Soliton Propagation Experiment

GENERAL CAUTION: THE SOLITON PROPAGATOR LIKES ***<u>POSITIVE VOLTAGE LOWER THAN 15VOLTS</u>*** ONLY. CHECK APPLIED VOLTAGES WITH THE OSCILLOSCOPE BEFORE CONNECTING TO THE LINE.

<u>General Description</u> The soliton propagator is a transmission line in which the capacitance of each of the capacitors depends on its applied voltage. To get anywhere with this experiment you'll need to know what a transmission line is and why such a line should be interesting. Look for descriptions of how transmission lines behave. Teach yourself the basics. You could start by looking for "The Telegrapher's Equation", which provides the basic understanding of how a discrete set of elements lead to a 1-dimensional medium that is expected to support wave propagation, and which explains how the velocity of the waves depends upon the discrete elements. When thinking about velocity of propagation take the length of an element on the line to be the distance between identical parts of adjacent inductors.

<u>Procedure</u>

1. (**a**) Measure the phase shift of Vout relative to Vin as a function of frequency, from 0 to 20MHz for LOW AC voltage (<0.1V p-p). Calculate velocity vs. frequency.
   (**b**) Measure the dependence of the phase shift (velocity) on the magnitude of a DC bias applied in addition to the AC.

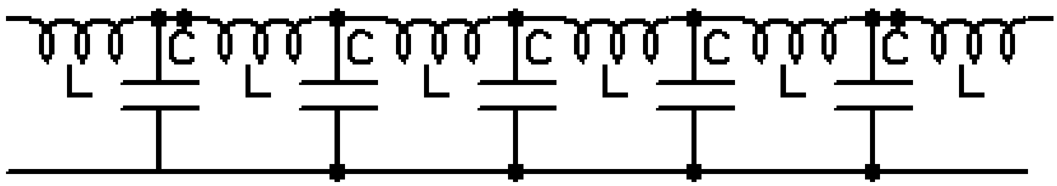
2. (**a**) For a 100nsec long triangular pulse train measure the propagation delay (velocity) vs. pulse height (< 15V peak).
   (**b**) For a 5V peak pulse measure the propagation delay (velocity) vs. applied DC bias voltage.

3. Study what happens with two pulses on the line, (5V peak and 15V peak triangles). One of these might be slower (which one?) and, if launched first, will be passed by the other. This process will alter the propagation delay due to the voltage effect.

Problems

These problems are designed to help you understand transmission lines, transmission lines with nonlinear elements, and the basic physics underlying solitons on such lines.

1. Ideal transmission lines: Our transmission line is composed of repeated sections that contain a series inductor and a capacitor to ground. The circuit schematic looks like this:



The circuit is a repeated set of cells, with a certain amount of series inductance and parallel capacitance in each unit length of the circuit. The 'Telegraphers Equation' determines the properties of this type of circuit by going to the continuum limit of a smooth inductance and capacitance per unit length, and an infinitely long transmission line. Under those conditions, you find that sinusoidal waves will propagate with a common speed. Assume that each repeated section is composed of a series inductance of 10 nanohenries and a capacitance to ground of 100 picofarads. Also, presume that the components occupy a region of space that is 5 millimeters long. Determine the expected wave velocity and the 'characteristic impedance' of the line assuming the continuum limit.

2. 'Dispersion' on transmission lines: For a transmission line like a piece of coaxial cable, where the capacitance and inductance really is continuously distributed, it's easy to imagine that the continuum approximation is pretty good. We expect a piece of coax to continue to behave like a transmission line for arbitrary frequency waves as long as the materials (the conductive metals and dielectric between them) continue to behave the same for all frequencies (that eventually does become a poor assumption). However, for a transmission line composed of discrete elements, such as the line you'll use for this experiment, you are pretty certain that something is going to change when the wavelength of a wave becomes similar to the spatial extent of the discrete components. For a wave whose length is twice the spacing between discrete LC sections, what happens is this: Half the

wave fits inside one discrete section. The other half fits inside the neighboring section. These two halves oscillate without moving. The wave becomes a standing wave that sits locked into the spacing of the components. Electric and magnetic energy oscillates back and forth between the capacitor and the inductor, but the wave doesn't go anywhere.

As in Problem 1, you know that long wavelength waves travel with some speed. However, waves that are short enough to be twice the component spacing have a speed of ZERO. In general, waves are found to have a speed that varies with wavelength, going smoothly from a maximum value for longest wavelength (very nearly equal to the value you calculated in Problem 1) to zero for wavelengths that are twice the component spacing. This variation of speed with wavelength (and therefore with frequency) is called DISPERSION. <u>Use a component spacing of 5 mm and the speed you calculated in Problem 1 to estimate the frequency of wave that will have zero velocity. For this problem, just assume that the dispersion (change in speed with frequency) is a straight line. It is not a straight line and this fact is critical in soliton propagation, but we are looking for a rough estimate here.</u> Now you understand why it might be fun to measure wave velocity for different wave frequencies.

3. <u>Nonlinearity</u>. Normally, we think of a capacitor as having a fixed capacitance, independent of the charge stored (or the voltage drop across the capacitor). Obviously, this assumption is an idealization: Eventually, if the voltage drop is high enough SOMETHING bad is going to happen and the capacitor will 'change' (lightning bolts, melting, etc.). Usually, we think of this type of 'nonlinear' response as a bad thing, but it can be intentionally designed into the circuit elements to do useful things. For the Soliton Experiment, we use a transmission line built from capacitors, each of which has a capacitance that changes with the voltage across the capacitor. These circuit elements are referred to as 'varactors' (guess why). In any case, these varactors are made by forming a PN junction diode. We call them 'semiconductor varactor diodes'. The diodes conduct electricity well in one direction (they behave like a very low resistance), but not in the other (then they behave like an open circuit i.e., still have some capacitance). That's why you want to be sure to apply voltages to your transmission line of POSITIVE VOLTAGE difference across the varactors. Then, they behave like capacitors.

Further, in the non-conducting region where the varactor behaves like a capacitor, the capacitance value depends upon voltage. They are used not so much as rectifiers, but as variable capacitors in circuits. If you want to have a variable capacitor, say for tuning a resonant circuit, and you want the tuning to be done electronically, rather than having a knob to the front panel, then a varactor diode is what you want.

The varactors in our transmission line are made by Zetex Semiconductors. Assume that the varactors are Model 836A. Use the Zetex datasheet for the 830 Series varactors and estimate the wave velocity on the transmission line assuming a dc voltage of 5 Volts and very small ac wave voltage amplitude. Why is it important to assume a small ac wave amplitude? When we say 'small amplitude' explain what 'small' means. Small compared to WHAT? List at least one thing you could use such a line for if you were interested in manipulating sinusoidal waves in some electronic circuit. Now you know why it might be fun to measure wave velocity for different voltages applied to the transmission line.

4. Nonlinear and dispersive propagation. Fourier tells us that, any arbitrary time-dependent signal can be decomposed into a sum of sinusoidal contributions. In the case of an ac signal, of wavelength, λ, and angular frequency, ω, traveling on a transmission line, the wave is of the form:

$$V(x,t) = V_0 \sin\left(\frac{2\pi}{\lambda}x - \omega t + \phi\right)$$

Nice, because it is already written in terms of a Fourier decomposition. For a more general shape, we expect that the wave is composed of a sum of these sinusoids with different frequencies and phase shifts and amplitudes.

Because of dispersion, we expect different speeds for the different possible wave frequencies. Therefore, for a more general wave that is composed of several different sinusoidal contributions, you expect that the shape of the wave will change with time as the different sinusoidal frequency components travel with different speeds. BUT:

Because of nonlinearity, we expect different speeds for the different possible wave amplitudes. Therefore, for a more general wave that is composed of several different sinusoidal contributions of different amplitudes, you expect the shape of the wave will change with time as different components travel with different speeds.

A soliton is a particularly shaped wave that balances these two effects to give a shape that does not change as the wave travels.

<u>Compare the propogation of two square pulses of the same width, but different pulse heights. Which one travels faster (or do they travel at the same speed)? Give a rough explanation of your answer, using the ideas above.</u>