Coaxial Traps for Multiband Antennas, the True Equivalent Circuit

A new perspective on the analysis and design of this popular antenna element.

By Karl-Otto Müller, DG1MFT

Multiband Antenna Design

Parallel-resonant circuits (called traps) are widely used to isolate parts of multiband antennas to make the antenna resonant on different frequencies (see Fig 1). For more than 20 years these circuits have been implemented as coils wound from coaxial cables.[1,2,3] As shown in Fig 2, the inner conductor of the coil end is connected to the outer conductor at the beginning. Therefore the current is going around the core two times the number of turns. The coaxial cable capacitance represents the capacitor of this parallel-resonant circuit. For an easy design of coaxial traps, VE6YP offers a program in the internet.[4]

In order to design multiband antennas with programs such as EZNEC,[5] traps must be modeled as "loads," defined by their equivalent circuit as shown in Fig 3. The easiest way to determine the values of this circuit is to measure C, L and R_s. C may also be calculated from the coaxial cable length and the capacitance per unit length (reasonable estimate if L < 1/10 λ), but L has to be measured by an appropriate inductance meter. To find out the series resistance R_s, the 3-dB bandwidth of the trap must be measured as described in Fig 4.

[1]Notes appear on page 22.

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The Surprise

Insertion of the measured values of C and L into Thomson's formula

$$fres = \frac{1}{2 \bullet \pi \bullet \sqrt{L \bullet C}}$$

gives exactly half the frequency value which was used in the coaxial trap program of VE6YP to get the number of turns of the trap.

An example: The VE6YP calculation of a coaxial cable trap for 9.5 MHz using RG58 with a core diameter of 35 mm yields 10 turns. The resonance check using a network analyzer results in 9.262 MHz, which is close. EZNEC asks for C, L and R_s, and we have to determine these three values before we can start an EZNEC simulation.

Assuming that the resonant frequency is measured correctly, either the value of L or C is only a quarter of the measured and calculated value or both are half the value. Only one of the following formulas is valid, but which?

$$fres = \frac{1}{2 \bullet \pi \bullet \sqrt{\frac{L}{4} \bullet C}}$$

or

$$fres = \frac{1}{2 \bullet \pi \bullet \sqrt{L \bullet \frac{C}{4}}}$$

or

$$fres = \frac{1}{2 \bullet \pi \bullet \sqrt{\frac{L}{2} \bullet \frac{C}{2}}}$$

For a decision, the impedance versus frequency of the resonant circuit is calculated for all three cases, and compared with the measured values as shown in Fig 5.

It can be seen clearly that the parallel combination L and C/4 is correct. Now somebody may argue that it makes no difference which combination is used for the antenna design as long as the resonance frequency is the same. But there is a significant difference:

The impedance of the three parallel-resonant circuits differs by the factor two or four respectively. The impedance of the correct combination L, C /4 is four times higher than the impedance of the non-correct parallel combination of L/4 and C, which is given as a result of the VE6YP calculation. Thus, the inductive load of the correct combination, L and C/4, has a lengthening effect on the antenna below the first resonance (half the resonant frequency). As a result, the *EZNEC* antenna design, based on the correct equivalent circuit, results in a physically shorter antenna and therefore comes closer to reality.

The Explanation

Three steps are used to show, why the parallel combination of L and C/4 is correct.

Step 1: Symbolical reduction of the number of turns to one, see Fig 6.

Step 2: The winding is cut at the opposite side and connected "cross-over" as in Fig 7. The inputs are connected in series.

Step 3: As can be seen from Fig 8, now the two capacitances, C/2 are connected in series, resulting in an effective capacitance of C/4.

Influence of the cable length

Looking again at Fig 5, we find a significant difference between measured and calculated value, based on L in parallel with C, around 60 MHz. It is suggested that this is caused by the cable length. Fig 9 shows the equivalent circuit of our symbolic "one-turn-coil" for frequencies much higher than the resonant frequency. Fig 10 shows the voltage distribution at these frequencies. At the input port, half the voltage is across each of the coaxial cables. However, at the cross-over connection, both voltages are in phase and have the same amplitude. Therefore there is no current here as illustrated in Fig 10. Consequently, the cross-over connection can be opened without changing the behaviour at high frequencies, see Fig 11. For lower frequencies, up to approximately four times the resonant frequency, the coil inductance can be simulated by a con-

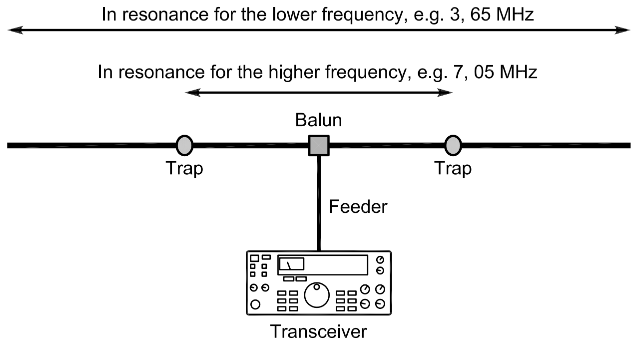

Fig 1—Two-band dipole antenna

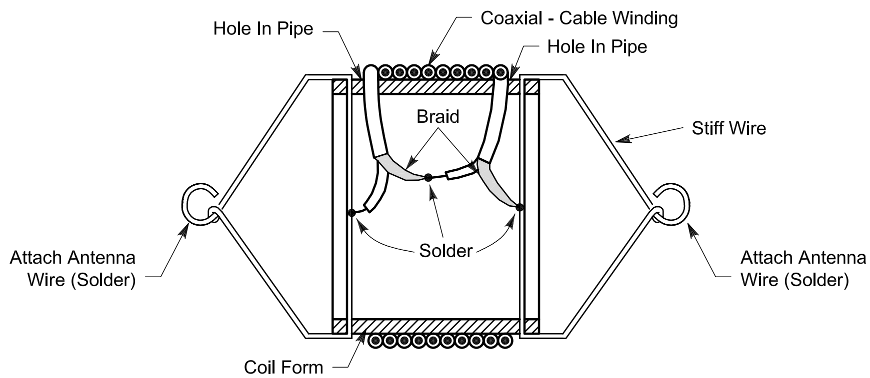

Fig 2—Typical coaxial cable trap (*QST*, Dec 1984)

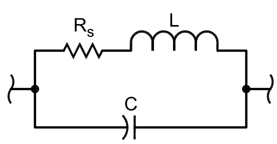

Fig 3—Equivalent circuit of a trap

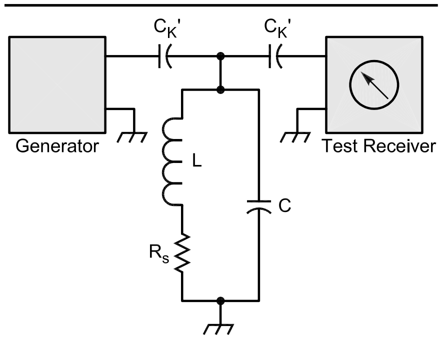

Fig 4—Measurement of the 3-dB bandwidth for calculation of R_s

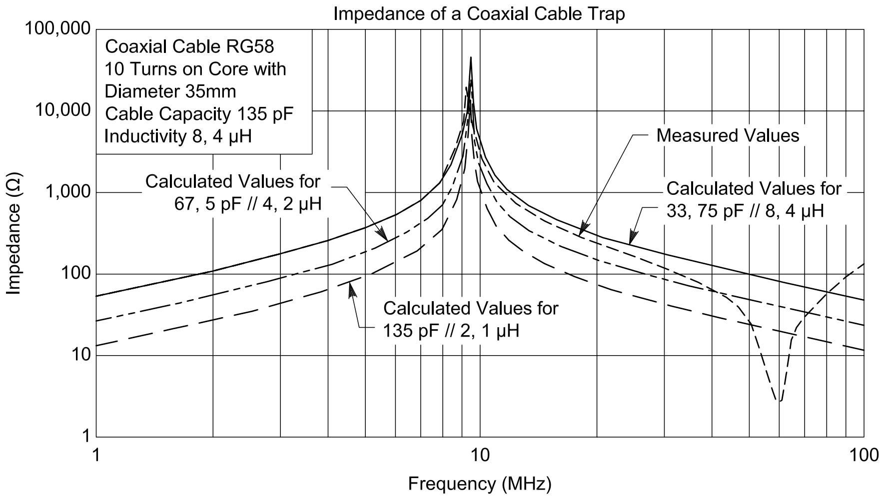

Fig 5—Impedance comparison

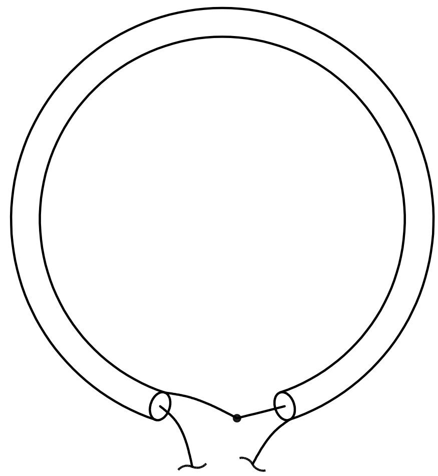

Fig 6—For an easy explanation, number of turns is reduced to one.

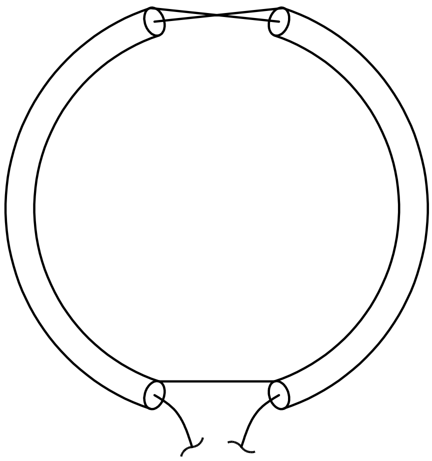

Fig 7—The winding is cut at the opposite side and connected "cross-over". The function of the coil remains totally unchanged.

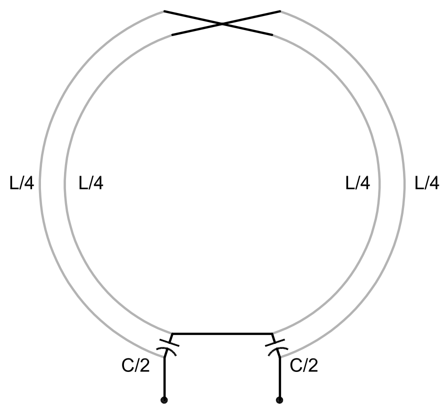

Fig 8—Distribution of capacitance and inductance of the coil

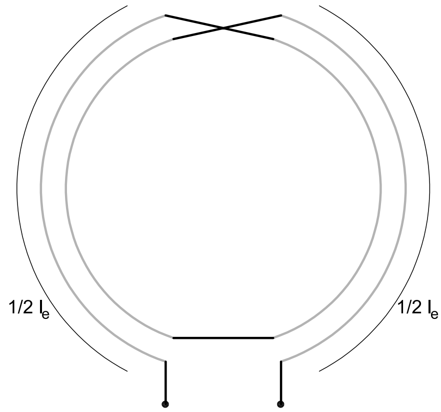

Fig 9—For higher frequencies the electrical length l_e of the coaxial cable is paramount.

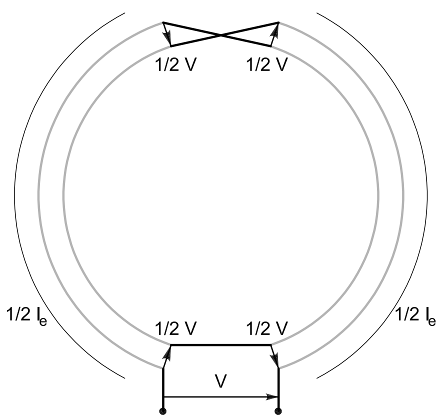

Fig 10—At the cross-over connection both voltages are in phase and have the same amplitude.

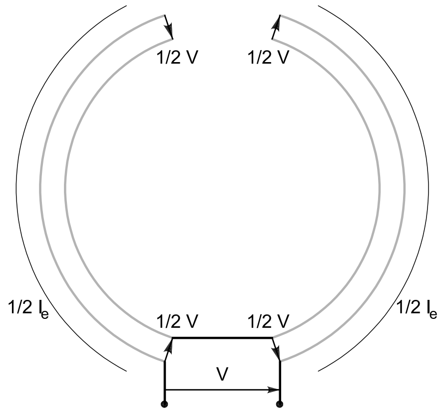

Fig 11—The cross-over connection can be opened without changing the behaviour for high frequencies.

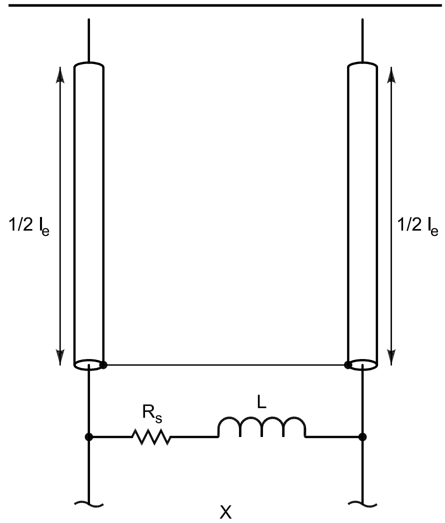

Fig 12—The complete equivalent circuit of a coaxial cable trap with electrical cable length l_e and coil inductance L with losses, represented by R_s

centrated inductance L in parallel with the input port. In series with this inductance we can insert the resistance representing the losses of the trap, as measured by the method of Fig4. Now, Fig 12 shows the complete equivalent circuit of a coaxial cable trap. The measured impedance over a wide frequency range (1 to 500 MHz) is given in Fig 13, showing minima where the total cable length $l_e = 1/2 \cdot n \cdot \lambda$ (for odd n only) and maxima, where $l_e = n\,\lambda$ (for arbitrary n).

Conclusion

It has been shown that the coaxial cable trap (electrical length l_e of the cable) behaves as a parallel resonant circuit, where $\lambda = (1/n)\, l_e$ (arbitrary n) and for

$$\frac{1}{2 \bullet \pi \bullet \sqrt{L \bullet \frac{C}{4}}} = fres$$

and as a series resonance circuit at all frequencies where $\lambda = (2/n)\, l_e$ (for odd n only).

Consequences

The correct higher impedance of the coaxial traps, compared to the now-in-use impedance values according to the VE6YP software has two consequences.

- The antenna length is more realistic (i. e. shorter) than predicted by the design software.
- The trap losses are significantly different than predicted and should be considered.

Both are illustrated in Fig 14.

Acknowledgements

I would like to thank Hartwig, DH2MIC, for helpful discussions and the Rohde & Schwarz company, Munich, for providing me with valuable test equipment.

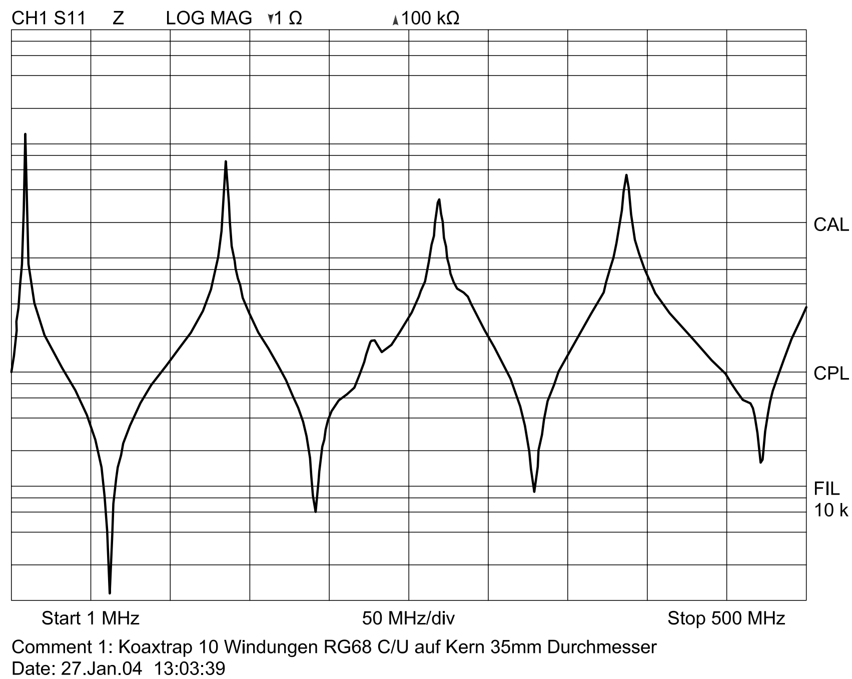

Fig 13—Impedance minima and maxima of the coaxial cable trap from 1 MHz to 500 MHz; vertical log scale from 1 Ω to 100 k Ω

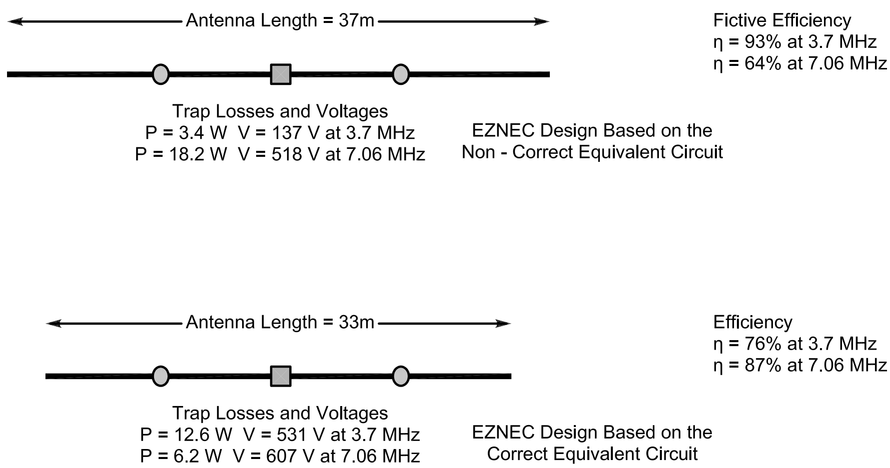

Fig 14—Errors, caused by the use of the wrong (¼ L // C, upper picture, printed in red) equivalent circuit. The antenna below (green) is calculated on basis of the correct equivalent circuit (L // ¼ · C). The differences in trap losses and voltages are not negligible! Example is a dipole antenna for 40/80 m, applied power is 100 W, wires are lossless, 10 m above ground, traps made from RG58 C/U, Q = 100.

Notes

[1] R. Johns, W3JIP, "Coaxial Cable Antenna Traps", *QST*, May 1981, pp 15–17.

[2] R. Sommer, N4UU, "Optimizing Coaxial Cable Traps", *QST*, Dec 1984, pp 37–42.

[3] *The ARRL Antenna Book*, 1988, Chapter 7, pp 8-9.

[4] T. Field, VE6YP, *Coaxial Trap Design*, (Freeware, *CoaxTrap.zip*), **www.members.shaw.ca/VE6YP**.

[5] EZNEC is available from Roy Lewallen, W7EL, at **www.eznec.com**.

[6] K. Müller, DG1MFT, "Ersatzschaltbild für Koaxiale Sperrkreise", *Funkamateur 53* (2004) Jan, pp 60-61 (in German).

[7] K. Müller, DG1MFT, "Koaxiale Traps für Multiband-Antennen, Das korrekte Ersatzschaltbild", paper, presented at the DARC Radio Amateur Meeting in Munich, Mar 13/14, 2004 (in German), **www.amateurfunktagung.de**.

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