

CONTROLLING ULTRA WIDE BAND TRANSMISSIONS FROM A WIRELESS MICROMACHINED GEIGER COUNTER

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ABSTRACT

This paper reports a parametric study of the wireless spectrum generated by discharge-based devices with focus specifically on micromachined Geiger counters as a function of the packaging, biasing circuitry, and sample isotope. Experiments are conducted with discharge devices attached to commercial high voltage (HV) packages with hermetic sealing capabilities. Influences of packaging as well as isotope type are studied and reported. Preliminary results show that current discharges emit RF spectra spanning a bandwidth greater than 3 GHz, which extends into the ultra wideband (UWB) window (from 100 MHz to 10.6 GHz) that decreases in intensity with increasing observer distance.

I. INTRODUCTION

Networked radiation sensors are envisioned for monitoring public buildings with high pedestrian traffic. Past work in lithographically-microfabricated radiation sensors has included solid-state and gas-based X-ray detectors [1-5]. A micromachined Geiger counter capable of performing energy spectroscopy has also been reported [6]. Other microdischarge-based transducers including chemical sensors used for vapors and liquids produce emission spectra that are characteristic of chemical species [7]. Additionally, microdischarges are generated unintentionally in electrostatic transducers [8].

Wireless communication between sensors can enable rapid and low cost deployment or reconfiguration of networks. Wireless networks can also be employed for monitoring environmental hazards and in inaccessible terrains. It has recently been reported with very preliminary experiments that the electrical microdischarges initiated by the passage of a beta-particle in a discharge-based device such as a micromachined Geiger counter transmits ultra wide-band (UWB) radio-waves potentially suitable for sensor networking [9]. The prospect of utilizing the inherent RF transmissions from discharge-based sensors to implement a wireless network is attractive from a number of viewpoints, including power efficiency, miniaturization, and cost.

The idea of using spark discharges for communication dates back to Guglielmo Marconi in the mid-1890's [10]. In 1901, Bose reported utilizing discharges within waveguides in order to generate microwaves, and more recent activity has also been reported [11]. This paper

reports a parametric study of the wireless spectrum generated by discharge-based devices with focus specifically on micromachined Geiger counters as a function of the packaging, biasing circuitry, and sample isotope. In Section II, the basic device operation as well as theoretical modeling of the emission spectra is discussed. Section III presents the recent experimental results while Section IV concludes with a discussion of possible applications.

II. DEVICE CONCEPT

Basic Geiger Operation

The basic device (Fig. 1a) is a glass-Si-glass sandwich in which a central Si post forms the cathode and a peripheral square Si ring forms the anode. The electric field is shaped so that near the cathode is a weak-field drift region, whereas near the anode is a high-field avalanche region. As beta particles pass through the glass window into the drift region, they ionize the Ne atoms, resulting in a sharp avalanche current pulse and its concomitant RF transmission. The device inherently operates as a UWB transmitter along the guidelines specified in [12]. For the purpose of this study, the microGeiger was enclosed (Fig. 1b) at atmospheric pressure in an industry-standard high-voltage compatible metal package with a 500 μm machined glass lid.

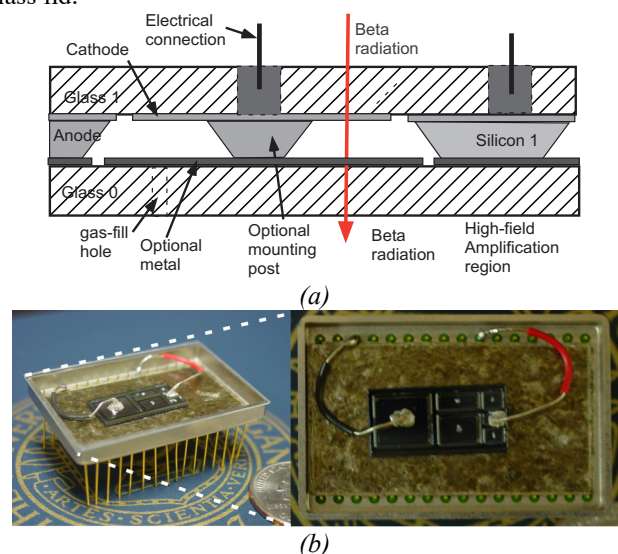


Fig. 1: (a) Cross-section of microGeiger showing glass-Si-glass stack. (b) MicroGeiger is shown bonded to an industry standard high-voltage package with a 500 μm glass lid.

Theoretical Modeling of Emission Spectra

The theoretical work reported in [13] provides an analytical estimate for the high frequency (UHF > 500 MHz) electromagnetic radiation emitted during discharges. If l is the characteristic length scale in the current channel, r is the distance from the observer to the channel, and λ the radiation wavelength, then the dipole ordering is $l < \lambda < r$. Given a square-wave shaped current pulse that is described by:

$$I(t) = I_0, \quad 0 < t < \tau_0 \quad (1)$$

the magnetic flux density due to dipole radiation is approximately given by:

$$B = \frac{-2l \sin \theta}{c^2 r} \frac{\partial I(t - r/c)}{\partial t} \quad \text{Gauss}, \quad (2)$$

where c is the speed of light and θ is the viewing or observation angle. The Fourier components of B are given by:

$$b = \frac{4iI_0 \sin \theta \exp(i\omega[r/c + \tau_0/2 - (l/c)\cos\theta])}{c r \omega \cos \theta} \times \sin\left(\frac{\omega l}{c} \cos \theta\right) \sin\left(\frac{\omega \tau_0}{2}\right) \quad (3)$$

Table 1: Emission Spectra Modeling Parameters

Parameter Name	Value
Frequency of interest, ω	200 MHz \rightarrow 10 GHz
Observer distance, r	0.5 m
Channel length, l	100 μm \rightarrow 500 μm
Pulse width, τ_0	\sim 1 ms

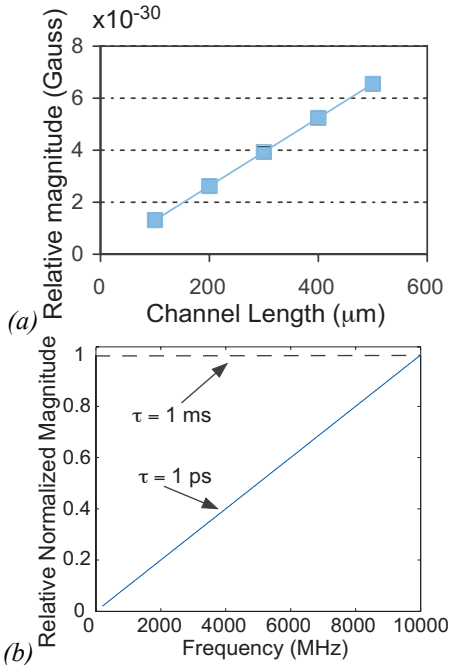


Fig. 2: (a) Plot of theoretical relationship between current channel length and relative emitted spectra. Using values given in Table 1, rel. signal strength increases with discharge length. (b) As the current pulse width is scaled down, the shape of the spectra envelope turns from nearly constant to linear.

Specific dimensions and frequency interval of interest were examined. The model parameters used are summarized in Table I. The relationship between channel length, which is representative of the trajectory of current flow in the discharge, and relative strength of emission was evaluated (Fig. 2a). As channel length increases, the relative magnitude increases linearly. As the pulse width duration in time is decreased, there is a significant change in the overall shape of the emission spectra envelope. As seen in Fig. 2b, if the pulse width is on the order of milliseconds, the spectral envelope appears to be constant, but if the width is scaled down several orders of magnitude (1 picosecond) the relationship appears to be linear.

III. EXPERIMENTAL RESULTS

Figure 3 shows the experimental setup used in this effort. Tests were conducted in a Ne gas-filled environment. Neon was chosen because it has a relatively low ionization energy. An RF field strength analyzer (Protek, Inc., #3290) was used to measure the resulting RF spectra. An 8-in whip antenna designed for the 800 MHz cellular band was positioned at various distances away from the device while the source-to-detector distance was fixed at 5 cm.

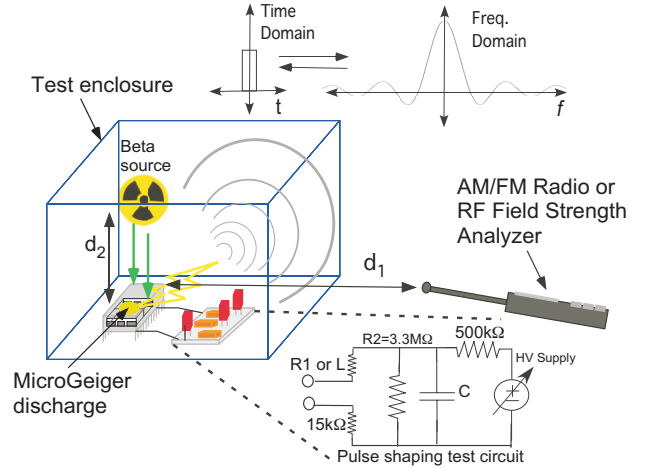


Fig. 3: Test setup showing RF field strength analyzer with RF spectrum shaping circuitry. Detector to antenna distance, d_1 , was fixed at 25.4 cm while source to detector distance, d_2 , was fixed at 5 cm. All tests were operated in a Ne/air environment. Applied voltage was between 850 – 900 V.

Figure 4 shows the relative decrease in signal strength as detector to RF meter distance increases. Measurements were taken with the field strength analyzer tuned to 5 MHz. Figure 5 presents the results from frequency scans taken in narrow band FM reception mode in the presence of ^{204}Tl . They were found to span from 80 MHz to more than 3 GHz, which is the upper detection limit of the field strength analyzer. As the capacitor, C , was scaled down from 22 nF to 10 pF, spectral content was seen to increase significantly. This presents an important design compromise because a large C can accommodate a wider dynamic range of incident beta particles without changing

the bias across the electrodes. For example, if there is a surge of beta particles that are incident upon the detector, a small C will be discharged more rapidly, reducing the bias, and thereby the electric field available to detect beta particles following immediately after. Figure 6 represents another parametric study – this time in AM reception mode

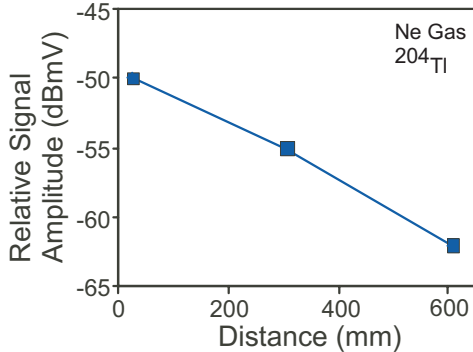


Fig. 4: Measured attenuation of signal power at 5 MHz as a function of separation d_2 from the RF meter and the microGeiger.

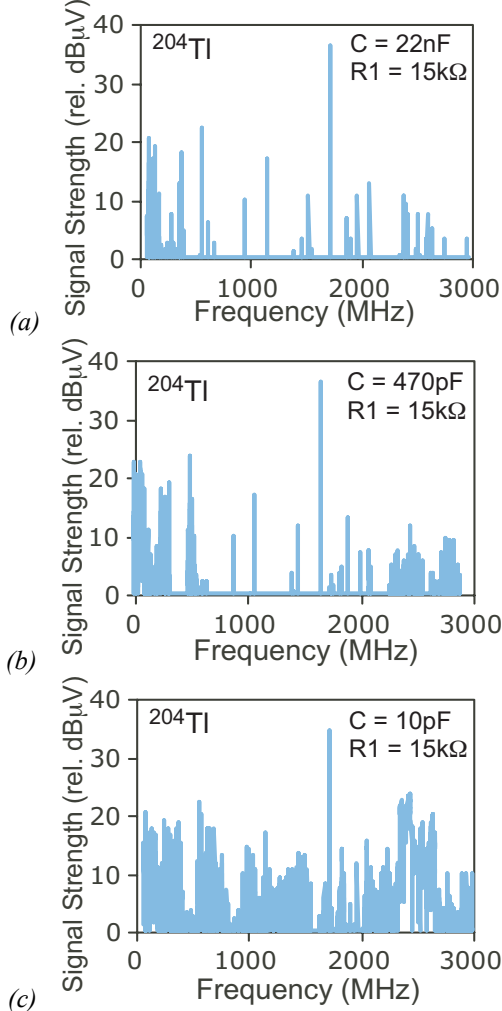


Fig. 5: Frequency sweeps were conducted from 80 MHz to nearly 3 GHz. Figure 6a, 6b and 6c correspond to $C = 22$ nF, 470 pF, and 10 pF respectively. As capacitor size is scaled down, not only does relative signal strength increase but an increase in overall signal content is realized as well. The signal was collected in narrow band FM reception mode. All tests were conducted in a Ne/air atmosphere while detecting ^{204}Tl .

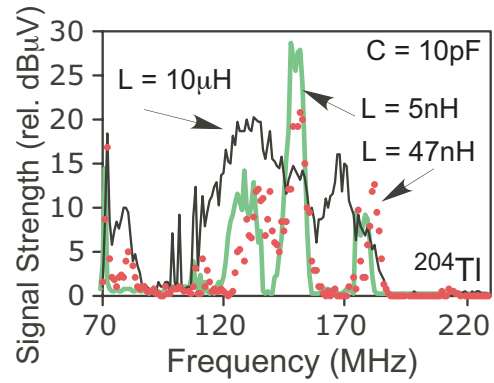


Fig. 6: Tests varying L showed an increase in inductor size leads to an increase in average rel. signal power. The resulting spectrum widens and attenuates sharp frequency spikes as seen around 150 MHz. The signal was collected in AM reception mode.

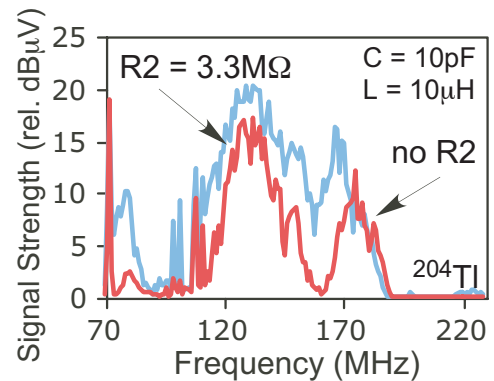


Fig. 7: Using a 10 pF capacitor with a 10 μH inductor, in the presence of the 3.3 M Ω resistor, R_2 , has increased the signal strength by approximately 5 rel. dB μV . Taken in AM reception mode.

– which shows that the discharge spectrum can be tuned and increased by series inductors (in place of the R_1 resistor). The 3.3 M Ω resistor, R_2 , exists as a safety measure, to discharge the capacitor, C when the power is turned off. However, with the appropriate choices for the other elements, its presence improves spectral strength by nearly 5 relative dB μV (Fig. 7). These preliminary results demonstrate how the standard bias circuit can shape and limit the inherent performance of the microdischarge to enable remote detectors to communicate with unique spectral signatures to help in identification.

The possibility of performing isotope recognition utilizing the inherent discharges were explored. Three radioactive chemicals were used, ^{60}Co , ^{90}Sr , and ^{204}Tl . Figure 8 shows the resulting spectra from each of them. No direct link could be concluded between emitted spectra and isotope identity.

To address the impact of packaging on device performance, Figure 9 shows there is minimal influence or change in the measured output spectra after the device was bonded to the HV metal packaging. Care was taken to isolate the device from the surrounding package by using an insulation material. A 500 μm glass lid was specially machined for this effort.

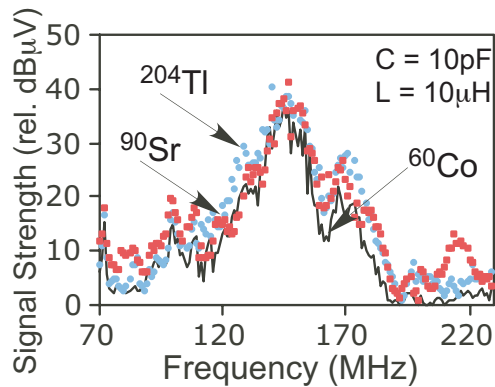


Fig. 8: The RF spectrum of microGeiger discharge in presence of three different radioisotopes (^{60}Co , ^{90}Sr , and ^{204}Tl) using the same circuit parameters gave nearly identical spectra. Taken in AM reception mode.

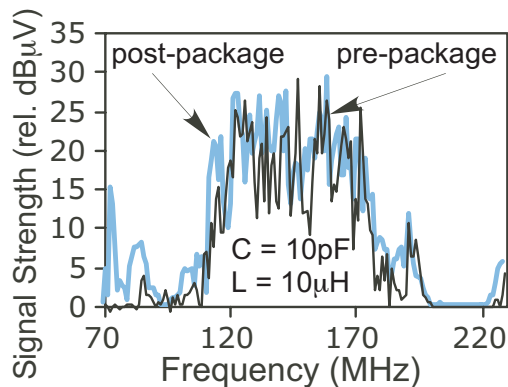


Fig. 9: The effect of packaging the microGeiger in an industry standard high-voltage package were minimal. Taken in AM reception mode.

IV. CONCLUSIONS

With the fast emergence of wireless sensor applications along with new wireless standards, developing distributed wireless sensing networks is very attractive. Utilizing the inherent emission characteristics of discharge-based transducers that do not require additional electronics appears to be a natural evolution. Experimental results have demonstrated that the relative signal strength falls off as observer distance increases. This effort has also shown that the current discharge emitted from within the microGeiger electrodes spans more than 3 GHz, allowing for specific tailoring of bandwidth by varying the bias capacitor, C . It is possible to produce unique RF spectra by varying bias circuit values and configurations, which can then be utilized in network sensing systems. Each sensor could possibly have slightly different spectral shaping bias circuitry that could be used to decode the identity and thereby location of the individual sensor. Tests to determine whether information regarding isotope identity was contained within the inherent microGeiger discharges seemed to conclude that this information is lost or never contained at all. Possible packaging options and their influence on the discharge performance were measured and found to be minimal. Discharge-based transducers have been shown to offer a new advantage in

terms of remote sensing capabilities because of their inherent transmission capabilities.

V. ACKNOWLEDGEMENTS

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