Quarter Wave Transformers and how they are used in a 3dB T-junction Power Splitter
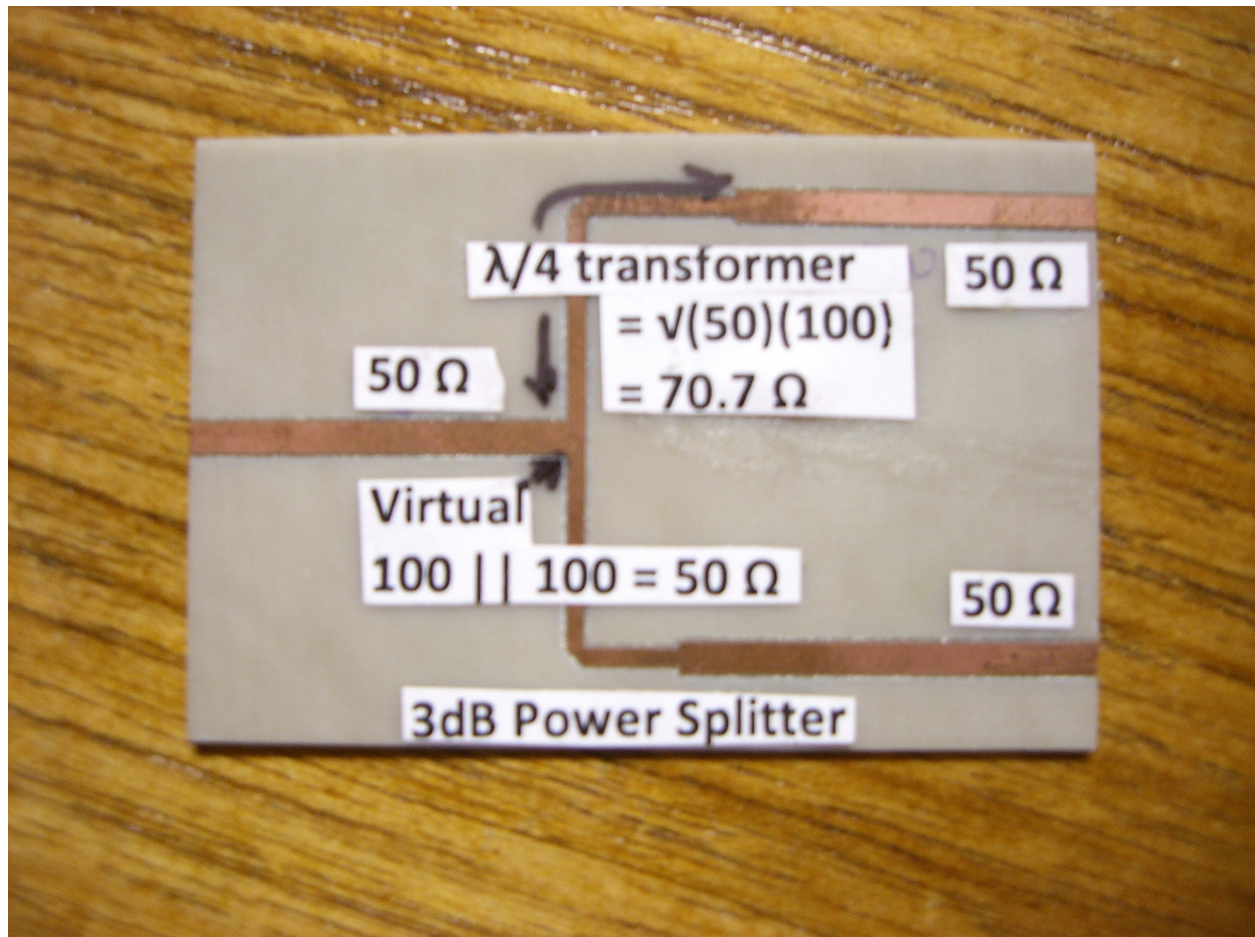

What is a Quarter-Wave Transformer?

A quarter wave transformer is used to match two transmission lines with different impedances. It can only be used if the impedances of both lines are strictly REAL (no imaginary parts).[1] A length of transmission line that is a quarter of a wavelength long ($\lambda/4$)[2] is used. The impedance of the quarter wave transformer is

$$Zq = \sqrt{Z_1 Z_2} \hspace{4cm} (1)$$

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[1] In Microwave Engineering, you will learn to transform impedance from complex to strictly real. THEN you can use a quarter wave transformer to match them. The way you transform from complex to real, is to add a length of transmission line to move (around the Smith chart, for instance) from a complex point to the real axis. The real axis on the Smith Chart is the horizontal axis through the middle of the chart, where X (the imaginary part) =0.

[2] REMEMBER that this wavelength is in the transmission line material and NOT in air when you do your design!

where Z_1 and Z_2 are the two impedances being matched. A quarter wave transformer provides a perfect match (ZERO reflection) at the ONE frequency where the length of the transformer is $\lambda/4$. At all other frequencies, there is some reflection. This is considered a narrow-band matching device.

How do you design a Microstrip T junction Power Divider?
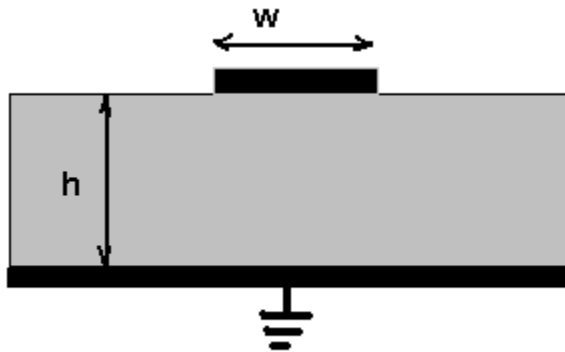
For the microstrip cross section shown above, find an effective dielectric constant that does a 'sort of' volumetric averaging between the relative permittivity of the substrate material (shown in gray) ε_r and air that has $\varepsilon_r = 1$:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12h/w}} \qquad (2)$$

Then

$$\lambda = \lambda_o / \sqrt{\varepsilon_{r\,eff}} = (c_o/f)/\sqrt{\varepsilon_{r\,eff}} \qquad (3)$$

and (for thin substrates where w/h <1)

$$Z_o = \frac{60}{\sqrt{\varepsilon_{reff}}} \ln\left(\frac{8h}{w} + \frac{w}{4h}\right) \Omega \qquad (4)$$

Use (2) to calculate $\varepsilon_{r\,eff}$ and (3) to calculate length = $\lambda/4$. Determine h from the available choices of substrate material (see the Duroid products from Rogers Corporation, for instance). Determine the value of Zo needed for the transformer from (1). Then iteratively vary w in (4) until you get the value of Zo you need. This will tell you the width w to etch the quarter wave transformer. (Note that high impedance lines are THINNER (smaller w) than low impedance lines.)

What is a T-junction Power Splitter?

A power splitter is used to divide (split) power. In the picture above, the device is shaped like a "T", so is called a "T-junction power splitter". Power comes in from the left, and is split equally to come out on the right. Half of the power comes out of each of the arms on the right. 10 log(½) = -3dB. Hence the

name "3dB Power Splitter".   Power can also be brought in from the two arms on the right and combined to come out on the left. Then it is a T-junction power combiner!

**Matching the T-junction Power Splitter**

An example T-junction power divider is shown below. The 50 ohm line is the input, and two 100 ohm lines are the outputs. This splits the power evenly (the 100 ohm lines are equal magnitude). Also, the splitter is matched, since the two 100 ohm lines in parallel create a 50 ohm match. Unfortunately, the output lines are now 100 ohms and do match other 50 ohm components to which they might be attached.
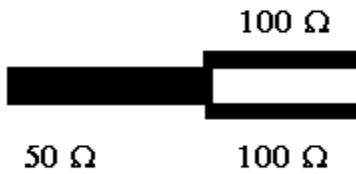

To match the 100 ohm lines to 50 ohm lines on the output, we will use quarter wave transformers. The impedance of the quarter wave transformer is calculated from (1). Thus Zo = √(100) (50) = 70.7 ohms. Now choose a substrate material, and find the thickness h and relative permittivity ε_r from the manufacturer's specifications. Next, iteratively change w in (4) until you get Zo = 70.7 ohms. Finally, calculate the length of each transformer. They will be λ/4 long, where λ is calculated from (3).
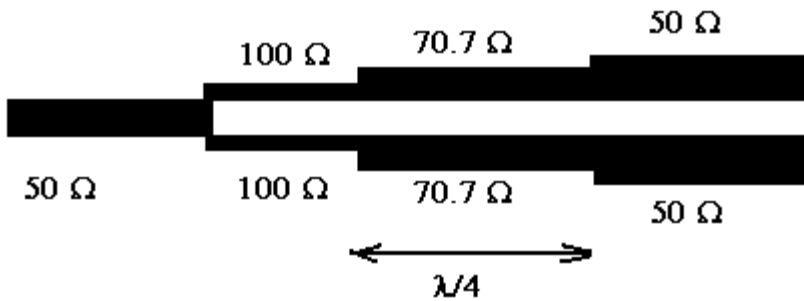
Now, let's consider the length that is required for the 100 ohm lines. They are used to split the power equally and to match to the 50 ohm lines. They can be any length … any length at all … including zero length. We can remove them entirely, and just butt the quarter wave transformers up against the input line as shown below, and our system will work exactly the same!
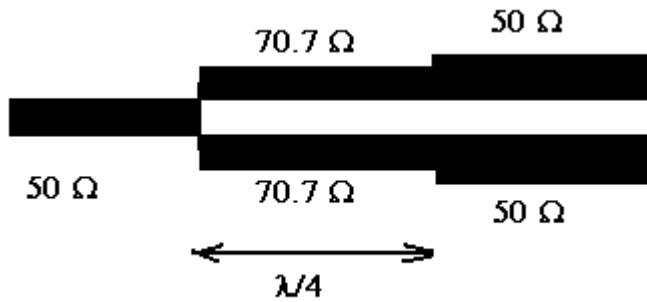
A photo of how this is built in practice is shown below:
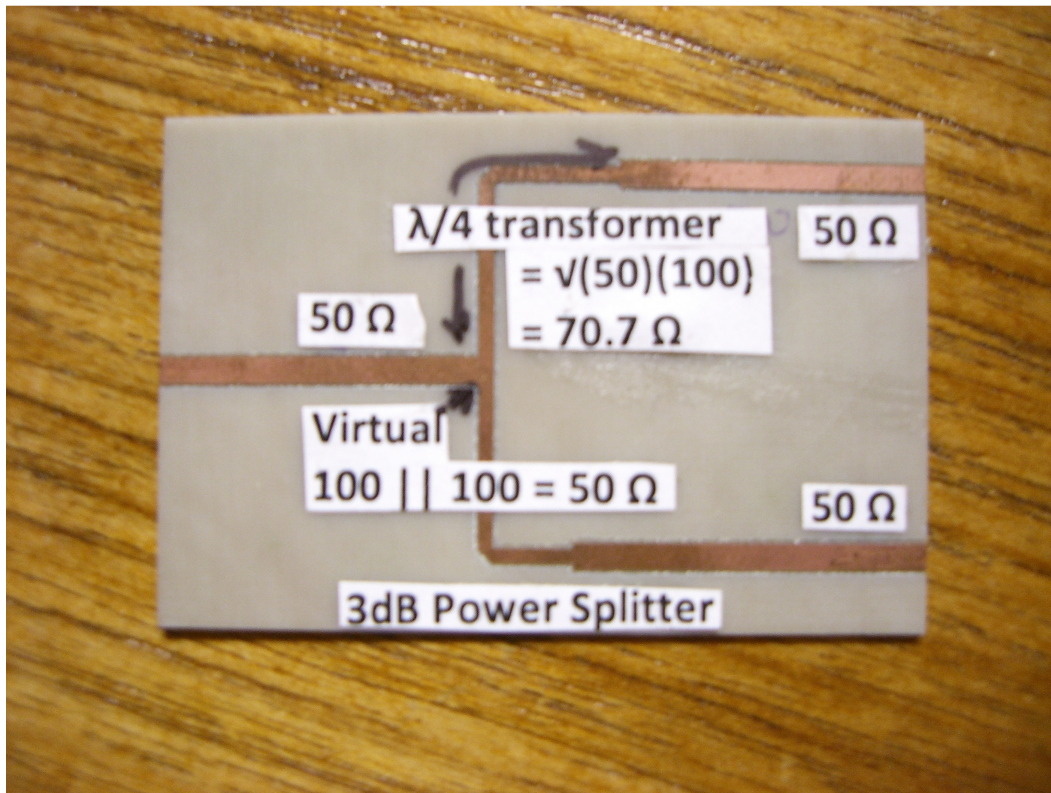
The quarter wave transformer is "bent" to fit a specific configuration. They can be straight, bent, whatever. In this case, our test system needed the two output lines to be 1" apart, which dictated the bend and separation. Note that the 100 ohm line is never milled. It is there in 'virtual', but not in reality. This particular splitter is used in an FSK WLAN experiment. The top line is for 2.4 GHz, and the bottom line is for 2.6 GHz. The lengths of the two quarter wave transformers are slightly different (look carefully!) on account of this. The widths vary so little between these two frequencies that you can't see that difference. Also observe what was mentioned above… the higher impedance lines in the quarter wave transformer are thinner than the lower impedance lines that make up the input and output. And finally, just one more interesting note. Take a close look at the 'elbow' in the quarter wave transformer. The corners are beveled, to reduce the impedance mismatch going around the corner. If they were not beveled, then the effective width of the line around the corner would be wider (and hence lower

impedance) than the rest o the line. Also, the sharp corners on a bend like this would radiate towards other (possibly sensitive) elements of the circuit.