12. D. Monzón-Hernández, J. Villatoro, and D. Luna-Moreno, Miniature optical refractometer using cladded multimode tapered tips, Sens Actuator B Chem 110 (2005), 36–40.
13. J. Villatoro and D. Monzon, Low cost optical fiber refractive index sensor based on core diameter mismatch, J Lightwave Technol 24 (2006), 1409–1413.

EFFICIENT GENERATION OF RF USING A BIASED SOLITON GENERATING NONLINEAR TRANSMISSION LINE WITH A BIPOLAR INPUT

Quinn R. Marksteiner, Bruce Carlsten, and Steve Russell
Los Alamos National Laboratory, MS H851, ISR-6, Los Alamos, NM 87544; Corresponding author: qrm@lanl.gov

Received 19 August 2009

ABSTRACT: *A method of generating more efficient RF from a soliton generating nonlinear lumped element, transmission line (NLETL) is presented. A bipolar input is coupled into an NLETL, which is DC, biased to the amplitude of the input pulse. The input evolves into a soliton containing pulse that would take twice as much power to produce from a unipolar input. Simulations demonstrate that, this method increases the maximum RF generating efficiency of an NLETL from 1/3 for a unipolar input pulse to 2/3 for a bipolar input pulse to a biased line, in agreement with simple analytical arguments.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1411–1413, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25170

Key words: *soliton; nonlinear transmission line; RF generation; efficiency; bipolar*

1. INTRODUCTION

A soliton is a solitary wave or pulse that propagates infinitely as a result of a balancing effect between nonlinearity and dispersion [1]. Electrical solitons can be generated by using a nonlinear lumped element transmission line (NLETL) [2]. An NLETL is a ladder network of repeating inductors and capacitors, where the inductors, the capacitors, or both are nonlinear in their response to voltage or current. A schematic of a NLETL with linear inductors and nonlinear capacitors is shown in Figure 1. High power, high frequency NLETLs have been built from periodic transmission lines with nonlinear dielectrics [3–5].

An appropriately designed NLETL that accepts an input pulse with a large DC or low frequency component will break the pulse into a train of high frequency solitons [2]. If the soliton oscillations can be well matched to a linear load, the device has converted a percentage of the input power into high frequency oscillations. A soliton generating NLETL acts like a frequency step-up device. The efficiency of such a device at generating useful RF can be calculated as $Eff = E_{RF}/E_{in}$, where E_{RF} is the output energy in the desired frequency range (calculated from the Fourier transform), and E_{in} is the total input energy.

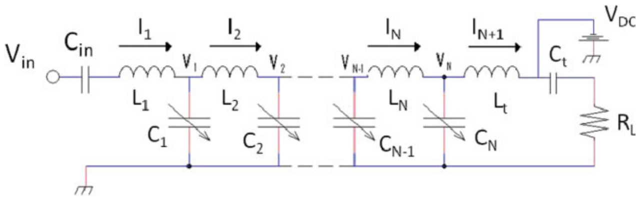

Figure 1 Schematic of a biased nonlinear lumped element transmission line (NLETL), which can accept a capacitively coupled bipolar input. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

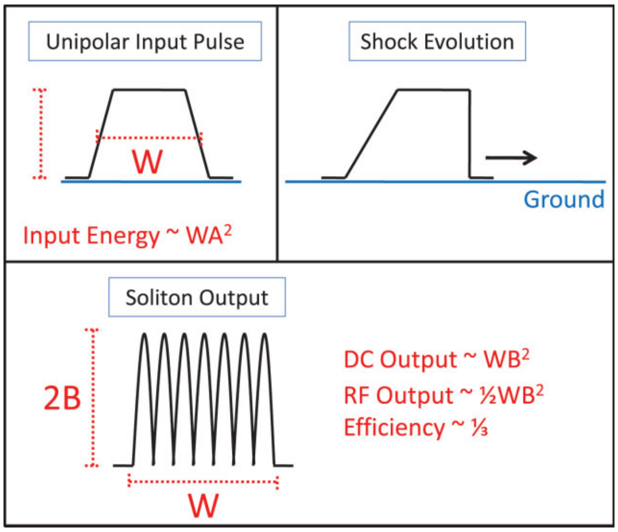

Figure 2 Traditional method of soliton formation from an NLETL, accepting a unipolar input pulse. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

In this article, a method is proposed and demonstrated via simulation, which increases the RF efficiency of such a line by a factor of 2, compared with traditional methods. In this method, the NLETL accepts a bipolar input pulse across a DC blocking capacitor, into an NLETL that has a voltage bias that is near the amplitude of the input pulse.

Figure 2 is a cartoon showing the generation of RF energy from a unipolar input pulse into an NLETL. The rise time of the input pulse sharpens until solitons begin to form. At best, solitons will form so that the minimum between each soliton has a voltage of zero. If the soliton pulse can then be matched to a linear load (which has been demonstrated numerically [6]), then 1/3 of the energy in the input pulse will have been converted into useful RF. The reason for this is sketched in Figure 2: the output of a fully modulated soliton pulse is approximately described by the sum of a DC and an oscillating component, $V(t) = B + B\sin(\omega^2 t)$.

The power in the DC component is $\approx B^2$, whereas the power in the RF component is $\approx B^2/2$. Then, assuming dissipation in the line is negligible and the load is well matched, so that $E_{in} = E_{out}$, we get $Eff = E_{RF}/E_{in} = E_{RF}/E_{out} = 1/3$. Simulations of unipolar input pulses to an NLETL have found RF efficiencies of 1/3, when there is no dissipation, the nonlinearity is appropriate, and the line is long enough for soliton oscillations to form fully [7].

The efficiency can be increased by inputting a bipolar pulse into a DC biased line, as illustrated in Figure 3. As this line is biased, there must be DC blocking capacitors at both ends of the NLETL. As shown in Figure 3, the line is DC biased to a level of $A/2$. Then a bipolar pulse, with voltage $\pm A/2$ on the positive and negative sides, is inputted into the NLETL.

For the sake of comparison, both the positive and the negative sides of the bipolar input (Fig. 3) have the same duration, W, as the unipolar input shown in Figure 2. The power in the unipolar input pulse is A^2, and the duration is W, so that the

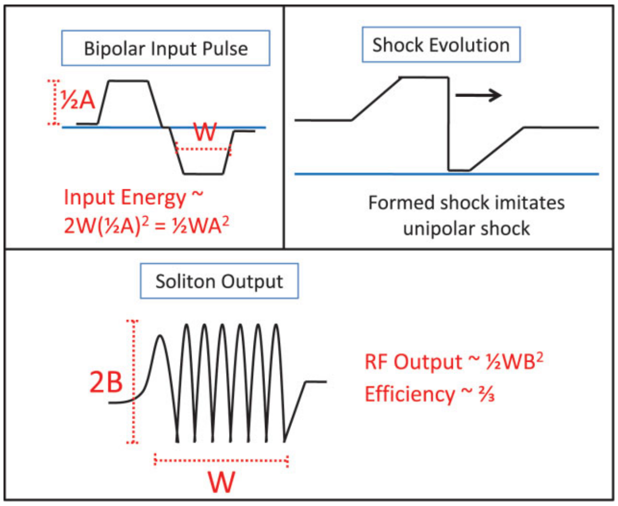

Figure 3 Soliton formation from a DC biased NLETL, accepting a bipolar input pulse. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

total input energy is WA^2. However, the peak power for both the positive and negative sides of the bipolar input pulse is $(A/2)^2 = A^2/4$, and the total input energy is $WA^2/2$.

Despite the fact that the bipolar input in Figure 3 requires only half the input energy, the pulse evolves inside the NLETL into a shock containing waveform that is almost identical in the region of interest to the pulse that evolves from a unipolar input. A similar chain of solitons will form from the bipolar input, and the device will produce approximately the same amount of RF energy out. The efficiency of a biased NLETL accepting a bipolar input will be twice that of an NLETL accepting a unipolar input, or 2/3.

A numerical lumped transmission code was written in MATLAB to test these ideas. The code assumes an absolute capacitance, $C(V) = Q(V)/V$, given by

$$C(V) = C_0[\alpha + (1-\alpha)\exp(-|V|/\beta)]. \qquad (1)$$

For the simulation shown below, $\alpha = 0.2$. Details of this code are given in [7]. The relevant parameters can be made dimensionless in terms of the small signal impedance of the line, $Z_0 = \sqrt{L/C_0}$, where $C_0 = C(0)$, the small signal time constant of the line, $\tau_0 = \sqrt{LC_0}$ (with the small signal frequency cutoff $f_0 = 1/(\pi\tau_0)$), and the parameter β in Eq. (1).

Because of the DC blocking capacitor at the output, shown in Figure 1, the NLETL has a reactive output. This is shown in [7] to improve the RF efficiency. The reactive output is defined in terms of the complex impedance $Z_{\rm i} = \sqrt{L_{\rm t}/C_{\rm t}}$, the real impedance $R_{\rm L}$, and the resonant frequency $f_{\rm t} = 1/(2\pi\sqrt{L_{\rm t}C_{\rm t}}$.

The bipolar input pulse for this simulation is given by the following analytical function:

$$V_{\rm in} = \frac{-A}{0.3} J_2\left(\frac{8.5t}{B}\right)\cosh^{-1}\left\{-\left[\left(\frac{8.5t}{B}-6\right)\Big/C\right]\right\}. \qquad (2)$$

Here J_2 is a second order Bessel function of the first kind. Equation 2 is plotted in Figure 4, and essentially describes a monocycle with a smooth transition to $V = 0$ at $t = 0$. The parameter A approximately equals the amplitude of the pulse, B describes the period, and C controls the relative sizes of the positive and negative peaks (being close to equal when $C = 2.5$).

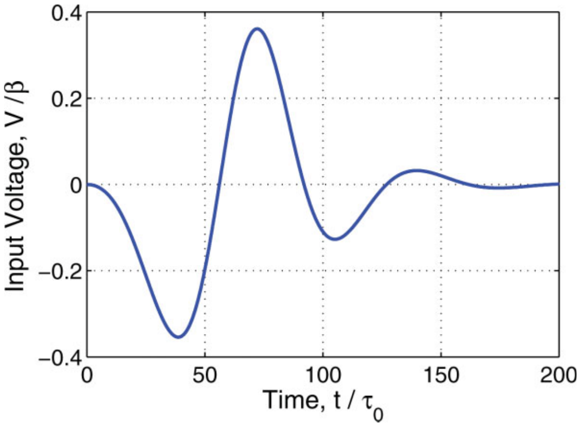

Figure 4 Bipolar input into the DC biased load. This pulse is described by Eq. (2), with $A/\beta = 0.36$, $B/\tau_0 = 92.9$, and $C = 2.5$. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

This function is used to ease numerical calculations: the function is smooth, and the input decays away rapidly enough so that a single bipolar input pulse can be effectively studied.

Figure 5 shows how solitons evolve from a biased line with a bipolar input. The NLETL is DC biased to a value of $V_{\rm DC}/\beta = 0.26$, and the input is the pulse shown in Figure 4. On Stage 1, we see the sinusoidal oscillation in the transmission line. This oscillation brings the total voltage on the NLETL close to zero at its minimum, and near two times the DC bias of the line at its maximum. The low frequency pulse propagates down the NLETL, and steepens because of the nonlinear nature of the capacitors, in the same way that a unipolar input pulse with a long rise time steepens [6, 8, 9]. By Stage 40, the sine-like input pulse has evolved into a shock with a triangular tail. The nonlinearity and dispersion of the line then combine to create solitons with amplitude of four times the peak amplitude of the input pulse. For this simulation, $R_{\rm L} = 2.2\ Z_0$, $Z_{\rm i} = 3.13\ Z_0$, $f_{\rm t} = 0.95\ f_0$, $V_{\rm DC}/\beta = 0.26$, there is a total of 140 stages, and the DC blocking capacitor at the input is set to $60C_0$.

Because the line is biased to a large DC value, the bipolar input pulse evolves into a unipolar shock on the NLETL that has twice the voltage variation as the peak voltage of the bipolar input.

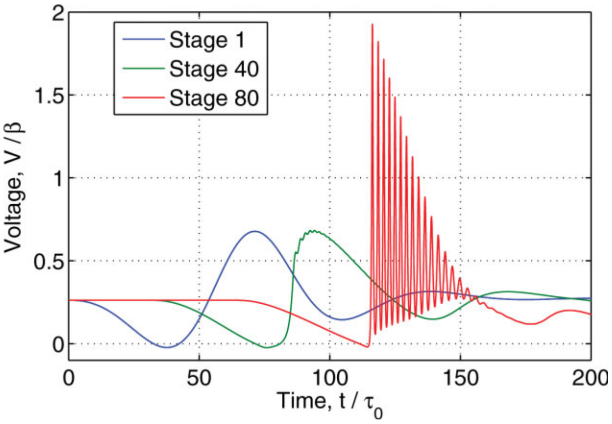

Figure 5 Evolution of solitons from a bipolar input pulse onto a biased NLETL. Here $R_{\rm L} = 2.2\ Z_0$, $Z_{\rm i} = 3.13\ Z_0$, $f_{\rm t} = 0.95\ f_0$, $V_{\rm DC}/\beta = 0.26$, and there is a total of 140 stages. The input is the pulse shown in Figure 4. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

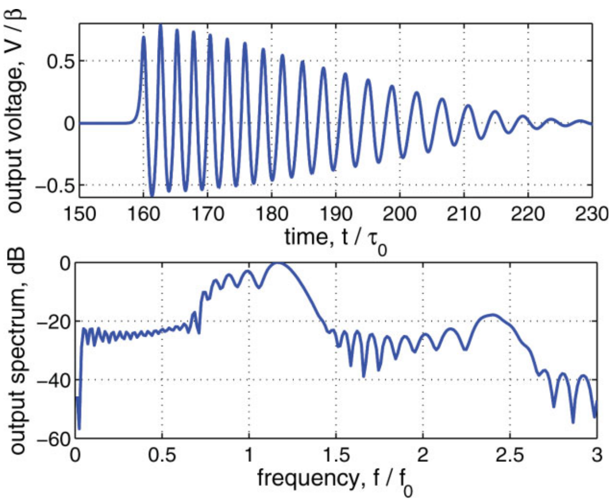

Figure 6 Output of solitons on the resistive load RL, from a bipolar input pulse through a biased NLETL. (Top) Output in time domain; (Bottom) Output in frequency domain. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Figure 6 shows the output of this simulation in the time and frequency domain, with the frequency spectrum calculated from the FFT. Defining RF energy as all output energy $> 0.7\,f_0$, the RF efficiency from this simulation is 0.66. Because the output load is reactive and only absorbs energy in a narrow frequency band, the RF efficiency and total matching efficiency are the same in this case, and the 1/3 of input energy that is not converted to RF is reflected back into the load. The efficiency from this simulation is in good agreement with the predictions discussed above.

The full 140 stages were needed to achieve the maximum predicted efficiency. Using the same bipolar input pulse as before, and the same values of R_L, Z_i, and V_{DC}/β but with only 100 stages on the biased NLETL, the best RF efficiency is 0.43 (when $f_t = 1.1\,f_0$). A large number of stages are needed because the bipolar input pulse has a gradual rise time, and it takes almost 40 stages to sharpen this into a soliton forming shock. Increasing the nonlinearity can lead to faster soliton formation [3], but this increases the matching problems with the linear load and does not increase the RF efficiency of the line [7].

One of the practical reasons for limiting the total number of stages in an NLETL is that conductor and dielectric loss will dissipate much of the energy in the oscillations. This can significantly reduce the overall efficiency of the line [3, 5], for NLETLs with a large number of stages. As both conductors and dielectrics become lossier at high frequencies, the energy dissipated during the initial pulse sharpening stage will be small compared with the energy dissipated after the high frequency solitons have formed. Thus the extra stages needed to sharpen a sinusoidal bipolar input pulse will not lead to significant additional dielectric or conductor loss. Simulations similar to the one described in this article, but including Debye relaxation (using the technique described in [5, 8]), indicate that essentially no power is dissipated during the initial pulse sharpening stages.

ACKNOWLEDGMENTS

The authors would like to thank Max Light, Greg Dale, Lawrence Earley, and Fred Mueller for useful discussions. This project was supported by the JNLWD.

REFERENCES

1. M. Remoissenet, Waves called solitons, concepts and experiments, Springer-Verlag, Berlin, 1996.
2. K. Lonngren and A. Scott, Solitons in action, Academic Press, New York, 1978.
3. H. Ikezi, S.S. Wojtowicz, R.E. Wlatz, J.S. deGressie, and D.R. Baker, High-power soliton generation at microwave frequencies, J Appl Phys 64 (1988), 3277.
4. H. Ikezi, J.S. deGressie, and J. Drake, Soliton generation at 10 MW level in the very high frequency band, Appl Phys Lett 58 (1991), 986.
5. M.P. Brown, High voltage soliton production in nonlinear transmission lines and other pulsed power applications, PhD thesis, University of Oxford, 1997.
6. Y.R. Lin-Liu, V.S. Chan, J.S. deGrassie, and H. Ikezi, Characteristic impedance of a soliton-bearing nonlinear transmission line, Microwave Opt Technol Lett 4 (1991), 468.
7. Q. Marksteiner, B. Carlsten, and S. Russell, Simulations of RF generation using a soliton generating nonlinear transmission line, submitted for publication in J Appl Phys (2009).
8. G. Branch and P.W. Smith, Fast-rise-time electromagnetic shock waves in nonlinear, ceramic dielectrics, J Phys D Appl Phys 29 (1996), 2170.
9. C.R. Wilson, M.M. Turner, and P.W. Smith, Electromagnetic shock-wave generation in a lumped element delay line containing nonlinear ferroelectric capacitors, Appl Phys Lett 56 (1990), 2471.

A NOVEL WIDEBAND MICROSTRIP FRACTAL BANDPASS FILTER WITH A NOTCH BAND AT 5–6 GHz

Justin Church, David West, Pankaj Dagar,
and Satish K. Sharma
Department of Electrical and Computer Engineering, San Diego
State University, San Diego, CA 92182; Corresponding author:
ssharma@mail.sdsu.edu

Received 2 July 2009

ABSTRACT: *This article presents a novel wideband Sierpinski fractal stub-based microstrip filter that provides a notch band at 5–6 GHz. The frequency bandwidth is 103% from 2.89 to 9.0 GHz, which has two passbands of 40 and 25% separated by the notch band. The filter has been designed using full wave analysis tools and has been experimentally verified. The simulated and measured results are found to be in acceptable agreement.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1413–1416, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25194

Key words: *microstrip filter; Sierpinski fractal; wideband; notch band*

1. INTRODUCTION

One of the limitations of the ultra-wide bandwidth (UWB: 110% from 3.1 to 10.6 GHz) communication system is the low-power requirement that prohibits significant power being radiated over other smaller communication bands, such as the wireless local area networks (WLANs) at 5–6 GHz. Basically, UWB wireless communication requires that signal be kept under −41.3 dBm/MHz [1]. Therefore, to prevent the relatively high-powered communication signals from interfering with the low-powered UWB signal, a filtering system is required. Several microwave filter designs have been reported in Ref. 2–5 illustrating novelty that minimizes the filter size and also provides the notch band.