposure detector using a small dipole antenna and a tunable energy harvesting rectifier. In the future, we will develop a compact sensor with surface-mount device components for a wider frequency band and evaluate it in a wearable form factor.

V. ACKNOWLEDGMENT

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