# Where's the Loop?

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Today we're going to have another quiz!

**Figure 1** illustrates a driver connected to a receiver by a trace which we have designed as a 50 Ohm transmission line. The trace is referenced to a ground plane, to which both the driver and receiver are connected. Let's say the trace is 3 nsec long. The driver applies a step function signal of 3 Volts to the trace and that voltage wave begins to propagate down the trace toward the receiver. Since the trace is 3 nsec long, it takes three nanoseconds for the voltage (signal) to travel between the driver and the receiver.

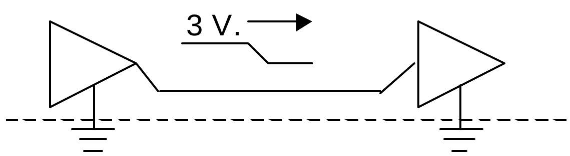


Figure 1
Driver sending signal over transmission line to receiver 3 ns away.

Now, current is the flow of electrons. Two fundamental laws in electronics are (a) current flows in a closed loop, and (b) current is constant everywhere along a loop.

So, here's the problem. Is it a contradiction that it takes a finite time for the signal to travel from one end of the trace to the other AND that current is constant everywhere in the loop? Can both these statements be true at the same time? Which of the following do you think is most correct?

1. The law that states current must be a constant is a "steady state" law and may not apply to transients with nsec time frames.
2. There is no current flowing along the trace until the voltage reaches the load at the far end of the trace.
3. The current laws apply to average current, but there may be short term, transient variations around that average.
4. There is no contradiction (even if I can't define what the correct "loop" is.)

If we have a 50 Ohm trace (or transmission line) and apply a 3 Volt signal to it, Ohm's Law applies. So there *will be* 60 mA current flowing into the trace (3 Volts/50 Ohms) as soon as the voltage is applied. So much for choice 2! The current and voltage will travel sort of in "lockstep" together down the trace. You can think of them as if they were a "wave" (which in fact they are!)

**Figure 2** helps us visualize what is happening. Figure 2 illustrates how we "model" a transmission line. We think of a transmission line of being made up of an infinite string of inductors and capacitors. The inductors represent what we call the "intrinsic inductance" (Lo) of the line, and the capacitors the "intrinsic capacitance" (Co) of the line. The "Characteristic Impedance" of the line is given by the relationship:

$Zo = (Lo/Co)^{.5}$

In our illustration, Zo equals 50 Ohms.

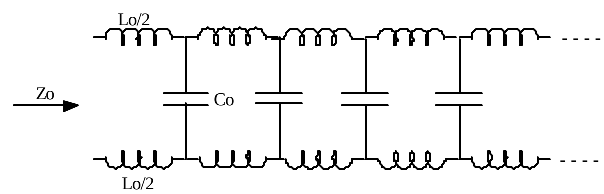


Figure 2
Lumped constant model of a transmission line.

Now here is the part that can be hard to see. As the voltage wave "passes by" a capacitor, the capacitor must charge up – to three volts in this example. That means electrons must flow onto one plate of the capacitor and flow off from the other plate – i. e. current flows "through" the capacitor. The **return** current flows off the opposite side of the capacitor and back to the driver.

As the voltage wave passes by one cap, that capacitor charges up and current then stops flowing through it, but begins flowing through the next one. In this way, there is a constant current flowing down the line and returning back to the driver, flowing through "each" capacitor in turn along the line. Thus, current ***is*** flowing in a loop and it is a constant everywhere in the loop. The loop is (approximately) defined by the distance from the driver to the front of the voltage wave, from there through the intrinsic capacitance of the transmission line (which is charging at that point), and then back to the driver.

Now please understand that Figure 2 is a "discrete" or "lumped constant" model to help us

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visualize what is happening. In truth, the inductance and capacitance are "continuous," or "distributed" effects that cannot be easily visualized. One way to try to visualize this is to consider them to be very small (infinitely small) and therefore *very* close together. Since the effect is really a "continuous" one, it occurs at every point (not just discrete points) along the line.

So, there is no contradiction to the scenario we opened with. Even though the waveform propagates down the line with finite speed, and may take some finite time to reach the receiver at the far end, current is still flowing in a defined loop and is still constant at all points along that loop.

But perhaps this scenario helps us visualize another potential problem. Suppose the impedance changes at some point along the line (either because the intrinsic inductance, capacitance, or both change.) At that point there is a certain, defined amount of energy available (3 Volts at 60 mA). If, for example, the intrinsic capacitance has increased, then the waveform cannot charge the capacitance fully as it goes by, and the voltage drops as a result of the increased load. This causes a distortion in the voltage waveform which becomes a distortion of the signal flowing down the trace, often referred to as "noise". This illustrates why it is so important that the impedance of a trace remain *constant* when propagation times become significant.