RECENT MEASUREMENTS OF THE FERRATRON: A HIGH-VOLTAGE, FAST RISETIME GAS SWITCH WITH A FERROELECTRIC TRIGGER*

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Abstract

We provide here an update on the status of ferratron development. The ferratron is a high-voltage, fast risetime, gas switch with low-jitter and high repetition rate. It is triggered by the emission of electrons from a ferroelectric device. It may be suitable for phased arrays due to it's low jitter. We have designed and built a test chamber for measuring the output of the ferratron. The test chamber is designed to launch a fast-risetime wave into an electrically large coaxial structure. The transition from gas to oil is accomplished with a polyethylene lens with one surface being a hyperbola of revolution. The goal of the transition is to preserve the risetime of the wave as it transitions from gas to an electrically large oil coax. We provide here preliminary data on the test chamber characteristics, in terms of both TDR (time domain reflectometry) and TDT (time domain transmission). We have included in our test chamber a method of connecting the gap to a feed cable, in order to drive the gap with a known source for calibration. We demonstrate that the risetime of the test chamber in time domain transmission (TDT) mode is around 50 ps, which is sufficiently fast to measure the anticipated 100 ps risetime of the pulses to be generated by the ferratron. We also provide measurements of the switch in a hybrid trigatron / ferratron mode.

I. INTRODUCTION

In this paper, we extend our prior work on ferratrons. As discussed in [1], ferratrons are a class of high-voltage repetitive gas switch with a ferroelectric (FE) trigger. In this work, we develop a new test chamber for the ferratron [2], and we build and test a novel hybrid trigatron/ferratron switch in the new chamber design. Thus, our ferratron measurements were carried out within an improved test chamber that launches TEM waves into electrically large coaxial structures with minimal dispersion.

The switching of Ultra Wide Band (UWB) sources has traditionally been accomplished with either oil or high-pressure gas switches in the self-break mode. While power output in the gigawatt range has been obtained in single-pulse operation, attempts to create a low jitter triggered switch have been difficult, especially for UWB sources.

The work presented here is an extension of prior work carried out to control jitter in a triggered ferroelectric switch. In [1], we demonstrated shot-to-shot jitter values of 63 ps in a train of consecutive pulses at 1 Hz repetition rate, at a few kilovolts, with a ferroelectric triggered gas switch operating at high pressure. This was accomplished using a simple ferroelectric ceramic as the trigger element.

The trigger mechanism is based on the injection of electrons by the ferroelectric ceramic. A key difference between ferratrons and conventional technologies is the small magnitude of the voltage (or electric field) required to trigger the gap. A ferratron operates by injecting electrons from the surface of the ceramic into the gas, and then allowing them to avalanche. Other systems initiate an avalanche by over-volting the gap, or by pumping photons to create photoelectrons. The ferratron injects electrons available from the ceramic surface and provided by the trigger power supply.

We begin with a review of the theory of ferroelectric materials, upon which the ferratron trigger is based. Next, we describe the test chamber, and the calibration procedure associated with it. Finally, we describe a set of measurements made on a hybrid ferratron/trigatron.

II. FERRATRON THEORY

The production of the surface electrons emitted from a ferroelectric material is accomplished by flipping the polarization vector of the ceramic by external means. A sketch of the material is shown in Figure 1. A conduction current can be established by such a mechanism. The polarization-induced charge is the result of using materials with a high dielectric constant (high electric dipole density), which are permanently "poled." The poling process involves the application of a high external electric field (tens of kV/cm) while the material is under a heating/cooling cycle.

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14. ABSTRACT
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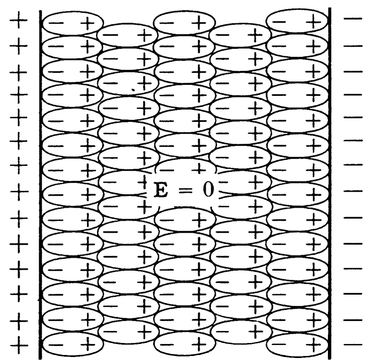

Figure 1. A sketch of the polar nature of a ferroelectric material, from [3].

The electron expulsion scheme is has previously been described in [1]. Briefly, the ferroelectric material consists of an ordered array of dipoles that can be flipped by applying either a positive or negative voltage to the capacitor. When the polarity flips, charged particles that are attracted to the surface are expelled, they flow into the main gap, and trigger breakdown.

The preceding description resolves several issues. First, the charges expelled from the surface are free charges, i.e., free electrons with no ions. Second, the electrons (free charges) are deposited by the external power supply. Third, there is no explosive emission, since no bound charges are being expelled. Last, long pulses are possible by controlling the polarization density and the ceramic's relaxation time.

Note that the current pulse is obtained at the end of the externally applied voltage. This has been observed in most experiments [5]. Also note that relaxation returns the polarization vector to its original state.

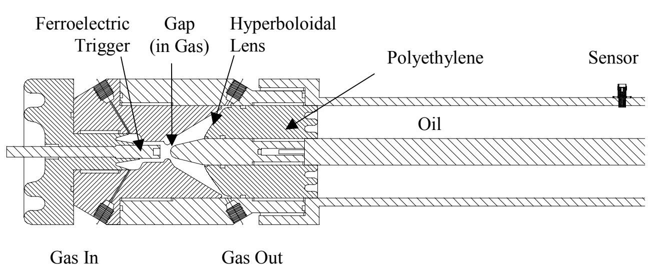

Figure 2. The single switch ferratron configuration.

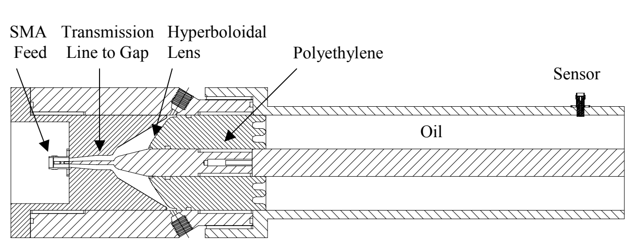

Figure 3. The calibration configuration.

III. THE TEST CHAMBER AND SENSOR CALIBRATION

We begin with a description of the experiments with a single switch. A sketch of the configuration is shown in Figure 2. The center conductor is charged to a large negative voltage, and the trigger is charged to a positive voltage. Gas flows from the trigger into the gap. When the trigger changes polarity, this triggers the main switch to break down. The wave is launched in gas onto a conical transmission line, and the hyperboloidal lens straightens the wavefront into a planar wavefront in the polyethylene and oil. The sensor is a standard SMA or N-type flange connector with center conductor protruding 1.43 mm (0.1575 in) into the oil. This results in a derivative sensor of the electrical field launched into the coax. Not shown in the diagram is a 50-ohm resistive load and a 1nF capacitor that is used to charge the center conductor with the 50 kV (adjustable) dc power supply.

A. Calibration

To calibrate the sensor in the above system, we short out the gap with the center conductor of a coaxial feed cable, as shown in Figure 3. The gap is then driven by a known pulser, the Picosecond Pulse Lab Model 4015C, whose output is shown in Figure 4. Data is then taken at the sensor, and fed into a Tektronix 11801B sampling oscilloscope. The raw data is shown in Figure 5, demonstrating a Full-Width Half-Max (FWHM) of 39 ps. Finally, the integral of the raw sensor data is shown in Figure 6.

To fit the data to a model, we note that the sensor voltage is approximately related to the gap voltage by

$$V_{sensor}(t) \approx K \frac{d V_{gap}(t)}{dt} \tag{1}$$

If we integrate both sides, we find a correction of the form

$$V_{gap}(t) \approx \frac{1}{K} \int V_{sensor}(t)\; dt \tag{2}$$

Noting that both waveforms above are step-like functions, we can take the ratio of their average magnitudes to find K = 0.583 ps. So to convert the sensor voltage to gap voltage, one uses equation (2).

The particular sensor that is calibrated here is an SMA connector with a flange. The center conductor penetrates the outer wall of the coaxial test chamber by 1.4 μm (0.057 in). Other sensor lengths will have a different calibration constant K.

With this test fixture, we can also measure the TDR of the system looking into the main gap from the left. We test this to see if the impedance is a flat 50 ohms, as designed. The TDR is shown in Figure 7, and from this we observe that the impedance is indeed quite flat throughout the test fixture. The only exception is the discontinuity at the load, which is expected.

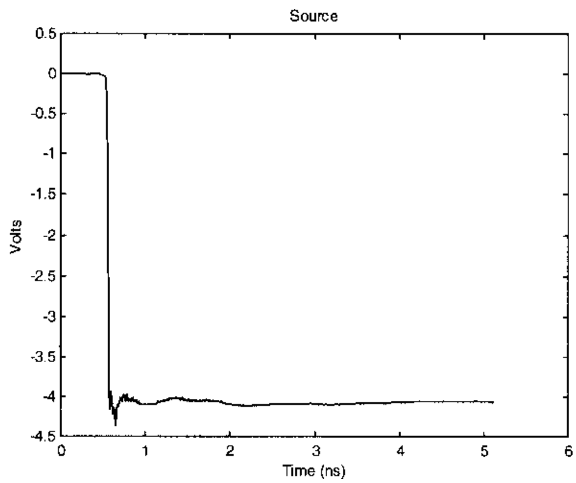

Figure 4. The voltage waveform driving the gap in the calibration procedure.

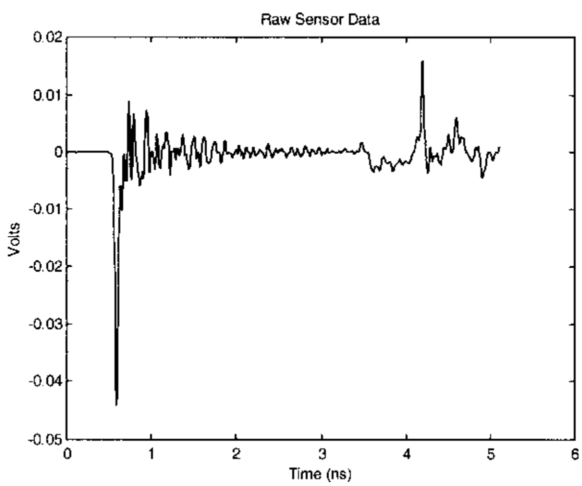

Figure 5. The raw output from the sensor, with FWHM = 39 ps.

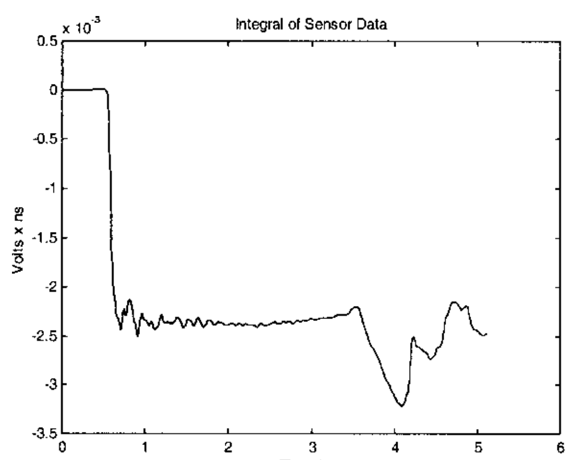

Figure 6. The integral of the raw sensor data, showing a near step-function.

IV. SWITCH EXPERIMENTS

The test configuration is shown in Figure 8. An Instrument Research Company (IRCO) pulser with 6 kV peak voltage is used to drive the trigger. The trigger signal is sensed by a Tektronix P6015A sensor, which is then fed into the trigger channel of a Tektronix SCD5000 oscilloscope. The signal from the sensor is passed through approximately 50 ns of RG-213 cable, before entering the signal port of the SCD5000.

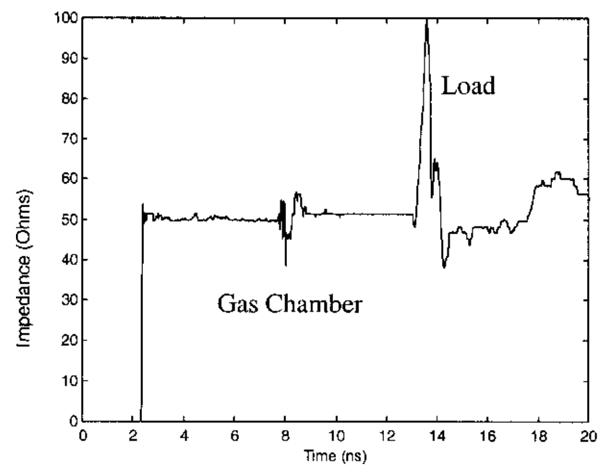

Figure 7. TDR of the test fixture.

The trigger configuration used here is actually a hybrid of a trigatron and ferratron. A diagram of the trigger is shown in Figure 9. In this configuration, the trigger has characteristics of a trigatron, in that it has a pointed end that arcs across to the center conductor. It also has characteristics of a ferratron, because electrons are emitted from the surface of the FE ceramic. The FE is model EBL3 from Stavely Sensor, Inc. and is 0.290 inches in diameter, 0.40 inches in length, with a wall thicknes of 0.0625 inches in diameter.

The main gap voltage was set at 10 kV, and the data was measured with the Tektronix SCD5000, using a trigger signal taken from the Tektronix P6015 voltage probe. A 10 dB attenuator was used to get the data within the 8-volt full-screen scale of the SCD5000. Nitrogen gas was slowly flowing across the gap, at a pressure just high enough to prevent self-break mode.

We overlaid four raw data sets in Figure 10. Because the baseline has a ramp in it, we removed a ramp from the data in order to achieve a flat baseline. The FWHM of the waveforms is around 350 ps and the jitter is about 175 ps. Finally, we integrated the data as shown in Figure 11. After integration, we observed a peak voltage of around 8.0 kV. This is around 80% of the charge voltage, so this is typical for triggered switches.

We believe that the removal of the ramp significantly improved this set of data, and it is a valid operation as long as the superimposed noise is low-frequency. We will consider using the deramping function in future data that is missing a flat baseline.

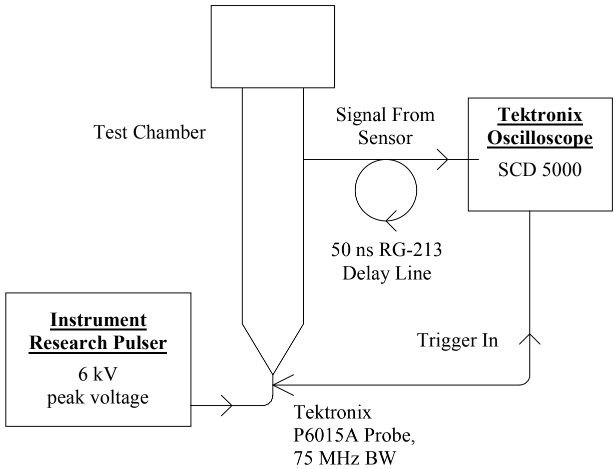

Figure 8. The experimental setup of the single-switch measurements.

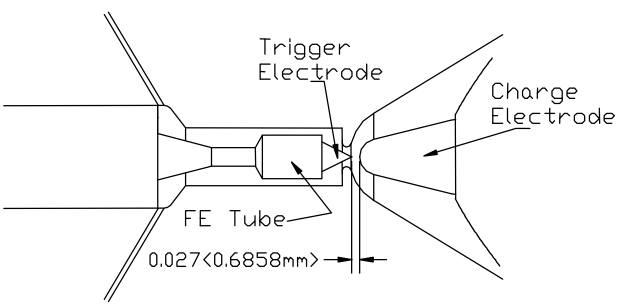

Figure 9 The hybrid ferratron/trigatron trigger configuration.

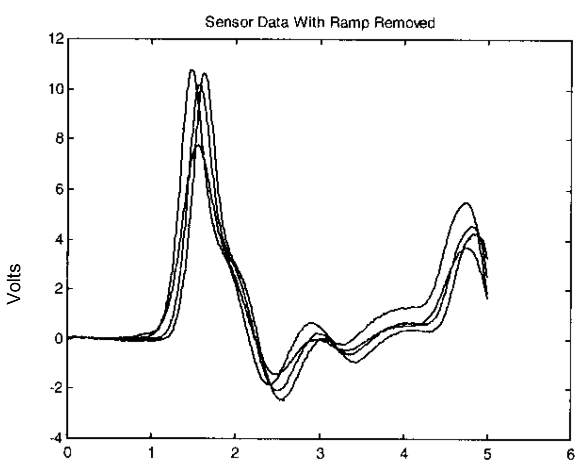

Figure 10. Sensor data after de-ramping. The FWHM is ~350 ps and the jitter is ~175 ps.

V. CONCLUSION

In this paper, we described a new test chamber for UWB gas switches, which had a very fast risetime and allows accurate measurement of the switch characteristics. This chamber was used to measure a hybrid trigatron/ferratron switch, observing risetimes as fast as 350 ps and jitters as small as 175 ps. In future research, we hope to develop a gas switch to be triggered either by a trigatron or ferratron, with goals of 100 ps risetime, 5 ns pulse width, 25 kV peak voltage, and 1 kHz repetition rate. It is intended that he switch, power supply, and trigger generator will all be housed in a single case to be mounted in a 19-inch rack.

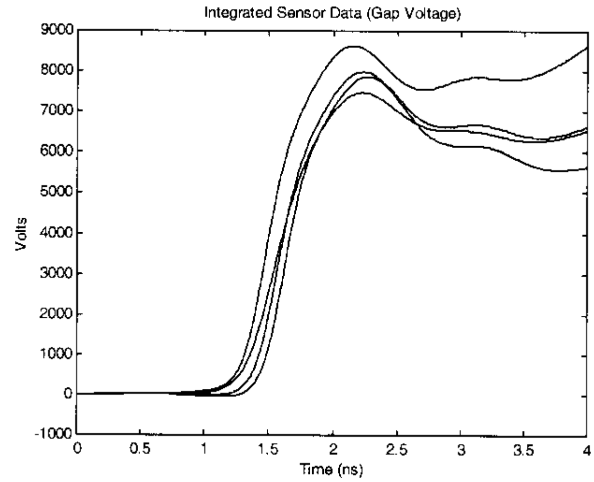

Figure 11. Integrated data, showing voltage at the main gap.

VI. REFERENCES

Note: Switching Notes are published by the Air Force Research Laboratory, Directed Energy Directorate, and are available from the authors, or from the editor of the series, Dr. Carl E. Baum, AFRL/DE, Building 909 3550 Aberdeen Ave. SE, Kirtland AFB, NM 87117

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