High Power Nonlinear Transmission Lines with Nonlinear Inductance

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Abstract**—**Nonlinear transmission lines have been demonstrated to be an effective technique for generating high power ultrawideband or mesoband radiation without the need for a vacuum system, electron beam, or magnet. Experiments have been performed at UM on a discrete element nonlinear transmission line using nonlinear inductance with input powers of 100 MW. Pulse sharpening of multi-kA input pulses has been observed in addition to the generation of oscillations at the characteristic LC frequency.

Keywords-*Nonlinear Transmission Line, NLTL, High Power Microwaves, HPM, Ferrite, Pulse sharpening.*

INTRODUCTION

Recently there has been intense interest in using nonlinear transmission line (NLTL) circuits for the generation of pulsed microwave radiation [1-5]. The two types of nonlinearities commonly used are nonlinear capacitance based on nonlinear dielectric materials or nonlinear inductance based on ferrite. There has been some success at high power using ferrite based lines for the generation of high power RF bursts [1],[4].

EXPERIMENTS

Several nonlinear transmission line circuits have been constructed at UM for the purpose of finding general scaling laws for RF generation at high power levels. In particular we examine the feasibility of a low impedance NLTL. For a given power, a low impedance circuit operates at a lower voltage than a high impedance circuit, which may be advantageous at high power levels. The circuits are built as discrete element LC transmission lines where the inductance is nonlinear due to the presence of ferrite beads over an inductive interconnect. The driver used for the circuits is a nominally 100 MW, 1 Ω, 10 kV 10 kA spark-gap switched circuit with a rise time of 175 ns into a matched load. The driver circuit contains an internal 1Ω resistance as the output is typically used to drive a short circuit load for the calibration of current diagnostics. A current trace with the output shorted is shown in Figure 1.

The first UM NLTL built was done as a proof of concept to determine if pulse sharpening and RF generation was achievable with a low impedance circuit with a slow risetime due to the available driver. The circuit was built using doorknob style high voltage capacitors and NiZn ferrite beads. The 9 stage circuit uses 3 nF capacitors for the first 3 stages, 1.5 nF capacitors for the next 2 stages, and 0.5 nF capacitors for the last 4 stages. The tapering of the impedance and characteristic frequency was done out of convenience as these capacitors were on hand. The inductance of this circuit at zero current and when saturated was approximately 2 μH versus 40 nH respectively. The ground plane of the circuit was a 4” × 0.029” strip of copper. The ground sides of the capacitors were screwed into the copper sheet and the high voltage side was attached to a 7/16” brass rod around which the ferrite beads were located. The circuit was terminated into a nominally 1.6 Ω load consisting of two 3.2 Ω carbon resistors.

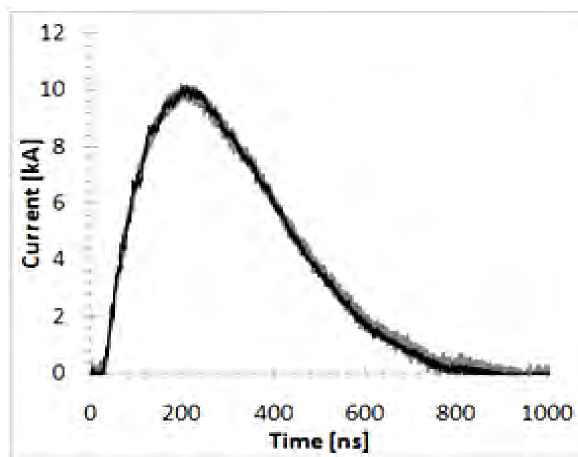

Figure 1. Output into a short (driver contains an internal matched resistive load).

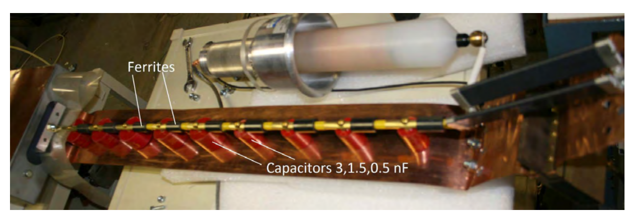

Figure 2. Low impedance proof of concept line.

The voltage across the load was measured with a high voltage probe and the current was measured with a commercial current viewing resistor. A photograph of the circuit is shown in Figure 2. The voltage and current were measured for cases with and without a pre-shot reset current. If the ferrite cores in the line are driven into reverse saturation and left at the bottom remnant point in the hysteresis curve the sharpening of the incoming current rise to 2 kA occurs in less than 20 ns and generation of oscillations is very apparent (top of Figure 3). The bottom graph in Figure 3 shows the same

NLTL with no reset current; therefore the cores are left at the top remnant point of the hysteresis curve. In this case, fewer oscillations are seen and the current rise is much slower, not reaching 2 kA until approximately 50 ns.

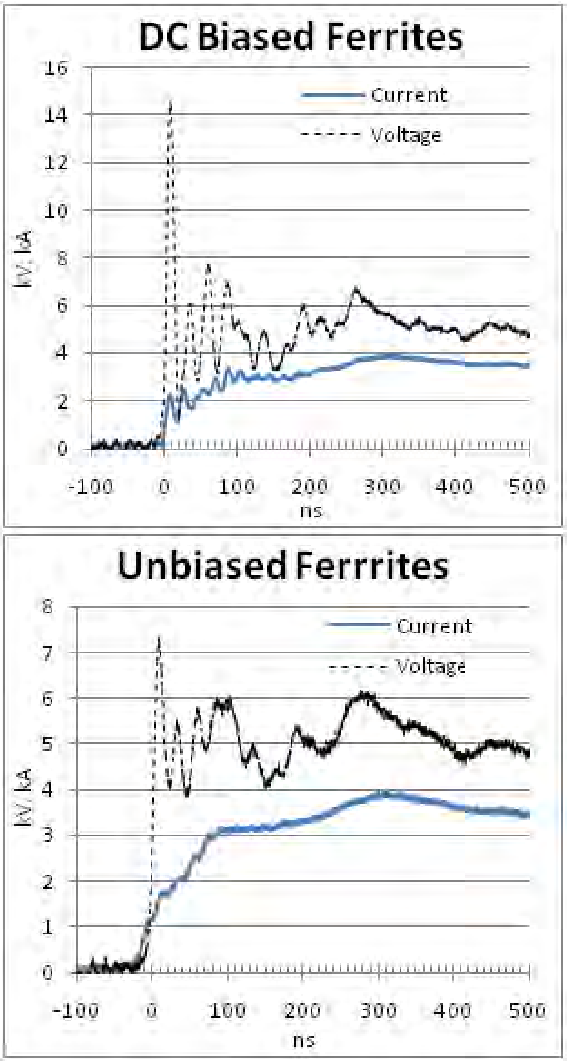

Figure 3.Voltage and current traces from proof of concept line with cores reset (top) and not reset (bottom).

The second UM NLTL that was built had 24 LC stages in order to increase the number of oscillations, as well as the depth of the oscillations, shown in the waveforms in Figure 4. This circuit was similar to the one shown in Figure 2 but used 1 nF capacitors and a slightly different geometry that resulted in a saturated inductance of 21 nH. The ferrites used for this line were MnZn and gave a zero current inductance of approximately 6 μH per stage. The spatially uniform impedance and characteristic frequency of this NLTL resulted in approximately 10 oscillations at a frequency of 36 MHz. This closely agrees with the predicted frequency of 34.7 MHz using the simple relation $f = (L_{sat}C)^{-1/2}/2\pi$ with the measured L_{sat} and C. The average power of the RF oscillations in the signal was 1.4 MW.

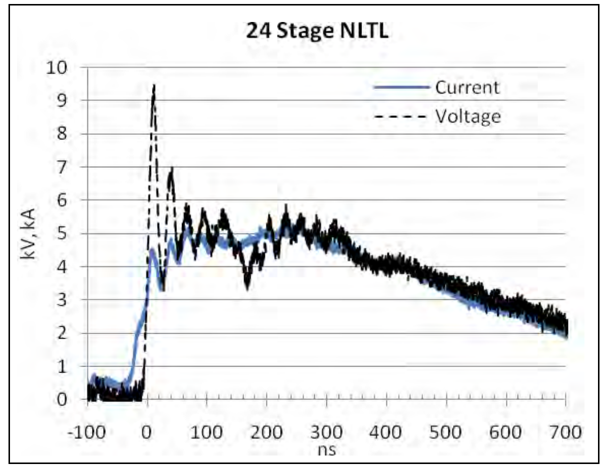

Figure 4. Output voltage and current of 24 stage NLTL.

CONCLUSIONS

We have successfully built and tested NLTL circuits using ferrite inductors at MW power levels. The circuits described here were limited to low frequency due to the slow available driver and the low impedance, requiring high capacitance values. The relatively simple scaling using characteristic LC frequency assuming saturated impedance properly describes the output frequency of the NLTLs considered here. The unfavorable scaling of frequency with impedance appears to make a high power GHz frequency NLTLs at low impedance somewhat impractical.

ACKNOWLEDGMENT

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