The Magic in a Quarter Wave

Meet Eli the Ice Man

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Many Radio Amateurs construct simple J-pole antennas for 6 meters and 2 meters, so let's take a look at how and why they work. The principle can be used at any frequency, not just at the 50 or 144 MHz bands.

An article by Ed Fong, *WB6IQN*, in the March 2007 issue of *QST Magazine* discussed a dual-band J-pole. Ed referred to the use of a Smith Chart, but let's take a simpler approach to explain how a J-pole works.

We'll also look at a second ham-shack application. It will show how you can use two quarter-wave sections of coaxial cable to replace a mechanical T/R changeover relay.

In The Beginning

Start by considering a quarter-wave length piece of transmission line. Although the principles apply to coax or twin-lead, let's conceptualize by discussing twin-lead.

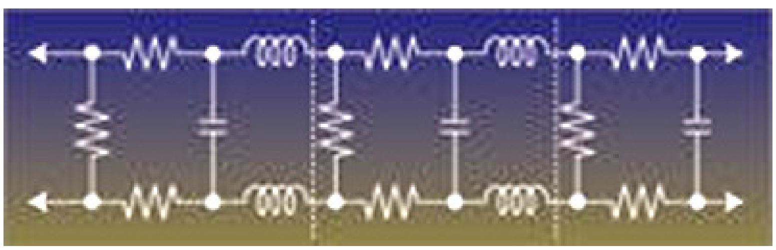
Twin-lead is the stuff that's readily available these days, as opposed to true open-wire line. Twin-lead, also called ladder line, is what's usually used in a roll-up 2-meter J-pole. J-pole antennas can also be made out of copper pipe or aluminum tubing.

Let's say you have a chunk of ladder line that's a quarter of a wavelength long at the frequency you're interested in (assume for the moment the *velocity factor* -- the delay imposed on a signal propagating through a transmission line -- isn't a factor).

For starters, keep the ladder-line open at both ends. That is, the two parallel wires are free at the ends, and not jumpered or shorted across the insulation.

Think of the wires themselves as inductors. Sure, the wires aren't in the shape of coils, but they do act like coils. The line is made of two pieces of wire, and isn't a coil (inductor) made of wire? The invisible field around the wire when current flows is a magnetic field.

Now, think of the space between the two conductors of the twin-lead. There's no wire bridging them, but there is insulation, so the wires act like the plates of a capacitor, and the insulation acts like the capacitor's dielectric.



There's capacitance between the two conductors. The invisible field between the wires is an electrostatic field.

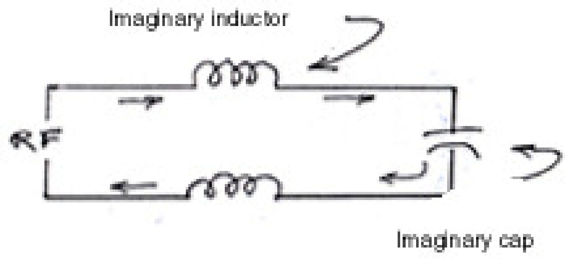
There's also a bit of DC resistance to the wires. But it is very low.

Two Fields In The Universe

We've now accounted for the two fields in the universe. One is electromagnetic, and the other is electrostatic.

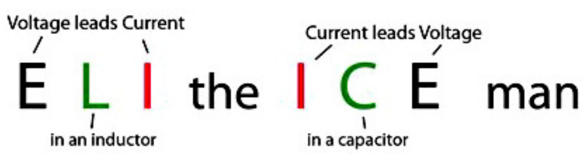
If the quarter-wave line is open at both ends, you could think of the whole shebang as two coils in series with a capacitor. The capacitance is distributed along the space between the wires, and the inductance is also distributed along the length of the wires. Again, the capacitance (C) and inductance (L) are essentially in series.

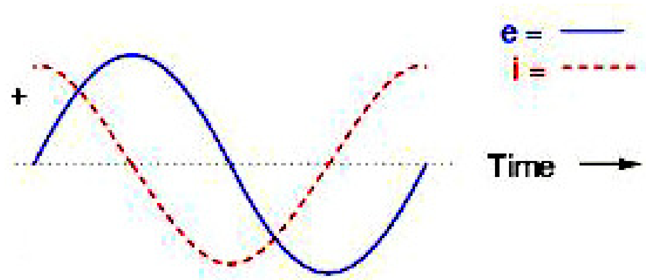
If you crack a beginner’s theory book and look at how L and C affect the difference between voltage and current, you’ll probably come across *Eli the Ice Man*.

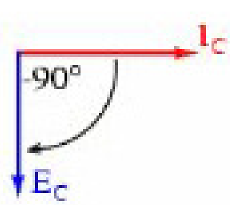


What’s this? You don’t know about Eli the Ice Man? It’s a mnemonic way to remember that alternating RF voltage (E) leads current (I) in an inductor (L). In this catchy little phrase E comes before I in the word “Eli.”

Conversely AC current (I) leads voltage (E) in a capacitor (C). The I comes before the E in the word “Ice.”





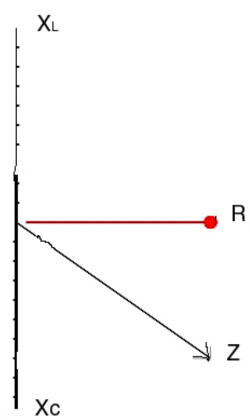


Consider, too, how an inductor or capacitor affects current and voltage. Inductance causes what's called *inductive reactance* (X_L). Inductive reactance is opposition to a *change* in the flow of current. This reactance is measured in ohms.

For its part, the capacitance in a circuit causes opposition to a *change* in voltage. That opposition is called *capacitive reactance* (X_C). The reactance is also given in ohms.

You probably learned about the Greek philosopher Pythagoras (570 – 495 B.C.) and his famous theorem in high school geometry class. If you go to the trouble of drawing what's called a vector diagram (nothing more than a way to visually show X_L and X_C using the *Pythagorean Theorem* and a right-triangle), you'll find that at a given frequency, X_C can equal X_L in value (ohms).

But, because the effects are equal and opposite, they cancel. Only the resistance, R, is left.



X_L and X_c are almost equal in magnitude but opposite in direction on this vector diagram. The hypotenuse shows the resultant of X and R. This is called the resultant vector, and is called Z, for impedance.

Note that X_L is at a right angle (90 degrees) to R. So is X_c, below the vector line depicting the value of R. That's because they lead and lag by 90 degrees, respectively. In this diagram capacitive reactance dominates by a bit, thus the resultant, Z, is drawn below the horizontal line showing R. If X_L and X_c happened to be exactly equal only R would be left.

The only thing remaining to oppose any AC current in your transmission line (a circuit of L and C in series) is the DC resistance of the wiring itself, R, and maybe some leakage current in the insulation in the capacitive path (also R).

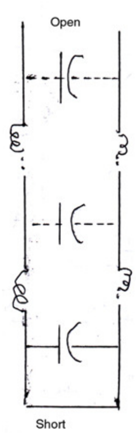
The copper wire resistance is really low, and can be considered negligible. Ditto for any leakage resistance.

Again, L and C are in series, so X_L and X_C cancel. The open quarter-wave transmission line section appears as a low-impedance (low Z) at the near end (the end where you might apply RF from your transmitter).

The Shorted Line

Now consider what happens if you actually physically short one end of the quarter-wave line, perhaps by soldering the two leads together. Obviously the shorted end is a low impedance; it's actually zero ohms for all practical purposes if you did a good soldering job.

The distributed inductance in the two wires is actually now bridged by the capacitance between the wires. Therefore the L and C are in parallel now; no longer in series.



This parallel LC circuit is also drawn vertically here, as a J-pole's matching section might be drawn.

This parallel LC circuit presents a high impedance at the far end away from the short.

Think of this as the opposite of a series LC circuit. Some folks refer to a parallel LC circuit as an anti-resonant circuit.

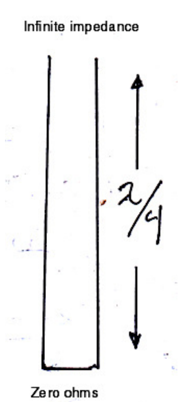
Get Practical

The reason a half-wave-long antenna and “tuner” works is because the antenna is fed with a network that transforms your rig’s low 50-ohm output impedance to a high impedance, feeding the end of the wire. The ends of a half-wave antenna are high impedance points.

The middle of the antenna is a low impedance. That’s why some hams cut a half-wave wire in the middle and feed it with low-impedance (usually 50 ohm) coaxial cable. Amateurs call this a dipole, pumping current into the (roughly) 50-ohm point, as opposed to tickling the ends of a half-wave wire with voltage.

Experienced antenna gurus call the ends of a dipole “voltage points.” The voltage feedpoint impedance can be thousands of ohms. Very little current flows into the antenna at that feedpoint.

Let’s go back to our shorted quarter-wave section. It's zero ohms at the shorted end, and very high impedance at the other end. The high end is not really infinite impedance, but it does exhibit quite a high impedance there, if we could measure it.

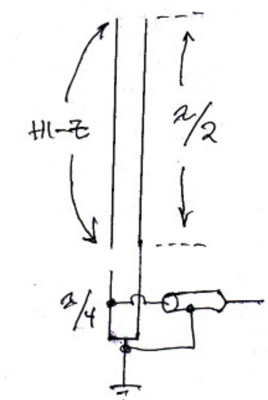


In a J-pole the vertical portion of the antenna is a half wave long. The feedpoint of that half wave antenna could be at the center, in which case you'd have a center-fed dipole, and you could feed it there with low-impedance 50-ohm or 70-ohm coax. But the J-pole is fed at the bottom end (that helps avoid nearby coax from distorting the antenna's radiation pattern).

A Match Made in Heaven

Here's the cool part. Putting a quarter-wave section at the bottom can make a match to the high impedance point of the end-fed half-wave wire or pole. The bottom of the quarter-wave is shorted, and the far end is open, or high.

Just a tad up the quarter-wave section you can tap in to find 50 ohms, and connect your coax there to get a 1:1 VSWR on the coax.



The quarter-wave section in this J-pole is tapped near the low-Z end to match to some 50-ohm coax. The value of 50 ohms is quite low, so it's close to the shorted end of the matching stub.

The J-pole can be made for 80 meters or 2 meters, or whatever frequency you wish. In the days of dirigibles a half-wave was trailed astern, and a quarter-wave section of transmission line was sometimes used to match it, with a low-impedance feed point inside the Zeppelin. Call that antenna-plus-feedline a Zepp.

Look Ma, No Relays

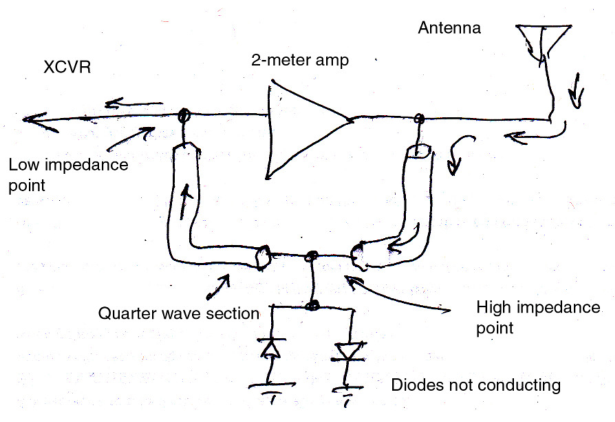
The same principles can be used to eliminate mechanical DPDT changeover relays in amplifiers. This works if an amp is going to be used on one frequency.

In a 2-meter 50-watt amplifier I built I cut two pieces of coax, making two quarter-wave lines. As a practical matter I figured-in the velocity factor when cutting the coax to length.

One line was connected to the RF input side of the amplifier, near to its coax connector. This is the point where my 2-meter transceiver that drives the amplifier is connected. The other quarter-wave section is placed at the coaxial output connector of the amplifier, where the amplifier feeds power to the antenna.

The inside conductors at the far ends of the two coax sections are connected together, and I placed two silicon diodes, like the kinds you use in a power supply's rectifier, at the junction of the two coax sections. The back-to-back diodes are placed at the far ends of the individual sections, with one end of each diode grounded.

Both coaxial cable sections share the diodes. When receiving, relatively weak signals (typically microvolts) from the antenna are fed to the RF antenna connector on the amplifier. The sections of the coax are open (not shorted at the far end), therefore the input looks into a low impedance and tiny signal currents flow into the coax, shown by arrows in this diagram.



At the diode end, the impedance is high. The voltage across the back-to-back diodes isn't high enough to cause them to conduct, or "turn on" (the voltage is lower than the 0.6V to 0.7V needed to cause the diodes to conduct).

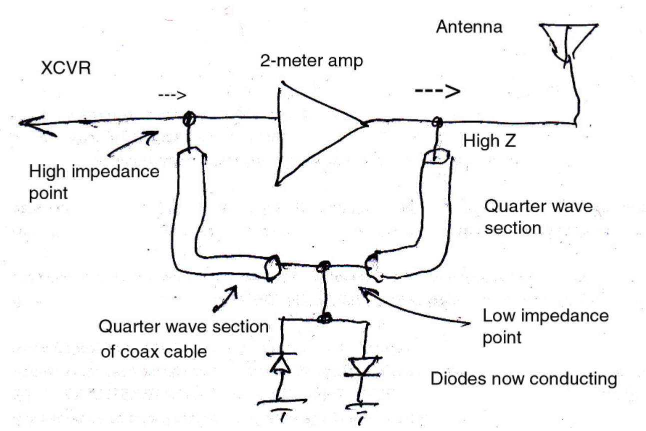
In effect, the diodes are "invisible" to the received signal coming from the antenna. The signal there would see the other quarter-wave section, and that would be a good match. At the opposite end of the second section the impedance would be low, and the signal would flow into the receiver.

Hit It With RF

Now consider what happens when the PTT button on the rig's microphone is closed, or the Morse key is depressed. A fairly high level of RF, usually some volts of RF, is applied from the rig to the coax line at the input port of the amplifier. Some of this RF appears at the other end of the line. The sensitive diodes conduct (on opposite halves of this alternating RF wave), as the RF voltage across the diodes is higher than 0.7 volts.

The conducting diodes now comprise a low-impedance point, which is nearly a short. Well now, there's a shorted quarter-wave section, eh? The opposite end is therefore a high impedance point. As such, little RF flows into the line. Instead, it goes into the input portion of the amplifier, so the transistors or tubes in there can be excited.

At the output of the keyed-up amplifier there's also a quarter-wave section, and it also looks like a high-impedance point. As such, very little RF will flow into that section. Instead, the RF current flows out of the low-impedance 50-ohm output coax connector of the amplifier and into your antenna's feed line. Voila, RF changeover without relays!



Here the 2-meter xmtr's output sees high impedance at the first coax section. RF chooses to flow into the low-Z input of the amplifier block instead. The same is true of the output, where the high RF flows into the antenna.

If you look at the March 2007 issue of QST you'll find another article, this one authored by *W1ZR*. He looks at the physics of quarter-wave sections more closely. You may also want to re-read *WB6IQN*'s explanation of his dual-band J-pole. It uses two quarter-wave sections as well; one on 2 meters and one on 450 MHz.

Once you catch on to this little trick I think you'll find ways to make your station gear and antennas work more efficiently and effectively.

Questions or comments: E-mail: ai2q@arrl.net

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