1 KHZ REP-RATE OPERATION OF A SPARK-GAP SWITCHED GYROMAGNETIC NONLINEAR TRANSMISSION LINE ARRAY *

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Abstract

This paper details the design, fabrication and performance of a coaxial ferrimagnetic nonlinear transmission line (NLTL), four element array, high power microwave (HPM) system operated at a 1 kHz repetition rate. Prime power is delivered from an 802L TDK Lambda power supply which charges a 5.2 nF capacitor bank up to -40 kV. The capacitors are discharged through a center pin trigatron spark gap. The trigger generator is optically isolated and battery powered for noise immunity and portability. It produces a 20 kV positive polarity pulse with a 20 ns risetime. The high dV/dt (1 kV/ns) is desirable to reduce jitter inherent to spark-gap switching. After the spark-gap switch has closed, the pulse is split four ways. The four pulses propagate through four adjustable delay lines for synchronization of the individual outputs. The four delay lines connect directly into four 76 cm NLTLs with NiZn ferrites where SF_6 is the insulating dielectric. Each NLTL is terminated into a custom fabricated, Rexolite-filled, TEM horn antenna via a zipper balun. Lastly, a LabVIEW based control system automates the whole system using a National Instruments cRIO controller. Experimental observations will include in-line D-dot measurements of voltage waveforms and radiated D-dot field measurements.

I. INTRODUCTION

This paper discusses the implementation of nonlinear transmission line (NLTL) technology in the design of a high power microwave (HPM) source, namely: power, high frequency operation and the general subsystems. The HPM system is a four element array of NLTLs, and this configuration increases the overall power output. The subsystems include: high power capacitor charger; capacitor bank; single spark-gap switch that is reprate capable; high voltage pulse trigger generator that closes the spark-gap switch; NLTL delay line; main NLTL; "in-line" D-dot probe; zipper balun; TEM horn antenna; free-field D-dot; and finally, control system. Each will be discussed in more detail.

NLTL oscillations are dependent upon the magnetic moments of the magnetic material being utilized. This is reason for the nonlinear behavior. The magnetic material implemented in the system is a ferrimagnetic NiZn ferrite. External magnetic biasing is applied axially to the coaxial NLTL aligning the magnetic moments of the ferrite. The incident pulse produces azimuthally directed magnetic fields causing the magnetic moments to rotate around an effective magnetic field. This is called gyromagnetic precession and is the mechanism for oscillation in the microwave frequency band. The effective magnetic field is made up of the azimuthal, axial, demagnetizing, exchange and anisotropy fields.

The Landau-Lifshitz equation explains the dynamic magnetic fields.

$$\frac{\partial \mathbf{M}}{\partial t} = \gamma \mathbf{M} \times \mathbf{H}_{eff} - \frac{\alpha}{M_S} \mathbf{M} \times (\mathbf{M} \times \mathbf{H}_{eff}) \qquad (1)$$

The first term on the right-hand side describes the precession around the effective magnetic field, and the second term describes the damping present which ultimately ends the rotation and bring s the magnetic moments back into alignment with the effective magnetic field. Terms: gamma-gyromagnetic ratio; alpha-damping term; and M_s the magnetizing saturation value of the material

II. EXPERIMENTAL SETUP

The entire system is operated at 1 kHz using an 8 kW TDK-Lambda 802L capacitor charger made by A.L.E. Systems. This charges the 5.2 nF capacitor bank, which is integrated into the spark-gap, to -40 kV in approximately 800 μs. The spark-gap used has the capability to adjust the distance between electrodes and uses pressurized dry air as in the insulator. It is also a center pin trigatron design; and furthermore, the switch is closed used a high voltage pulse trigger generator. This trigger generator is what

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allows the system to fire successively. A few of the characteristics of the pulser include: 20 kV peak, 20 ns 10-90% risetime, modular design for adjustable output voltage or current [1]. Once the spark-gap switch has closed, the energy stored in the capacitor bank is discharged through the switch into the NLTLs via a symmetrical current distribution plate so that each line is excited equally.

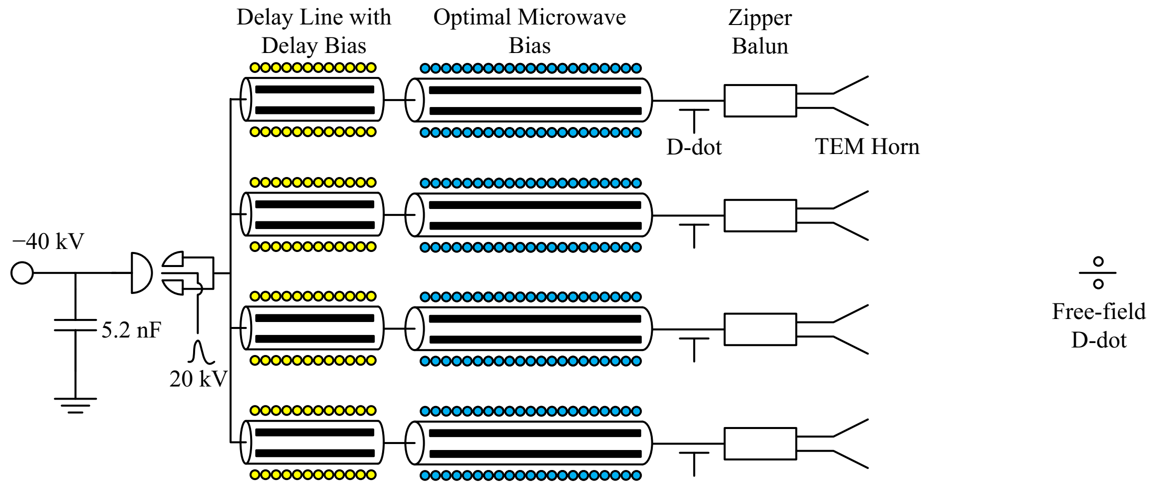

Figure 1. Circuit Schematic of NLTL Array

The incident pulse first reaches an NLTL used for delay purposes. This means that the NLTL is external biased to achieve the right propagation time so that each output is aligned to the others. The external biasing affects the permeability of the material, and this, in turn, affects the propagation time of the line. The longer the line is, the greater the effect of manipulating the permeability.

Now the main NLTL is excited by the propagating incident pulse. This NLTL is externally biased in order to achieve maximum output power at whatever frequency the user desires. The incident pulse has now been transformed into microwave frequency oscillations and is then measured by a custom made "in-line" D-dot probe. The measurements taken from this probe help the user to determine what biasing levels should be applied to each delay line to achieve phase alignment.

Because a TEM horn antenna is used in this system due to its large bandwidth characteristic, a special type of balun must be used in order to transition from coaxial geometry to parallel plate geometry. This balun is called a zipper balun due to its opening and flaring appearance. Rexolite ® is the insulating material for the balun as well as the TEM horn, and both are custom made. Finally, a free-field D-dot probe is used to measure radiation. The probe used is made by Prodyn Technologies, the AD-80 with a cutoff frequency of 5.5 GHz.

All of these things explained above may be seen in Figure 1.

III. RESULTS

Figure 2 demonstrates a 10 shot burst from the system at 1 kHz where each shot is placed over the other with reasonable consistency. The peak field is around 3.4 kV/m measure at 3 m by the free-field D-dot probe.

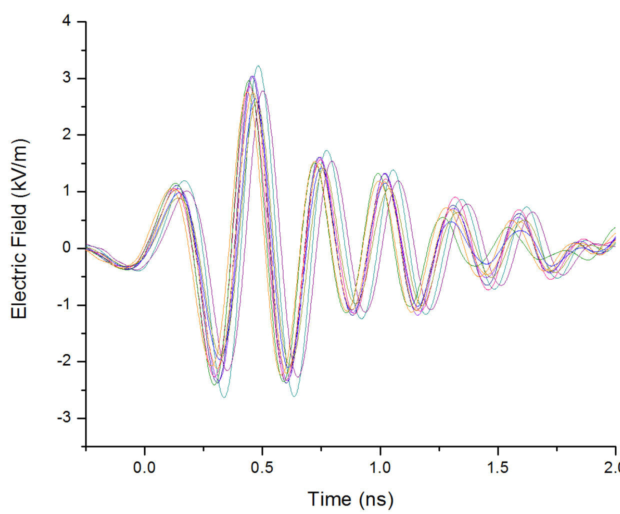

Figure 2. Burst 1, 10 Shots, 1 kHz

Figure 3 is a second burst of 10 shots at 1 kHz with each successive shot also placed over the previous one, again showing decent consistency from shot to shot with peak field levels reaching 3.2 kV/m.

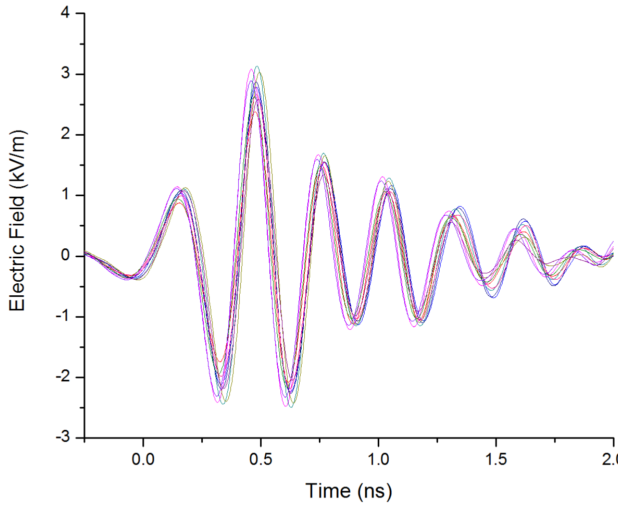

Figure 3. Burst 2, 10 Shots, 1 kHz

Figure 4 demonstrates the dominant frequencies present in each of the four lines of the NLTL system as well as the radiated center frequency superimposed on the four channel frequencies.

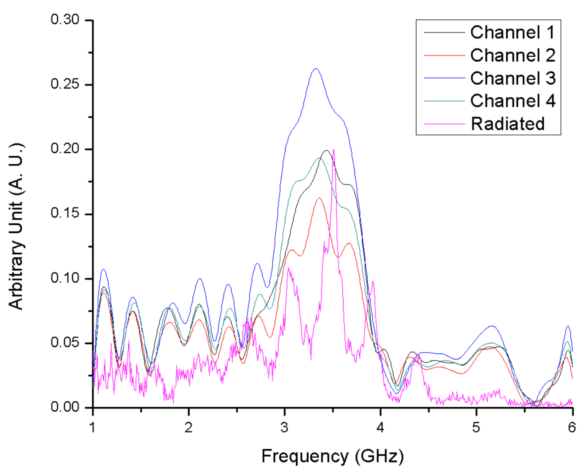

Figure 4. FFT of All Four Lines and Radiated

It may be seen in Figure 4 that each line is very close to 3.4 GHz and the center frequency of the radiated waveform is 3.5 GHz.

As long as the system is charged and triggered as it was designed to do then the NLTL system will produce fairly consistent results like that show in Figures 2 and 3. However, pre- and post-triggering plague the spark-gap switch at high reprates. Figure 5 shows three waveforms. The blue represent a pre-triggered phenomenon where the spark-gap switch "self-broke" before it was triggered, and the red line represent a happening where the gap "self-broke" after the trigger pulse.

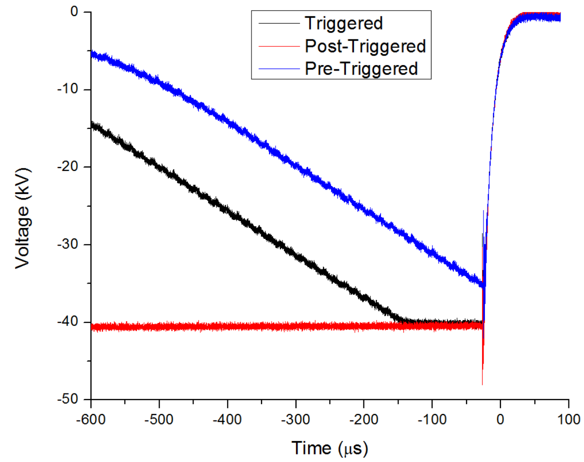

Figure 5. Pre-Triggered, Triggered and Post-Triggered Waveforms During the Charging Cycle

Figure 6 shows charge variability by the prime power source even with properly triggered spark-gap waveforms. There is some inherent inconsistency with the charging supply, but the charge voltages varying 10 kV are due to previous misfires throwing the system out of alignment.

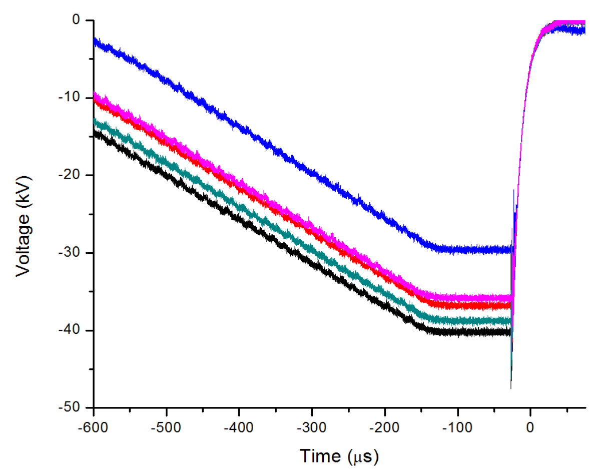

Figure 6. Charge Voltage Variation

Because the charge time of the system is 800 μs and the period of 1 kHz is 1 ms there is very little down time between charging cycle (high duty cycle). As a result, any misfire such as a pre- or post-triggered break can throw the system out of alignment for several shots and even ruin the entire burst. Since the frequency of oscillation for the NLTL system is dependent upon both the external bias field as well as the pulsed field [2], any variation in the charge voltage can throw the lines out of phase from one another and ruin a shot.

IV. SUMMARY

A mobile prototype NLTL HPM system has been created and demonstrated that it can radiated field levels over 3 kV/m at 3 m in the far-field in rapid succession up to 1 kHz. Simple changes to the spark-gap switch system will allow longer pulse trains at 1 kHz.

Future work will include an 8 element antenna array, possibly faster reprate operation at 2 kHz, as well as beam steering and beam scanning.

V. REFERENCES

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