Power Dissipation in Ferrite Bead Baluns at VHF

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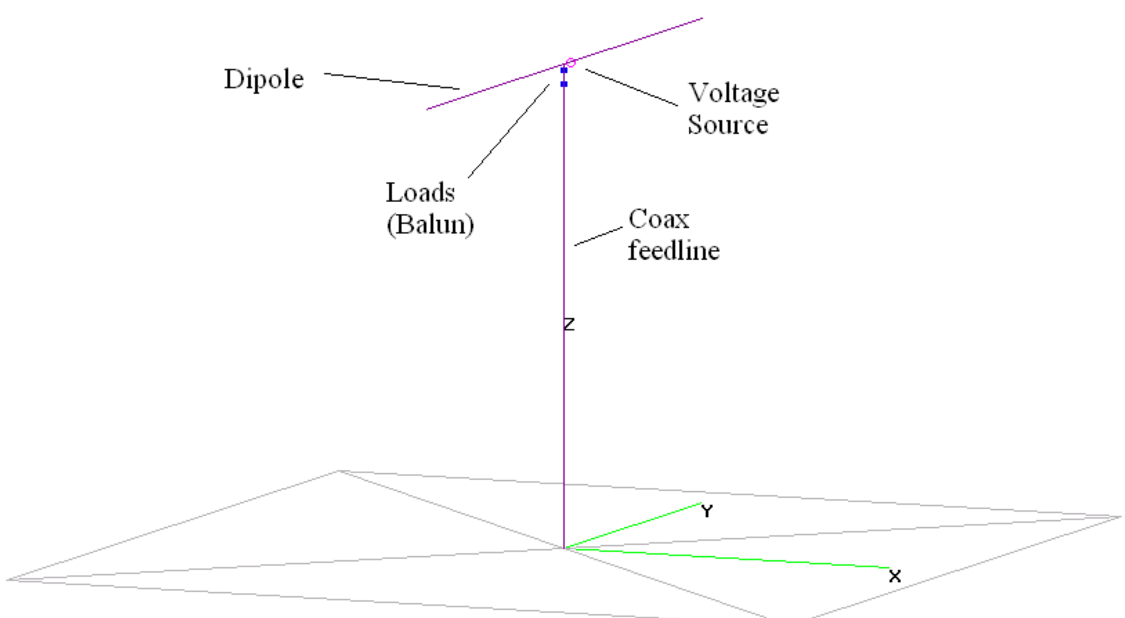
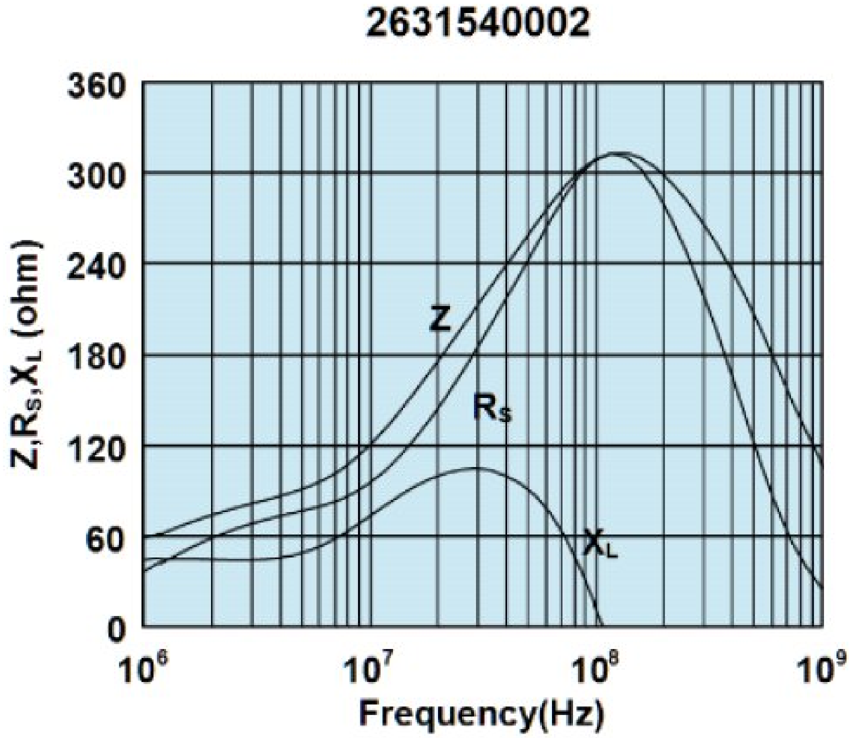
A balun made from a series of ferrite beads slipped over a coaxial feedline was originally suggested (in the amateur literature, at least) by W2DU. The power handling capacity of such a balun at HF has been a matter of some controversy. At VHF these baluns have been used, but I have found no published material on how much power they can safely handle. This paper seeks to begin to establish these power limitations.

An Example at 144 MHz

W8JI [http://www.w8ji.com/Baluns/balun_test.htm] has suggested the use (at MF/HF) of a NEC (or other moment method simulation program) model for balun power dissipation estimation involving a dipole, one half wavelength above ground, fed by a coaxial feedline which is grounded under the midpoint of the dipole. This is a case where the antenna itself is well balanced, as would normally be the case (especially at VHF) but current can flow on the outside of the feedline as it is connected to one half of the dipole. The half-wave height maximizes this current. A balun is inserted to reduce the current. In the model the balun is replaced by its equivalent impedances of each bead at the locations of each bead on the feedline. This is a small improvement at VHF over W8JI's model where a single impedance was inserted for the entire balun. The model of this antenna looks like this (using 4NEC2 software). At VHF this may not be typical usage of a dipole, but at least it provides a starting point for modeling.



This figure depicts a 2m dipole (4.8 mm diameter, 1.04 m long, 1.04 m high over perfect ground) with a balun made from two ferrite beads (Fair-Rite part number 2631540002, 0.562" O.D., 0.250" I.D., 1.125" long, #31 material), adjacent to each other, right at the feedpoint. Fair-Rite's website provides the following chart for the impedance of each bead.



Impedance, reactance, and resistance vs. frequency.

From this I estimated the impedance at 144.2 MHz at 310-j20 ohms. This value was used for each of the two loads in the model (solid squares in the figure on the previous page). The coax feedline was modeled as a 6 mm diameter conductor.

With a source of 1 V amplitude (0.707 V rms) the model showed a total input power of 7.3 mW, and balun current peak amplitudes of 0.812 mA (top bead) and 0.784 mA (second bead), corresponding to dissipated powers in the beads of 0.102 mW (top bead) and 0.095 mW (second bead). The powers dissipated in the two beads are 1.4% and 1.3% of the total input power. This corresponds to a total balun loss of 0.12 dB, which is a small impact on the overall antenna gain, compared to what would be obtained if the balun were lossless. Note that the input impedance of this dipole is about 70 ohms, which puts a slightly higher stress on the balun that would be the case if the same power were applied to a 50 ohm antenna.

Now we can calculate the power dissipation in the balun beads for more normal operating powers. Applying the 1.4% and 1.3% numbers to a variety of transmitter powers we get the following table.

Transmitter Power (W)	Power Dissipated in Top Bead (W)	Power Dissipated in Second Bead (W)
100	1.4	1.3
200	2.8	2.6
400	5.6	5.2
800	11.2	10.4

Note that these are average power numbers, since the thermal time constant of the beads is certainly more than the length of a dash in Morse, or the equivalent modulation period in SSB). So they apply to modes where full power is applied continuously, such as FM and many digital modes. For a given transmitter output power on CW or PEP on SSB, the dissipations are probably about half of the numbers shown here due to the duty cycle of about 50% in these modes.

At a gut-feel level, since these beads are each around the size of a 5-10 watt resistor, one could expect the dissipations in the bottom two cases in the table to result in the baluns getting very hot, perhaps hot enough to melt the insulation on the coaxial feedline, but that 100-200 W average transmitter power could be OK.

<u>More Beads</u>

Next I will look at what happens if more beads are used. One would hope that the extra impedance would further reduce the current on the outside of the coaxial cable, which in turn would reduce the power dissipated in the beads, allowing a higher transmitter power without excessive balun heating. The model was modified to include a string of four beads rather than two. The resulting power dissipations in the beads (as a percentage of the transmitter power) are shown in the following table.

Bead	Power Dissipated (% of TX Power)	
	2 bead case	4 bead case
Top	1.4	0.52
2nd	1.3	0.38
3rd		0.32
4th		0.29

In fact the current is reduced to somewhat over half the value in the 2-bead case, and so the dissipation in the worst case bead (the one nearest the feedpoint) is substantially reduced. In fact the total dissipation in the entire balun is also reduced. It seems this approach can be used to provide significantly higher power handling capability. In this case the transmitter power can be increased by a factor of 1.4/0.52 = 2.7 while maintaining the same power dissipation in the top bead.

Calculated Temperature Rise

W1VT [QEX, Jan/Feb 2004, p.58] provides an equation for temperature rise (in deg.C) of a balun core:

$$\Delta T = (P/A)^{0.833},$$

where P is the power dissipated in milliwatts and A is the surface area in square centimetres. This disregards any conduction via the coax, but will serve as a starting point. The surface area of the Fair-Rite 2631540002 beads used in the preceding examples is 21.1 cm^2. The temperature rise for various power dissipations is shown in the following table.

Power Dissipated in Single Bead (W)	Temperature Rise (degrees C)
1	25
2	44
4	79
8	141
12	197

These results seem to agree with the gut feel impression. One or two watts dissipation will be OK, but much more will result in temperatures high enough to boil water and melt the outer insulation of the coax !

Working in reverse, we can derive a power rating for a balun. Let’s fairly arbitrarily assign an allowable temperature rise of 35 degrees C. This will feel quite hot to the touch but will limit the operating temperature to about 70 degrees C (if we disregard solar heating), which should not melt anything ! This temperature rise will result from a power dissipation of 1.5 W in a single bead.

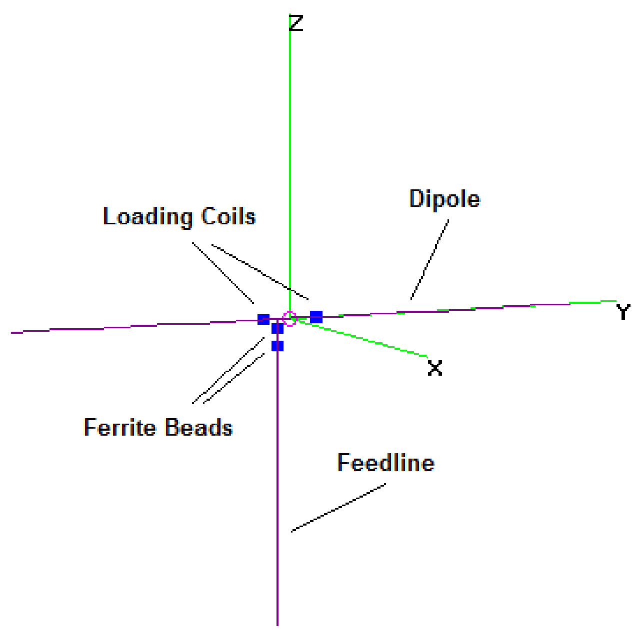
In the 2-bead 2m balun example above the top bead dissipates 1.4% of the transmitter power delivered to the antenna. So, for a dissipation of 1.5 W, the transmitter power is 107 watts average. In other words, the maximum transmitter power that can be used with this balun is 107 W on FM or other continuous duty modes, or about double this or 214 W on SSB or CW due to their approximately 50% duty cycle. For the 4 bead balun example the worst single bead dissipation is 0.52% of the transmitter power. 1.5 W is 0.52% of 288 W, so the maximum transmitter power that can be used with this balun is 288 W on FM or 576 W on SSB/CW.

Thus, a preliminary approach to defining a power rating for a ferrite bead balun has been established. Some useful refinements that should be looked into include:

- using an inductively loaded shorter dipole in the power dissipation model to provide a 50 ohm feedpoint,
- not counting the area of the end(s) of a bead in the temperature rise calculation, as appropriate in a string of beads.

An Alternate Model

Perhaps a model in which a VHF antenna is mounted only a half wavelength over ground is not very convincing. Another possible model uses a dipole in free space with one quarter wavelength of feedline attached to one side of the dipole at the feedpoint. The quarter wavelength dimension is used to maximize the current flowing on the outside of the coaxial line. This model was implemented in 4NEC2 at 144 MHz with the additional refinement of using an inductively loaded dipole with a 50 ohm input impedance at resonance. Adding 50 cm of 6 mm diameter "feedline" to the dipole in the model increased the calculated VSWR to 1.48, compared to an almost perfect match for the dipole alone. Once again, two impedances of 310-j20 ohms were inserted in the feedline segments nearest the dipole, to represent two Fair-Rite 2631540002 ferrite beads slipped over the coax. These brought the match back to almost perfect. The following diagram shows the model as used in 4NEC2.



With a source of 1 V amplitude (0.707 V rms) the model showed a total input power of 10.1 mW, and balun current peak amplitudes of 0.888 mA (top bead) and 0.947 mA (second bead), corresponding to dissipated powers in the beads of 0.122 mW (top bead) and 0.139 mW (second bead). The powers dissipated in the two beads are 1.2% and 1.4% of the total input power. These are close to the percentages obtained earlier with the half-wavelength-above-ground model, so it appears that the models are not very different as far as balun dissipation is concerned.

A 6 Metre High Power Example

For high power on 6m it will be necessary to use ferrite beads which can accommodate larger coaxial cable (RG-213/U, LMR-400, etc.). Fair-Rite has a standard bead size with a 0.505 inch hole, 1.06 inches outside diameter and 1.125 inches long. This is available in four different materials with the following impedance characteristics, according to the catalogue.

Fair-Rite Part Number	Material Type	Impedance at 50 MHz (ohms)
2631102002	31	185+j85
2643102002	43	170+j70
2646102002	46	135+j85
2661102002	61	110+j160

The Type 61 material looks very promising, since it relies more on inductance than resistance to provide the choking effect. I would, therefore, expect less power dissipation in this material.

These beads have a greater outside surface area than the ones in the previous examples, about 33 cm^2, not including the inside of the hole. For a 35 degree temperature rise this would permit power dissipation in a single bead of 2.36 watts, following the method used above.

A model very similar to the one in the previous section was used to evaluate the performance, except that baluns with 4 and 6 beads (Fair-Rite 2661102002) were used, and the dangling piece of "coax" is of larger diameter. Both had sufficient choking action to maintain SWR of about 1.02 at 50.2 MHz in the presence of the section of "coax" attached to one side of the feedpoint. As expected the current on the outside of the coax was significantly reduced by the extra two beads in the 6-bead balun. The calculated power dissipations in the beads were as shown in the following table (bead 1 is the one closest to the antenna).

Bead No.	% of Input Power Dissipated in Bead	
	4-Bead Balun	6-Bead Balun
1	0.35	0.11
2	0.41	0.15
3	0.45	0.19
4	0.46	0.21
5		0.23
6		0.23

So, for the 4-bead case, the highest dissipation of 0.460% of the input power will equal the 2.36 watt-per-bead limit at an input power of 513 W. This is the continuous power rating, with SSB or CW usable at about twice this, or about 1 kW.

For the 6-bead case, the highest single bead dissipation is 0.234% of the input power. This corresponds to an acceptable continuous input power of 1.01 kW, or about 2 kW of SSB or CW. So it appears that ferrite bead baluns can be used on 50 MHz at RF power levels in the vicinity of the legal limits for amateurs.

Some Practical Experience

I have used ferrite bead baluns, using the Type 31 beads used in the above 2 m examples, in two antennas:

(1) on 50 MHz, two beads on the feedline of a beam with a 25 ohm input impedance (coax matching network on the transmitter side of the balun). This was used in contest operation at the 100 watt level on CW and SSB with no problems.

(2) On 144 MHz, three beads on the feedline of a beam with 50 ohm input impedance. This was used for QSOs at about 250 watts on CW and SSB with no problems. A test was carried out where CW was transmitted for 1 minute and then the beads were felt with my fingers. No obvious heating was detected. This seems to indicate that the power dissipations calculated above are over-estimates of what may typically be seen in practice, which is what they were intended to be.

Both antennas used driven elements directly fed by the feed coax.

I have not made any attempt to try one at the kilowatt level.