

A Novel Way to Build Multiband Antennas

Dipl.-Ing. Juergen A. Weigl
OE5CWL/OE6CWL
Kaerntner Str. 212
A-8053 Graz, Austria
E-Mail: oe5cwl@tender.at

Preface

The last two or three years I have spent a lot of time (and money) solving the secrets of multiband operation with coil-loaded antennas. What we found seems to be a novel way to build multiband antennas.

Forget about the problems in homebrewing traps. Forget about traps with capacitors breaking down under higher power. All you need now to build a multiband antenna is some wire (or any other antenna-conductor) and some coils. By placing an inductor within the antenna element, it is possible to get an infinite impedance at a certain point of the element for a specific frequency. At the same time the inductor can act as a loading coil at another frequency. Thus by properly choosing the value and position of the inductance it is possible to achieve multiband operation. For a given total length of the antenna and any two (or more) frequencies we can always find a solution for multiband operation.

We have applied for patents on this principle, therefore commercial use of such antennas is prohibited. Nevertheless we are glad to introduce this principle to the amateur radio community. This article includes a lot of formulas, which are necessary to explain the theory of operation. As time permits we will provide more and hopefully more easy-to-read information for the casual antenna builder. We have enough material to write more than one book on that subject. But besides writing on antennas, I also try to be on the bands every now and then. So please QRX a moment. In the meantime feel free to contact me, if you have any questions on the subject.

Trap antennas as they are used now

One very common way to build multiband antennas is to use tuned circuits within the elements. The tuned circuit is a parallel combination of an inductivity L and a capacitor C (see Fig. 1). This tuned circuit is usually called a „trap“.

If the trap is resonant at the first operating frequency (f_{01}), it presents a high impedance at that point in the antenna system. The electrical effect at the first operating frequency is, that the trap acts as an insulator. Thus at the first operating frequency the outside ends of the antenna (l_b in Fig. 1) are separated from the antenna and only the inner part of the antenna (l_a in Fig. 1) is active. This inner part is made to be resonant at the first operating frequency. We therefore have for the first operating frequency a full size antenna.

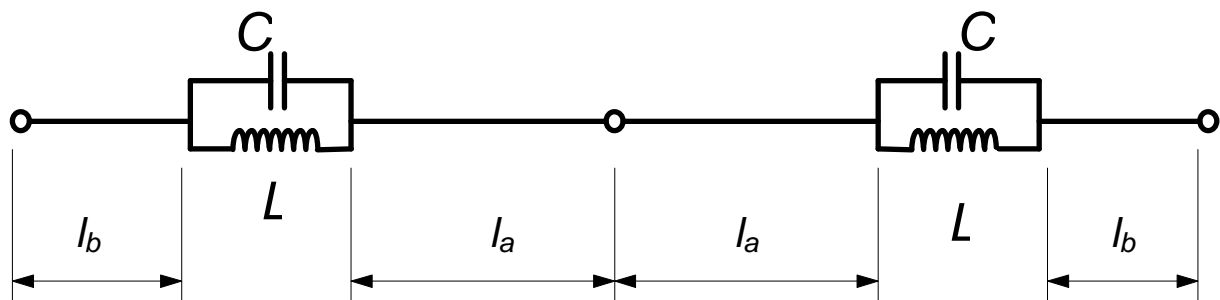


Fig. 1: Multiband dipole with tuned circuit as a parallel combination of L and C.

At any frequency which is not the resonant frequency of the tuned circuit, the trap presents an impedance within the antenna. This impedance is inductive for frequencies below the first operating frequency and is capacitive for frequencies above the first operating frequency. Thus the trap behaves either as an inductor or a capacitor. Inductive loading will electrically lengthen the antenna, capacitive loading electrically shortens the antenna.

With the inductive loading of the trap electrically lengthening the entire antenna element, there will be a second operating frequency (f_{02}) (which is lower than the first operating frequency $f_{02} < f_{01}$). By choosing the L/C ratio of the tuned circuit and length of the element l_b the second resonance f_{02} of the antenna is determined. Thus we have a two-band antenna. Additional traps may be added in an antenna section to cover three or more bands.

This kind of multiband antenna is widely used for amateur radio antennas in the shortwave spectrum. Traps are found in dipole and vertical antennas as well as in directive arrays and multiband Yagi antennas.

Tradeoffs of tuned circuits

The most severe limitation in trap antennas is the possible input power into the antenna. The tuned circuit is usually the limiting factor regarding to input power. The capacitor in the tuned circuit has to withstand high voltages. The breakdown voltage of the capacitor limits the input power to the antenna. The breakdown voltage is influenced by environmental factors, like humidity. Therefore the input power to the antenna is usually limited to about 1500 watts. Higher power levels are difficult to be achieved with trap antennas.

At the same time building and tuning traps for multiband antennas is an important cost factor for the commercial fabrication of antennas.

One further tradeoff of trap antennas is, that the tuned circuit is sensitive to environmental factors like temperature, rain, insects, etc. These factors can influence the resonance frequency as well as the breakdown voltage of the trap.

Traps without a capacitor

The high impedance at the first operating frequency may be achieved by the self-resonance of an inductor. Each turn of a coil is at a slightly different AC potential, thus forming a small parasitic capacitor. Therefore any existing inductance has a self-capacitance and consequently a self-resonance.

In the literature we find designs using the self-resonance of coils as the tuned circuit in an antenna. Some manufactures refer to such a design as „Iso-Frequency-Coils“.

Due to the fact, that the self-capacitance of a coil and its corresponding self-resonance are not very easily to control, such designs are not very popular. The self-capacitance of a coil is rather small and therefore the self-resonance very high. Most of these designs are for frequencies well above 100 MHz.

Let us clear up, that although our design might look very similar to antennas making use of the self-resonance of an inductor, the way and the dimensions how it works are completely different. Our design does not need any self-capacitance at all, but it works on a completely different principle. Apart from this the value and the position of the inductor are completely different.

A novel way for multiband antennas

We tried to find a way to achieve multiband operation preferably in the mediumwave and short-wave range. Such a design should avoid most of the problems with trap-antennas. We wanted to develop a design that completely avoids a capacitor, thus input power can be many times more than in conventional trap antennas. By avoiding trap LC-circuits antenna fabrication should be much cheaper and the antenna less sensitive to environmental factors.

The result is an antenna, that is as simple as favourable. It just consists of three conducting elements l_0 , l_1 and l_2 and an inductance L . Fig. 2 shows the principle arrangement of a said dipole.

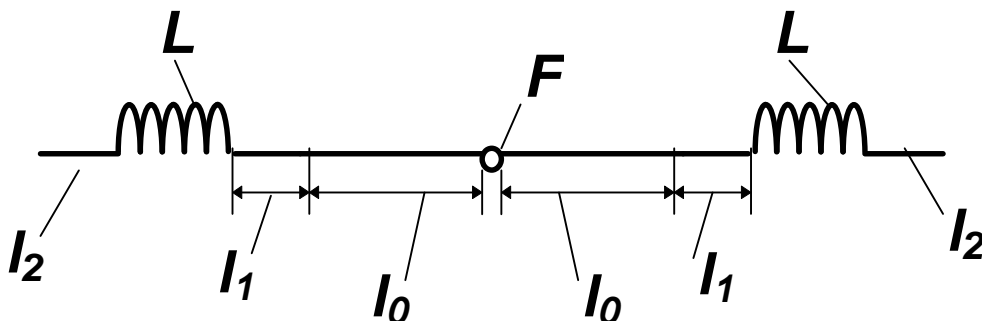


Fig. 2

Fig. 2: Multiband antenna without a capacitor. See text!

Please notice, that for a given pair of frequencies the dimensions of the lengths (l_0 , l_1 , l_2) of such an antenna do not correspond to the lengths (l_a , l_b) in a trap dipole! In our design the left and right arrangement of l_1 , l_2 and L represents at the first operating frequency f_{01} a high to infinite impedance at the junction point with element l_0 . Later we will show mathematically, how we can achieve this. Fig. 3 shows the impedance of such an arrangement (l_1 , L , l_2) at the junction point with l_0 around its design frequency.

As we can see, two conductors l_1 and l_2 and a coil L can act the same way as a conventional trap. In our example there is no self-capacitance involved. The trap function is only achieved by the proper transformation of the inductance L along l_1 and l_2 .

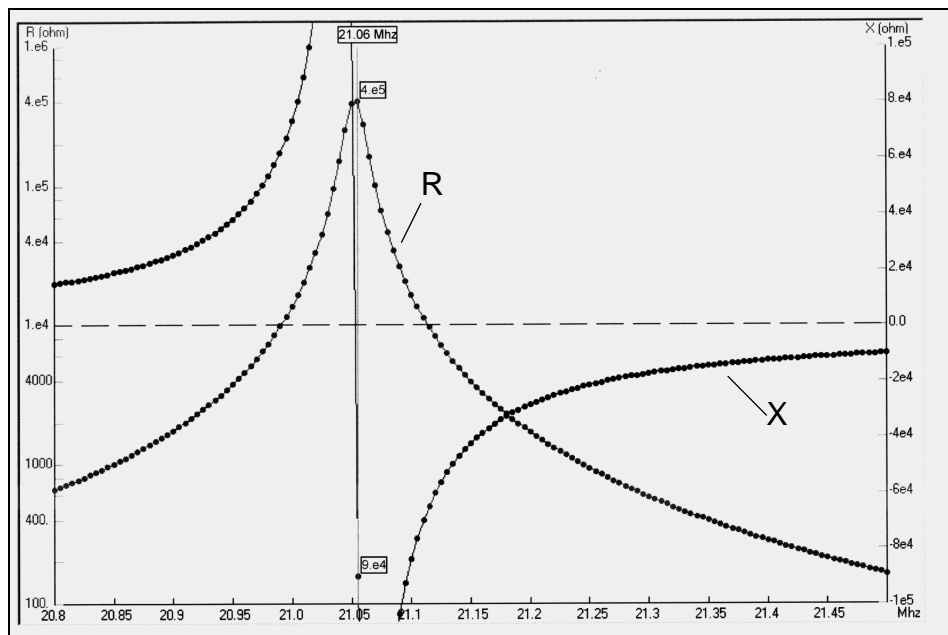


Fig. 3: Impedance of an arrangement of two conductors l_1 and l_2 with a coil L at the junction point with a further element l_0 . The two conductors l_1 and l_2 and the coil L were chosen in a way to represent a high impedance at the junction point with l_0 for 21 Mhz to build a two band antenna.

If we make now the arrangement of l_1 , l_2 and L resonant at the first operating frequency f_{01} , we find a high to infinite impedance at the inner end of l_1 . Therefore we can connect here a conductor l_0 . This conductor should be resonant at the first operating frequency f_{01} in the same way as it is done with trap antennas. As l_0 is resonant at the first operating frequency and the arrangement of l_1 , L and l_2 represents a high impedance at the junction point also the entire antenna will be resonant at this first operating frequency.

At any frequency different from the first operating frequency f_{01} we find a finite impedance at the junction of l_1 and l_0 . The antenna will act as a simple dipole with a loading coil. Therefore we find a second operating frequency f_{02} , where the antenna acts like a shortened dipole with a conventional loading coil.

As simple as it is finding the correct value for L and the correct position of the coil is a tricky task. Therefore we will need some formulas. If you would like to skip the formulas, you might try the example at the end of this article with your antenna simulation programme. But we highly recommend to go through the formulas for a complete understanding of our antenna design.

The mathematical solution:

For the first operating frequency we need the arrangement l_1 , l_2 and L to act as a high to infinite impedance at the junction with l_0 . This is accomplished by making use of the transforming characteristic of an antenna element. Let us explain this with Fig.

4

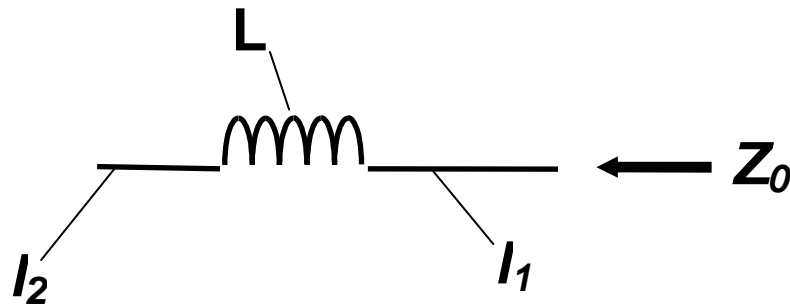


Fig. 4

We have two conductors (antenna elements) l_1 and l_2 and an inductance L with the impedance X_{L1} at the first operating frequency f_{01} (and the corresponding wavelength λ_1).

We now use the transmission-line equivalent: A single conductor antenna can be considered as a single-wire transmission line. Therefore a number of calculations can be done, just as on a transmission line.

The characteristic impedance of antenna elements l_1 and l_2 seen as a transmission line, the surge impedance Z_{S1} and Z_{S2} are given by:

$$Z_{S1} = 60 \cdot \left(\ln \frac{4l_1}{d_1} - 1 \right) \quad (\text{Eq. 1})$$

$$Z_{S2} = 60 \cdot \left(\ln \frac{4l_2}{d_2} - 1 \right) \quad (\text{Eq. 2})$$

where

l_1, l_2 = length of element l_1 or l_2

d_1, d_2 = diameter of element l_1 or l_2

Now we calculate the impedance Z_0 of this arrangement at the end of l_1 opposite to L (see Fig. 4).

Let us show it step by step:

An open-circuited transmission line with the surge impedance Z_s and the length l has an impedance

$$Z = -j \frac{Z_s}{\tan 2 \cdot \pi \cdot \frac{l}{\lambda}} \quad (\text{Eq. 3})$$

Using this formula we calculate the impedance of the element l_2 at the junction with the coil L (see. Fig. 5)

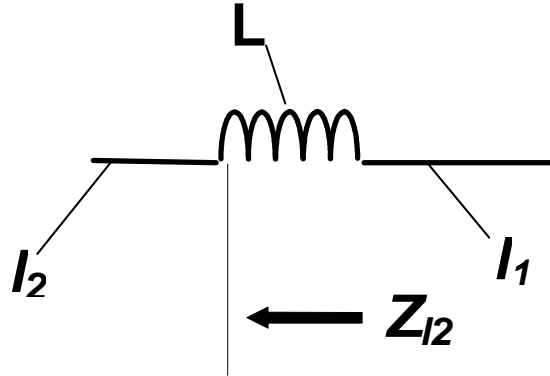
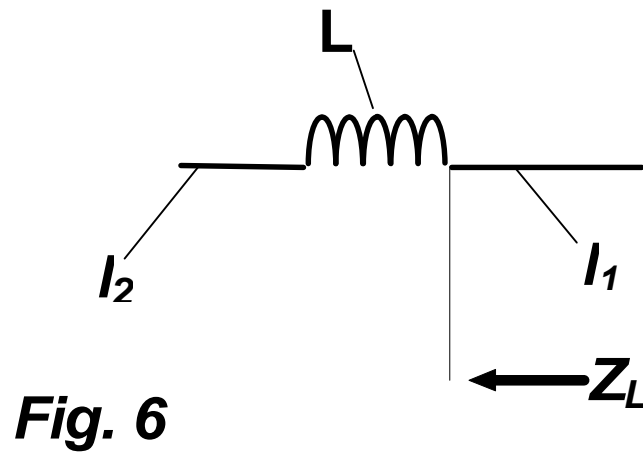


Fig. 5

$$Z_{l2} = - \frac{Z_{s2}}{\tan 2 \cdot \pi \cdot \frac{l_2}{\lambda}} \quad (\text{Eq. 4})$$

In the next step we consider the inductance L which is in series with l_2 (s. Fig. 6):



$$Z_L = -\frac{Z_{S2}}{\tan 2 \cdot \pi \cdot \frac{l_2}{\lambda}} + X_L \quad (\text{Eq. 5})$$

In the next step we calculate the impedance Z_0 at the end of l_1 opposite to L (see Fig. 4). We do this using the transmission-line equivalent and see Z_L as the termination of a line (element) l_1 with a surge impedance Z_{S1} (see Fig. 7 as the equivalent circuit diagram).

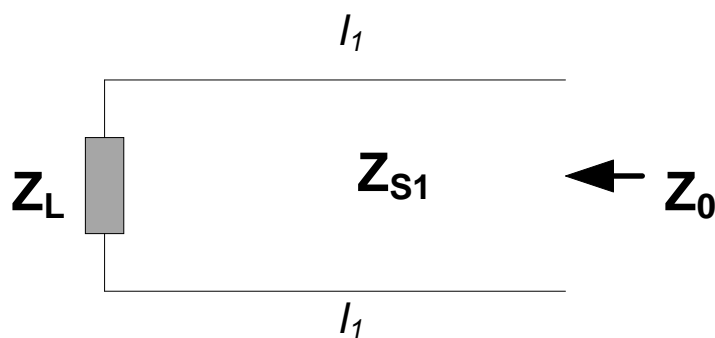


Fig. 7

Assuming a line (or elements) without losses we get for such a terminated line:

$$\frac{Z_0}{Z_{S1}} = \frac{\frac{Z_L}{Z_{S1}} + \tan(2 \cdot \pi \cdot \frac{l_1}{\lambda})}{1 - \frac{Z_L}{Z_{S1}} \cdot \tan(2 \cdot \pi \cdot \frac{l_1}{\lambda})} \quad (\text{Eq. 6})$$

Now we enter Z_L from Eq. 5:

$$\frac{Z_0}{Z_{S1}} = \frac{\frac{\left(X_L - \frac{Z_{S2}}{\tan(2 \cdot \pi \cdot \frac{l_2}{\lambda})} \right)}{Z_{S1}} + \tan(2 \cdot \pi \cdot \frac{l_1}{\lambda})}{1 - \left[\frac{X_L - \frac{Z_{S2}}{\tan(2 \cdot \pi \cdot \frac{l_2}{\lambda})}}{Z_{S1}} \right] \cdot \tan(2 \cdot \pi \cdot \frac{l_1}{\lambda})} \quad (\text{Eq.7})$$

This formula can also be written as:

$$\frac{Z_0}{Z_{S1}} = \frac{X_L - \frac{Z_{S2}}{\tan(2 \cdot \pi \cdot \frac{l_2}{\lambda})} + Z_{S1} \tan(2 \cdot \pi \cdot \frac{l_1}{\lambda})}{Z_{S1} - \left(X_L - \frac{Z_{S2}}{\tan(2 \cdot \pi \cdot \frac{l_2}{\lambda})} \right) \cdot \tan(2 \cdot \pi \cdot \frac{l_1}{\lambda})} \quad (\text{Eq. 8})$$

This gives us the impedance we find at the end of l_1 opposite to the coil L .

Now let us connect the arrangement of l_1 , l_2 and L with another antenna element l_0 (see Fig. 3). This element l_0 is resonant itself at the first operating frequency f_{01} (for example l_0 could be a quarter wavelength at the first operating frequency). At the junction of element l_0 with element l_1 we find the impedance Z_0 which we have just calculated. If we can find an arrangement of l_1 , l_2 and L that has a high impedance, preferably an infinite impedance at the first operating frequency f_{01} , antenna element l_0 will not see the rest of the antenna (l_1 , l_2 and L). The arrangement of l_1 , l_2 and L will work similar to a trap, although it is by far not equivalent to conventional trap operation. Remember we do not have any capacitance in the system!

To have an infinite impedance of Z_0 the denominator of Eq. 8 has to be zero at our first operation frequency f_{01} and the corresponding wavelength λ_1 . This leads us to Eq. 9

$$Z_{S1} = \left(X_L - \frac{Z_{S2}}{\tan(2 \cdot \pi \cdot \frac{l_2}{\lambda_1})} \right) \cdot \tan(2 \cdot \pi \cdot \frac{l_1}{\lambda_1}) \quad (\text{Eq. 9})$$

From this we get the first condition for the inductance L and its corresponding reactance X_L at the first operating frequency f_{01} and its wavelength λ_1 :

$$X_L = \frac{Z_{S1}}{\tan(2 \cdot \pi \cdot \frac{l_1}{\lambda_1})} + \frac{Z_{S2}}{\tan(2 \cdot \pi \cdot \frac{l_2}{\lambda_1})} \quad (\text{Eq. 10})$$

Now let us assume, that the total length for the arrangement l_1 , l_2 and L is determined, because of a given total length for the antenna. Then we can change the position of the coil or the lengths l_1 or l_2 , while the total length l_1+l_2 is constant.

Using equation 10 and changing the position of the coil within l_1+l_2 we get a graph for the necessary inductance like in Fig. 8. For these values of L and the corresponding position of L (determined by l_1 and l_2) the entire antenna ($l_0+l_1+l_2+L$) will be resonant at the first operating frequency f_{01} .

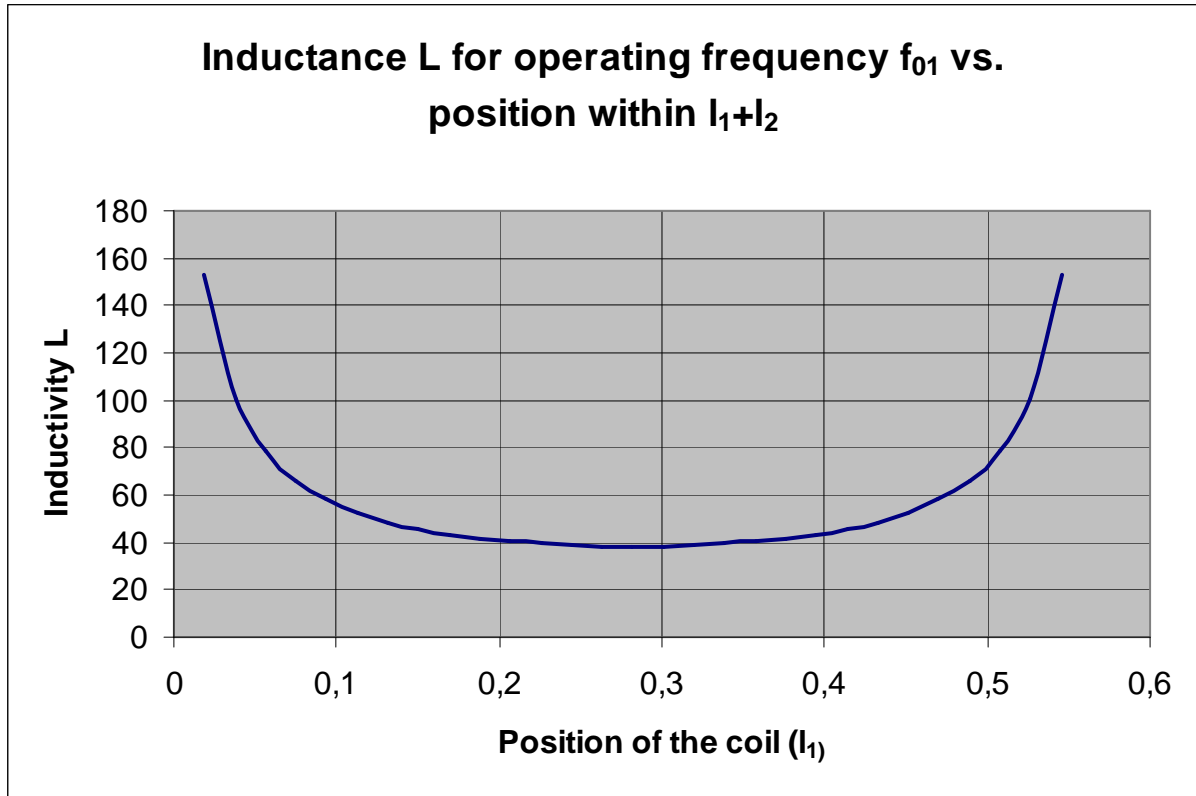


Fig. 8: Necessary inductance L for the first operating frequency as a function of the position of the coil within a determined total length for l_1+l_2 .

To get multiband operation of our antenna, the only thing we now have to do, is to let the coil work as a simple loading coil to achieve operation at another operating frequency. That is at the second operating frequency f_{02} the entire antenna ($l_0+l_1+l_2+L$) should electrically be for example a quarter wavelength λ_2 .

Calculating the value of a loading coil is common practice, so we will only give the condition of the loading coil at wavelength λ_2 .

$$X_{L2} = \frac{Z_{S2}}{\tan\left(2\pi \frac{l_2}{\lambda_2}\right)} - Z_{S3} \cdot \tan\left(2\pi \cdot \frac{l_0 + l_1}{\lambda_2}\right) \quad (\text{Eq. 11})$$

where the surge impedance Z_{S3} is

$$Z_{S3} = 60 \cdot \left(\ln \frac{4(l_0 + l_1)}{d_1} - 1 \right) \quad (\text{Eq. 12})$$

With Eq. 11 we have the second condition for the position (l_1 , l_2) and the value L of the coil. This is shown graphically in Fig. 9.

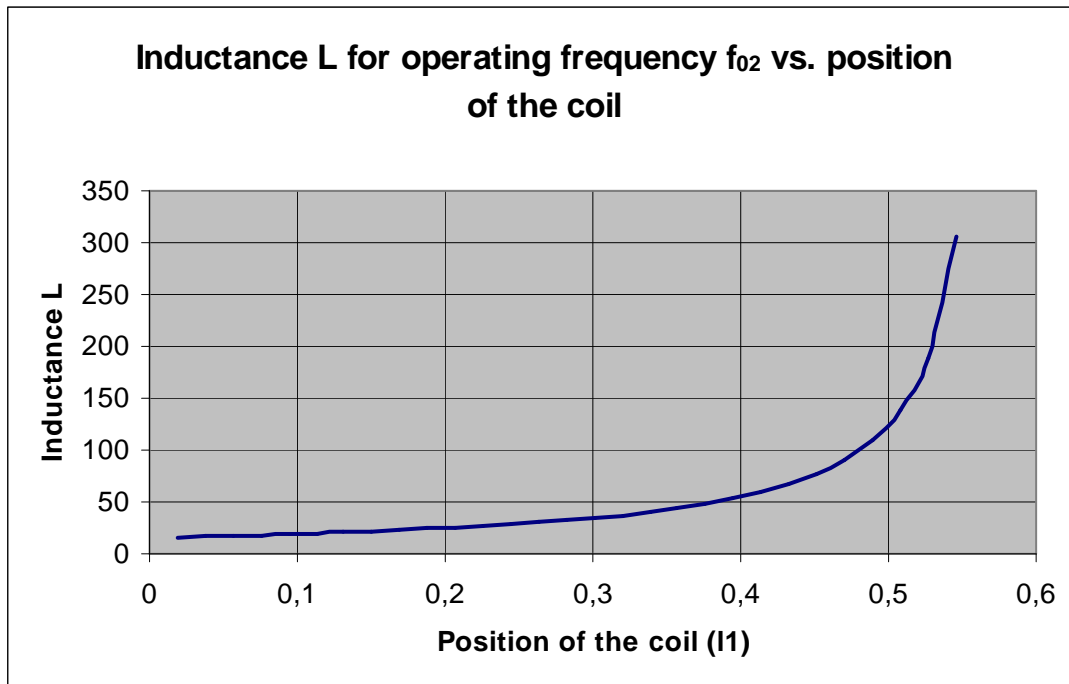


Fig. 9: Necessary inductance L for the second operating frequency as a function of the position of the coil within a determined total length for l_1+l_2 .

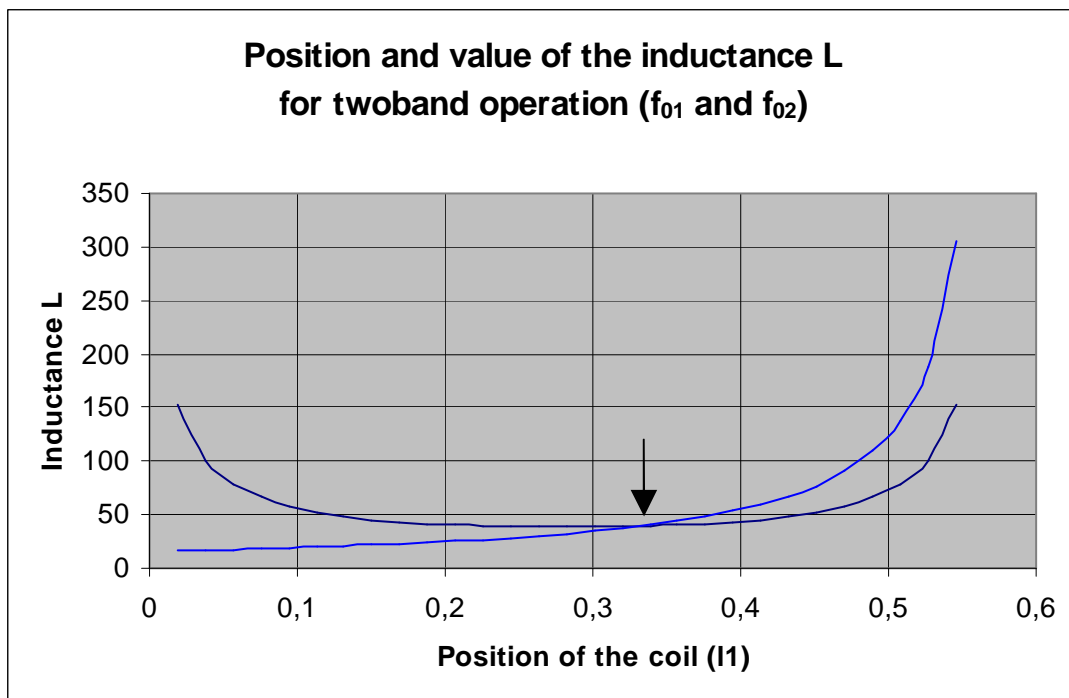


Fig. 10: Necessary inductance L for both operating frequencies as a function of the position of the coil within a determined total length for l_1+l_2 . At the point of intersection of both graphs we have the correct value of L and l_1 , l_2 for multiband operation

The only thing we now have to do, is to put both graphs (Fig. 10 = Fig. 8 + Fig.9) together. At the point of intersection of both graphs we have the correct value of L and l_1 , l_2 for multiband operation. Using these dimensions we get a multiband antenna for wavelength λ_1 and wavelength λ_2 .

For a given total length of the antenna ($l_0+l_1+l_2$) and any two frequencies we can always find a solution which allows multiband operation. Using an additional coil L_2 within the elements makes it possible to get three band operation and so on.

An example

You might like to try to validate our statements with your own antenna modelling programme. Therefore we include the design data for a two-band dipole. Use following settings for your model (see also Fig. 2):

$l_0+l_1 = 5,81 \text{ m}$
 $l_2 = 0,32 \text{ m}$
 $L = 62 \text{ } \mu\text{H}$
 wire diameter = 2 mm
 (height: $h = 7,5 \text{ m}$ for example)

Please make sure, that the inductance L is exactly at the given position! Most antenna modeling programs assume that a load (inductance) is at the center of a wire segment. You must choose a number of segments, which places the coil exactly 5,81 m from the feedpoint.

Our model was this:

Wire	Segs	X1(m)	Y1	Z1	X2 (m)	Y2	Z2	rad (mm)
1	21	-5,71	0	7,5	5,71	0	7,5	1,0
2	1	-5,71	0	7,5	-5,91	0	7,5	1,0
3	1	5,71	0	7,5	5,91	0	7,5	1,0
4	1	5,91	0	7,5	6,13	0	7,5	1,0
5	1	-5,91	0	7,5	-6,13	0	7,5	1,0

Source in wire 1, Segment 11.

Inductance L in Wire 2, Segment 1 and Wire 3, Segment 1.

With such a model run a frequency sweep between about 8 and 20 MHz. You should then see two resonance frequencies for the antenna, one at about 10 MHz, the other around 14,2 MHz. This could make a two-band antenna for the 30 m and 20 m amateur radio bands. Of course you could make some minor adjustments to get the resonance at the desired frequency within the band.

A similar two-band antenna can be designed for any pair of desired frequencies. Using more than one inductance-conductor combination makes it even possible to build antennas for more than two resonance frequencies. Triband antennas can easily be developed using this method, although the mathematics are a bit more complicated. We have designed and built many such antennas in the last years and

are currently erecting a giant three element three band (1,8/3,5/7 MHz) antenna for a radio club in the southern part of Austria. We have gathered a vast experience in designing and building such antennas. For example real coils have some self capacitance, which has to be considered, when designing such antennas. All these „little secrets“ are beyond the scope of such a short article. We hope to be able to publish more on that subject later.

Summary

By placing an inductor within the antenna element, it is possible to get an infinite impedance at a certain point of the element for a specific frequency. At the same time the inductor can act as a loading coil at another frequency. Thus by properly choosing the value and position of the inductance it is possible to achieve multiband operation. For a given total length of the antenna and any two (or more) frequencies we can always find a solution for multiband operation.

One of the most important features of this antenna is, that there are almost no limits regarding to input power into the antenna. This makes the novel multiband design not only favourable for antennas for radio amateurs, but as well as for commercial and military multiband antennas. As a further result building such antennas is cheaper and less complicated than building trap antennas. This novel principle can be applied to all kinds of antennas, e.g. dipoles, verticals or directive yagi-antennas.

Further benefits from our design are:

Very flexible construction principle

For any reasonable given length of the antenna and set of frequencies a multiband antenna can be constructed

Full element length active on all bands

In a trap antenna the outer parts of the antenna are inactive on the higher bands. In our design the entire element length is active on all bands. Therefore the gain and radiation characteristic can be slightly better on the higher bands.

Single-element multiband design

Our multiband antenna consists of just one element (i.e. a dipole), thus avoiding additional windload of many of today's designs using parallel elements.

Simple design

Avoiding trap LC-circuits in the multiband antenna makes fabrication much cheaper and the antenna less sensitive to environmental factors (i.e. temperature, rain, insects, etc.).

Possible applications

The principle can be applied to any kind of antenna, for example to multiband dipoles or verticals. It can also be used for directive antennas like yagi-antennas. It is also possible to replace the driven element of an existing trap-yagi with our design. By replacing only the driven element it is possible to run much higher power into an existing conventional trap-yagi antenna.

Important information:

Patents have been filed for such antennas. Therefore commercial use of such antennas is prohibited. Companies interested in our antenna are invited to get in contact with us.

Copyright © of this article 2005 by Dipl.-Ing. Juergen A. Weigl, OE5CWL/OE6CWL. All rights reserved. No part of this work may be reproduced in any form except by written permission of the author. All rights of translation are reserved.