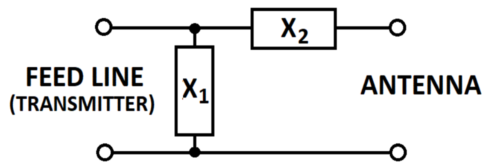
The "Hairpin" Antenna Match - (Bruce VK2DEQ)

To achieve an SWR of 1:1 and to transfer maximum power to the antenna, the impedance of the antenna must match the impedance of the transmission line. Typically, the impedance of a Yagi antenna is much lower than that of the feed line and some form of matching is required. The required impedance transformation can be achieved using the well-known L-match with the shunt element connected across the transmission line and the series element connected in series with the antenna. The hairpin match (sometimes called a beta-match) is a variation of the L-match and is a simple device designed to match (at the feed point) a low impedance antenna to a higher impedance transmission line.



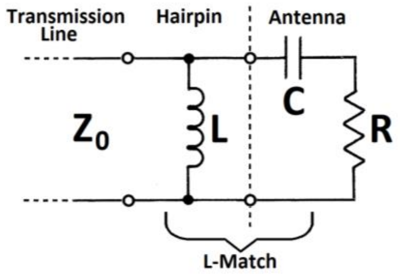
Shunt input L-match

The Hairpin Match

The hairpin design is based on the L-match with an inductor as the shunt element (X_1). The series element (X_2) of the match is obtained, not by adding a capacitor, but by reducing the length of the driven element as this will introduce capacitance at the feed point.

The equivalent circuit for the hairpin match is shown opposite. For a perfect match, the feed-line impedance must be equal to the parallel combination of the shunt element and the antenna. In other words,

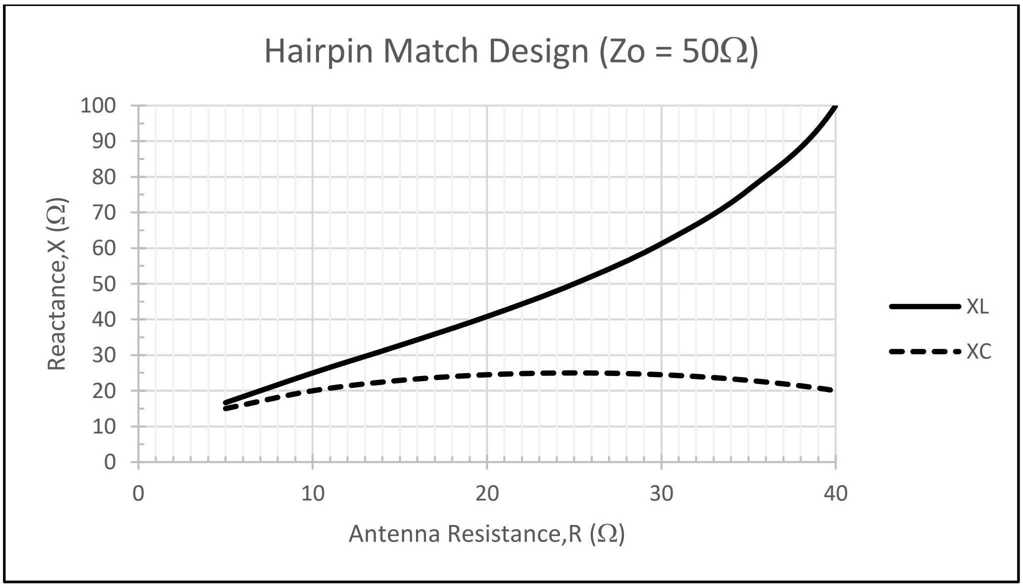
$$\frac{1}{Z_0} = \frac{1}{jX_L} + \frac{1}{R - jX_c}$$



It follows (with a bit of effort) that the equations required to calculate X_L and X_C are:

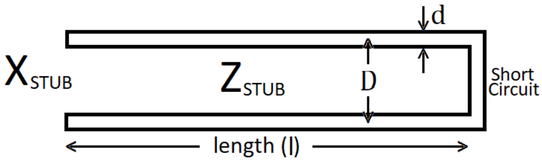
$$X_L = \frac{Z_0}{Q} \quad \text{and} \quad X_C = R \times Q \quad \text{where} \quad Q = \sqrt{\frac{Z_0}{R} - 1}$$

Readers with a dislike for equations may prefer to use the graphs (below) which assume that the impedance of the feed line (Z_0) is 50Ω.



Designing the Hairpin

In the classic hairpin design the inductor is formed using a shorted stub (a length of transmission line shorted across one end). The impedance at the open end of the stub will be <u>pure inductance</u>, provided the length of the stub is <u>less than a quarter wave</u>. (The name 'hairpin' comes from this U-shaped structure). The reactance at the open end of the stub is



The impedance of the stub element is

$$Z_{STUB} = 120 \ln\left(\frac{2D}{d}\right)$$

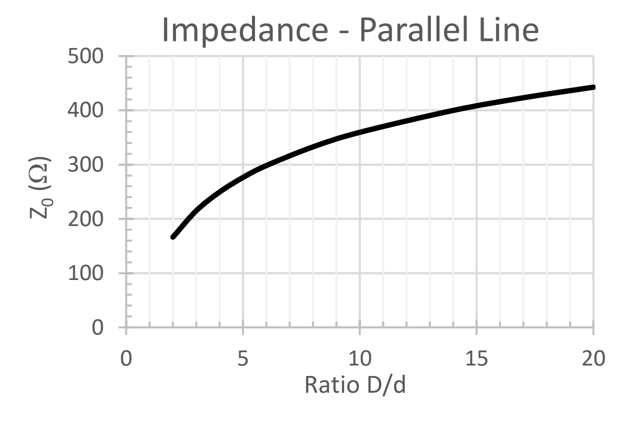
$$X_{STUB} = Z_{STUB} \times \tan\left(\frac{2\pi l}{\lambda}\right)$$

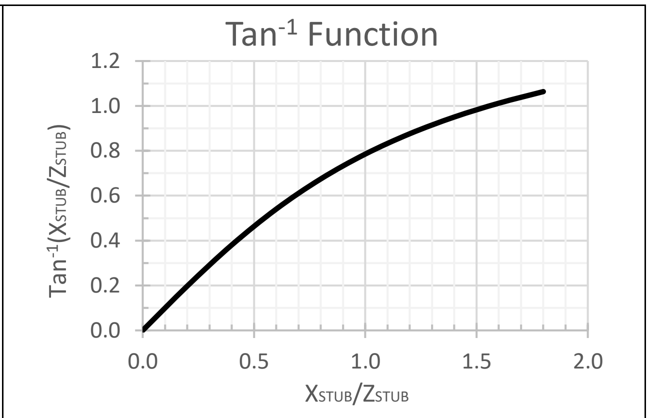
[Note: The impedance of the hairpin stub (Z_{STUB}) is either known or can be calculated from the geometry of the stub. (See above).]

Remembering that the wavelength (in free space), $\lambda(\mathrm{m}) = 300/\mathrm{f(MHz)}$, it follows that the length of the stub (l) is

$$\mathbf{l}(\text{metres}) = \frac{\mathbf{300}}{\mathbf{2\,\pi\,f}(\text{MHz})} \times \tan^{-1}\left(\frac{X_{STUB}}{Z_{STUB}}\right)$$

For readers who still find equations not to their liking, the following may be useful.

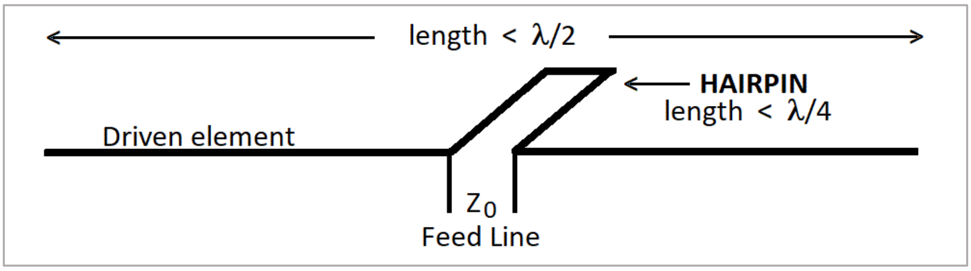




Note - for small values: $\tan^{-1}(X_{STUB}/Z_{STUB}) \approx X_{STUB}/Z_{STUB}$

In Summary:

1. Determine the antenna resistance (R) from the data sheet or by measurement.
2. Calculate values for X_L and X_C.
3. Knowing (or otherwise determine) the impedance of the hairpin element (Z_{STUB}) and the required X_L (= X_{STUB}), calculate the length of the hairpin.
4. Finally, carefully trim the driven element of the antenna to introduce the capacitance required for a near perfect match.



Example Calculation for a Hairpin Match The feed point impedance of a 3-element, 20-metre beam is 15Ω. Find the dimensions for the hairpin required to match the beam to 50Ω. (The operating frequency is 14.1MHz).	
1. Determine the values for X_{STUB} and X_C. $Q = \sqrt{\frac{Z_0}{R} - 1} = \sqrt{\frac{50}{15} - 1} = 1.53$	$X_{STUB} = X_L = \frac{Z_0}{Q} = \frac{50}{1.53} = 32.7\ \Omega$ $X_C = R \times Q = 15 \times 1.53 = 22.9\ \Omega$
2. Assuming that the hairpin is to be constructed from 5mm diameter wire and spaced 80mm apart, find Z_{STUB} (the impedance of the hairpin stub).	$Z_{STUB} = 120 \ln\left(\frac{2D}{d}\right) = 120 \ln\left(\frac{2 \times 80}{5}\right) = 416\ \Omega$
3. Calculate the required length (l) of the hairpin stub.	$l = \frac{300}{2\pi f} \tan^{-1}\left(\frac{X_{STUB}}{Z_{STUB}}\right) = \frac{300}{2\pi \times 14.1} \tan^{-1}\left(\frac{32.7}{416}\right)$ $= 0.266\ \text{m (or 26.6 cm)}.$

Other Forms of the Hairpin Match

The classic hairpin match was designed for a HF antenna with a balanced feed (See Fig.1 below).

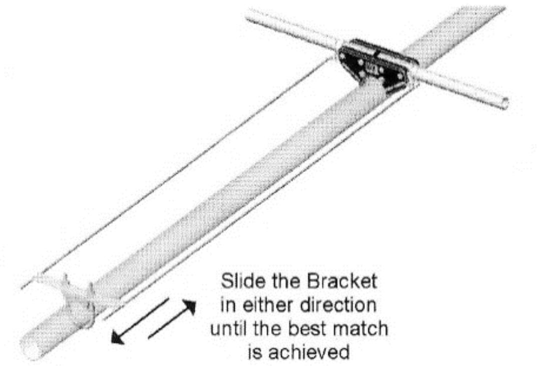


Fig. 1: Shows the classic hairpin match (with a moveable shorting bar) connected to the driven element of a balanced antenna. Note the split in the driven element.

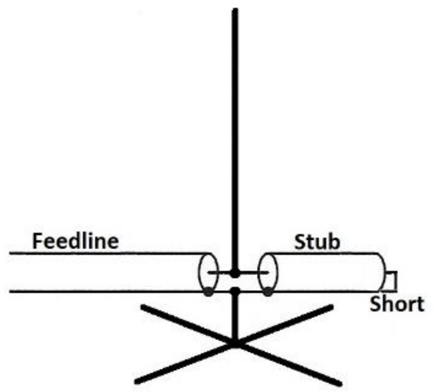


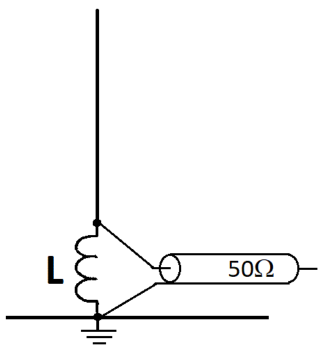
Fig. 2: Shows an end-feed vertical antenna with a shorted coax stub as the matching element.

However, the ideas can be applied to other (HF and VHF) antennas with an unbalanced feed. The following are two examples. (The reader is encouraged to check these calculations).

Example 1: 40-metre whip
When you connect your new 'home-brew' 40-metre vertical to the transmitter the SWR is about 2.5:1. Not good! It looks like the antenna impedance (R) is probably about 20Ω. (Why?).
You know that a match can be achieved using a shunt inductance at the feed point and then reducing the length of the antenna to create the necessary capacitance for a perfect match.
The reactance of the required inductor (X_L) equals 40.8Ω and at an operating frequency of 7.1MHz, the value of the inductor will be

$$L = 40.8/(2\pi \times 7.1 \times 10^6) = 0.92\mu H$$

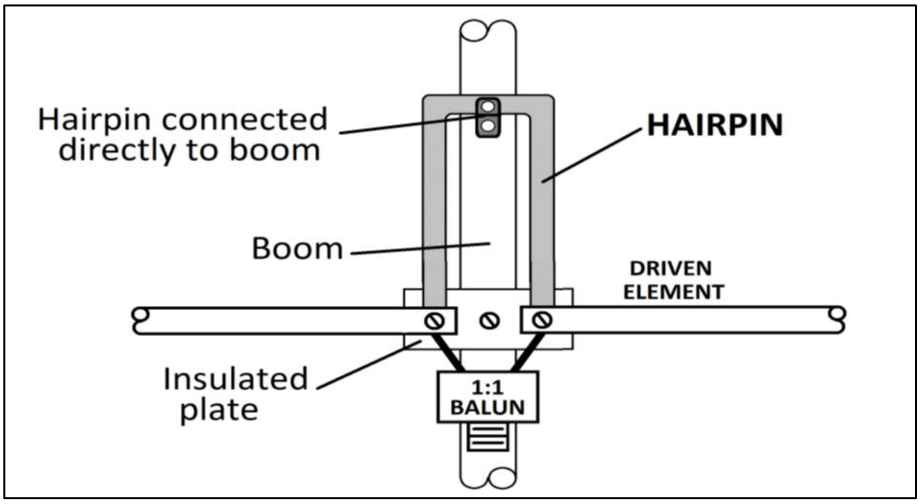
(about 10 turns, 20mm diameter spaced over a length of 35mm might be a good start).



Example 2: 2-metre vertical
In Fig. 2 (above) a shorted coaxial stub is to be used to match an end-feed 2-metre vertical antenna to a 50Ω feed line. The impedance of the antenna at its resonant frequency of 147MHz is 36Ω. Determine the length of the 50Ω shorted coax stub which will match the antenna to the feed line.
The inductance of the required stub is $X_{STUB} = 80.2\ \Omega$ and the length $l_{STUB} = 0.329\text{m}$. But, this is the electrical length. Assuming that the velocity factor of the coax to be used is 0.66, the physical length will be 0.66 x 0.329 = 0.217m (or 21.7cm).

Constructing and Adjusting the Classic Hairpin Match

The hairpin is constructed from a U-shaped metal (copper) conductor. The open end of the hairpin is connected to the feed point at the centre of the split driven element. The closed end of the hairpin (being electrically neutral) is connected directly to the boom to provide some support. This also restores the DC ground for the driven element which eliminates the build-up of static charge and aids with lightning protection. Connecting coax directly to the feed point will result in RF currents on the outside shield of the coax. To prevent this a 1:1 balun is required.



To obtain a good match, the hairpin and the length of the driven element will need to be adjusted before the beam is placed at the top of the tower. Point the beam upwards towards the sky with the reflector as far above the ground as is practicable. If you are using a sliding shorting bar, adjust the length of the hairpin for minimum SWR. If you are using a fixed length hairpin, some adjustment is possible by changing the spacing between the conductors. Now that the hairpin is adjusted, carefully trim the driven element (keeping each half equal) to minimise the SWR. A computer antenna modelling program can assist this process by simulating how the impedance of the real antenna changes when the length of the driven element is altered.

A Final Final

The hairpin match provides a simple, low loss method for matching the normally low impedance mono-band Yagi (or similar antennas) to a higher impedance feed line (typically 50Ω coax). An SWR meter is the only test equipment required to adjust the hairpin match.

The classic design does require the driven element to be split into two halves and to be insulated from the boom. This may require some lateral thinking about how to construct the antenna, but that's what amateur radio is all about.