The Two-Wire Beverage

Peter Pfann, DL2NBU

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translated by Ulrich Weiss, DJ2YA

1 Introduction

Looking at the very good results of the high-band antennas of our contest set-up, the antennas on the low bands did not appear to be optimal, especially with respect to receiving. To remedy that a Beverage antenna was built, but signals were extremely weak, contrary to what we had experienced in earlier contest operations of DL0CS. Furthermore the local site restricted the coverage of all directions.

After intensive studies of relevant articles in ham literature and the Internet the first Beverage was improved. This lecture summarizes the principles and constructional ideas employed to obtain optimal results.

2 How the Beverage works

The Beverage is principally a travelling wave antenna. Fig. 1 will help to illustrate its function [5].

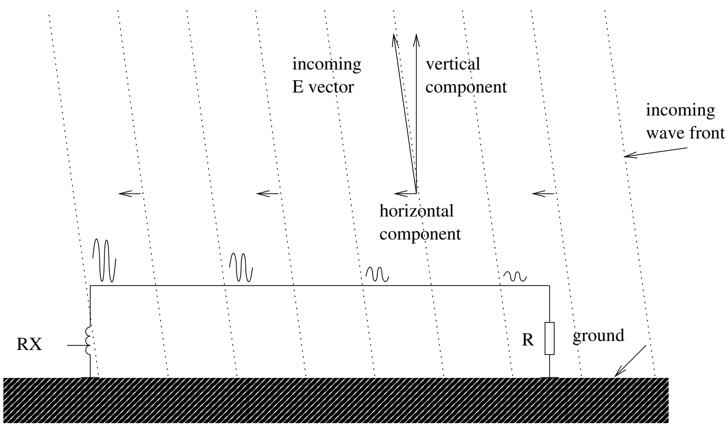

Figure 1: The principle of the beverage antenna

A wave front arriving from the right will travel along the wire following its direction. Close to ground the angle of the E-vector is determined by the ground conductivity and the elevation angle of the wave. When travelling in the wire the horizontal compound of the E-field moves electrons forward. In this direction they sum up in the proper phase to a maximum at the RX-end of the wire, while the voltage is significantly smaller at the end of the termination resistor.

Signals travelling from the opposite direction sum up from the left to the right reaching their maximum at the termination resistor on the right. When perfectly matched this resistor totally absorbs the signal and prevents its reflection back to the RX-end.

As with perfect (loss-less) ground the E-field is perpendicular to the horizontal wire there is no horizontal component in the E-field and for that reason no voltage will be induced in the wire. That means that - contrary to most other antennas - the Beverage works best over poor ground.

3 From the one-wire to the two-wire Beverage

The previous chapter has shown that the Beverage is a uni-directional antenna. How can it be used for the opposite direction? This can simply be done by swapping the feedline and the termination resistor. However, the feedline impedance is 50Ω while the value of the termination resistor is much higher. This problem can be tackled by transforming the impedance at the termination end to the value of the feedline impedance and terminate the coax with a 50Ω resistor. The direction of the Beverage is determined by the way you connect the two feedlines to the resistor and the receiver. This can be done remotely using a relay or by a switch in the shack if the lines are long enough.

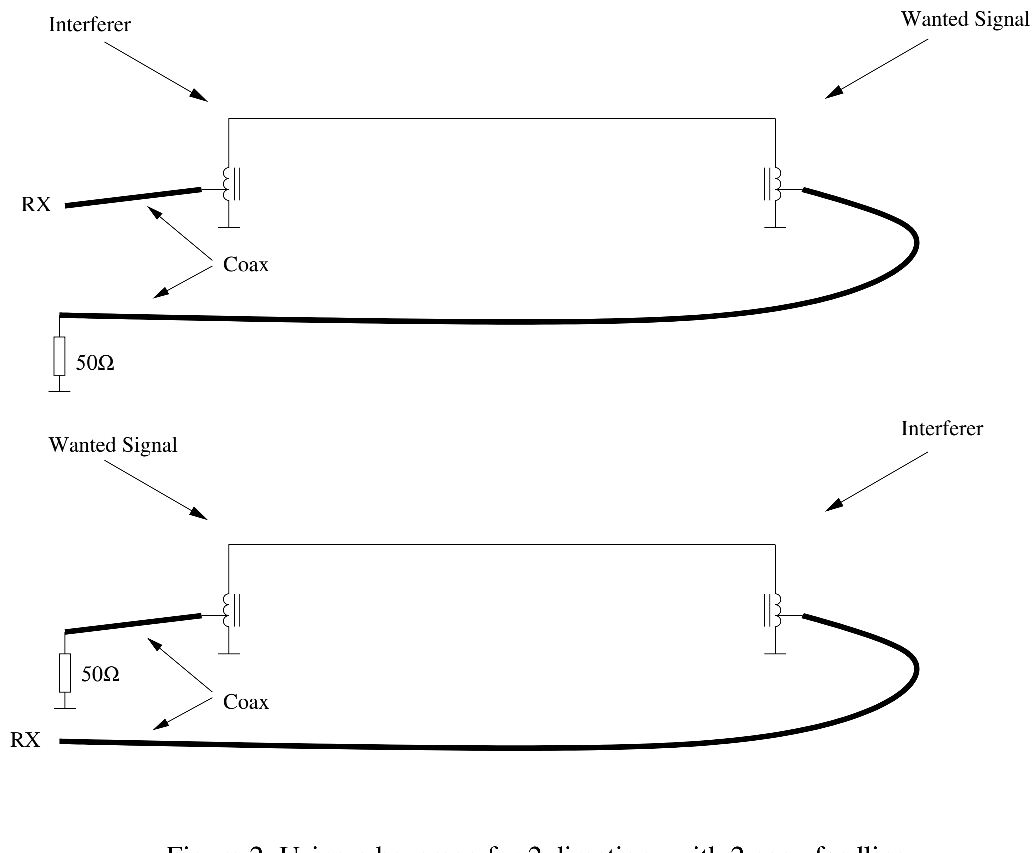

Figure 2: Using a beverage for 2 directions with 2 coax feedlines

As simple as this method looks, it has the serious disadvantage that you need a lot of coaxial cable, in the worst case an extra of more than the length of the Beverage itself. Because Beverages usually are very long that may mean several hundred metres of additional coaxial cable. Apart from the extra costs, cable losses, especially on 40m, cannot be ignored. A two-conductor coaxial feedline might be a good idea here. An even better one might be to do without a second feedline at all just at the price of a simple additional Beverage wire. Applying the methods described in [1, 6] this can be done as illustrated in Fig. 3.

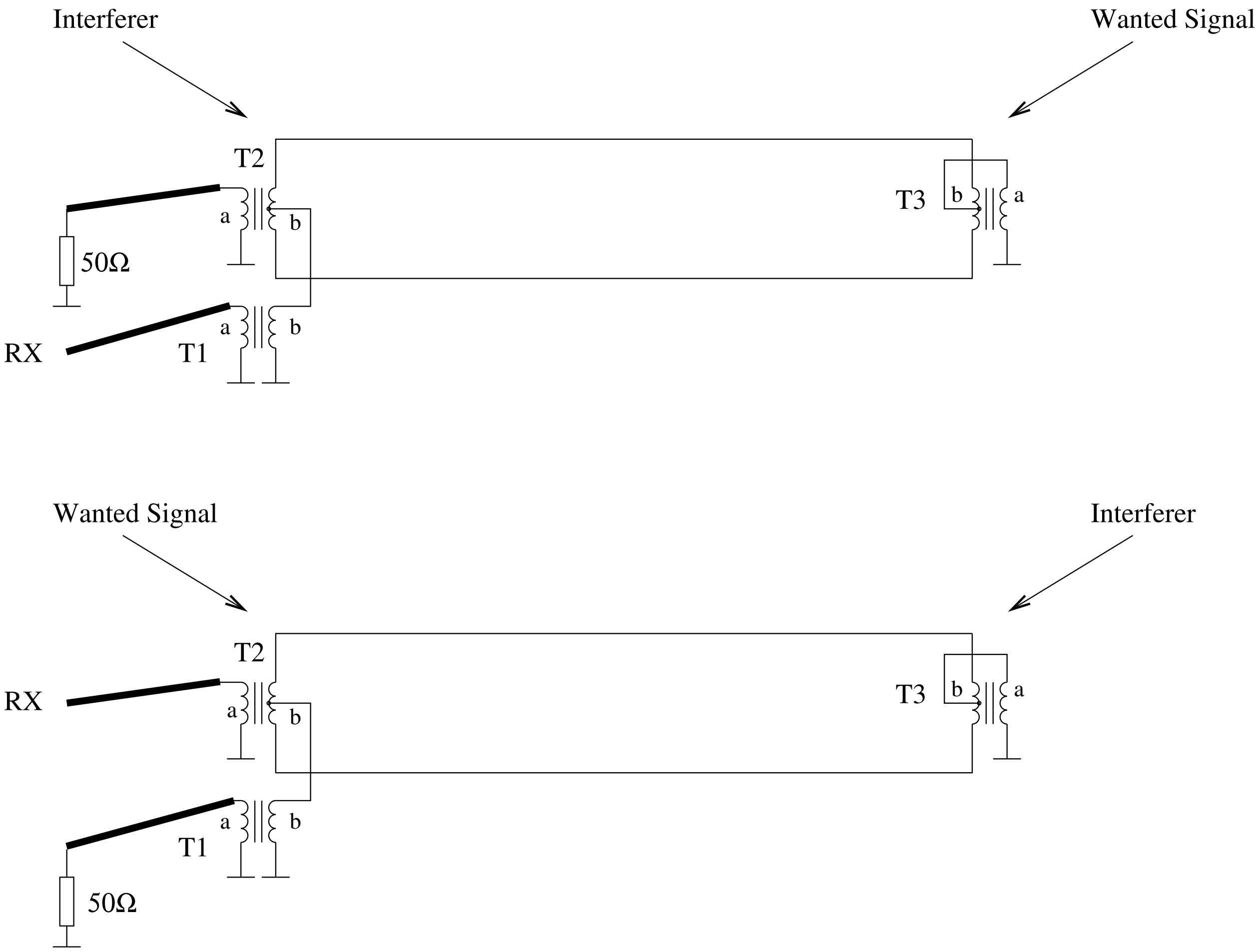

Figure 3: The principle of a 2-wire beverage

In Fig. 3a the wave front heaps up exactly the same voltage (and phase) in both wires at the left end of the antenna. As there is no voltage difference between the two terminals of winding (b) of T2, winding (a) does not provide any voltage. However, the common mode voltage is available at the centre tap of winding (b). After transforming the impedance of the Beverage wires to 50Ω in T1, it is fed into the feedline to the RX.

In the same way signals from the opposite direction produce identical voltages on either side of winding (b) of T3 and therefore no voltage across (a). The common mode voltage at the centre-tap of (b) is fed to side (a) of the transformer, which serves to transform the impedance of the Beverage to the impedance determined by the characteristics (diameter and distance) of the 2 Beverage wires, which now serve as a symmetrical feedline in balanced mode (push-pull). After impedance transformation in T2 the signal is absorbed in the 50Ω load on (a).

In Fig. 3b the desired signal causes identical voltages on the two wires at the right end of the antenna. As there is no voltage difference across side (b) of T3 there is no voltage induced on side (a). When the common mode signal from the centre tap of (b) is fed into (a) the push-pull signal across (b) is transferred back to T2 via the two Beverage wires that now serve as a symmetrical feedline again. With the balanced input (resulting in zero voltage at the centre tap of winding (b) of T1) the signal is totally transferred to the receiver after an impedance transformation to match the 50Ω coaxial feedline.

Unwanted signals from the opposite (right) direction accumulate as common mode signals at the centre tap on (b) of T2 and are dissipated in the 50Ω resistor after an impedance transformation in T1.

The characteristic impedance of a two-wire Beverage can be calculated with the formula [4]:

The surge impedance of a two-wire transmission line can be obtained from:

$$Z_{Bev} = 69\,\Omega \cdot \log_{10}\left[\frac{4h}{d}\sqrt{1+\left(\frac{2h}{S}\right)^2}\,\right]$$

In which

$$Z_{TL} = 276\,\Omega \cdot \log_{10}\left(\frac{2S}{d}\right)$$

h is the height of the wires above ground,

S the distance between the wires (center to center)

d the diameter of the wires (assuming $d \ll S$ and $d \ll h$)

The formula requires entries in the *same* measuring units. In references [6, 7] the term to be taken the root of is erroneously represented as $\frac{(2h)^2}{S}$.

With little harming effect to the function of the antenna, the actual impedances may slightly differ from the calculated values due to the influence of the ground characteristics or the dielectric of insulated wires.

4 Construction

4.1 Antenna

When building Beverage antennas there a some parameters that allow a reasonable amount of rope.

Length: The length of a Beverage should be at least 1λ(the absolute minimum is $\frac{\lambda}{2}$). According to [6] to obtain optimal F/B ratios the lengths should be:

160m	80m	40m
82 - 92 m (0.5 λ)	43 - 47 m (0.5 λ)	43 - 47 m (1.0 λ)
165 - 178 m (1.0 λ)	85 - 92 m (1.0 λ)	67 - 72 m (1.5 λ)
250 - 270 m (1.5 λ)	126 - 136 m (1.5 λ)	87 - 92 m (2.0 λ)
332 - 352 m (2.0 λ)	169 - 179 m (2.0 λ)	135 - 140 m (3.0 λ)
410 - 430 m (2.5 λ)	212 - 222 m (2.5 λ)	172 - 180 m (4.0 λ)
	258 - 268 m (3.0 λ)	

Up to a certain maximal amount the gain of a Beverage increases with its length while the forward lobe becomes narrower. However, the gain *decreases* again if you exceed the optimal length that depends on the velocity factor of the Beverage. The optimal length can be calculated as follows:

$$L/\lambda = \frac{1}{4 \cdot \left(\frac{1}{V} - 1\right)}$$

in which

L/λ means the length in λ yielding maximum gain and

V repesents the velocity factor of the Beverage.

The velocity factor of a Beverage antenna is mainly determined by its height and the frequency of operation. Normally it varies between 0.8 and 0.9, while heights of less than 1.5 m may reduce it to 0.75. Assuming a value of 0.9 the optimal length of a Beverage is 2.25 λ.

Height above ground: Normally antenna heights between 0.5 m and 3 m are being employed. Lower heights favour low angle reception, but provide less signal strength than higher Beverages. A height of 2m is generally considered as a very good value.

Spacing between the two Beverage wires: You can choose from a wide range of value between a just a few centimetres and about 50 or 60 centimetres. If the distance is small it may be difficult to obtain a constant impedance along the entire wire length, as variations in the spacing have a relatively strong effect on the value. Wide spacings result in high impedance values making transformer construction more difficult.

Wire diameter: There are little or no restrictions on the choice of the wire diameter. To avoid sagging wires should be pulled to a fair amount of tension. For such mechanical reasons relatively strong wires (ca. 1.5 mm^2- 2.5 mm^2) should be used.

Grounding: Beverage antennas require connections to ground at both ends. In most cases ground rods of about 1 m length will be sufficient. With very poor ground conductivity additional radials can be placed under the Beverage parallel to the wires. Their lengths must not exceed 10 m, because otherwise they might act as antennas themselves and contribute unwanted signals to the system. Two or three radials will be sufficient.

4.2 Transformers

As explained in Chapter 3 the two-wire Beverage requires three transformers:

- T1 to transform the impedance of the coaxial feedline to that of the Beverage,
- T2 to transform the impedance of the coaxial feedline to that of the 2-wire arrangement,
- T3 to transform the impedance of the Beverage to the two-wire arrangement.

Fig. 4 explains how the wires and transformers must be connected.

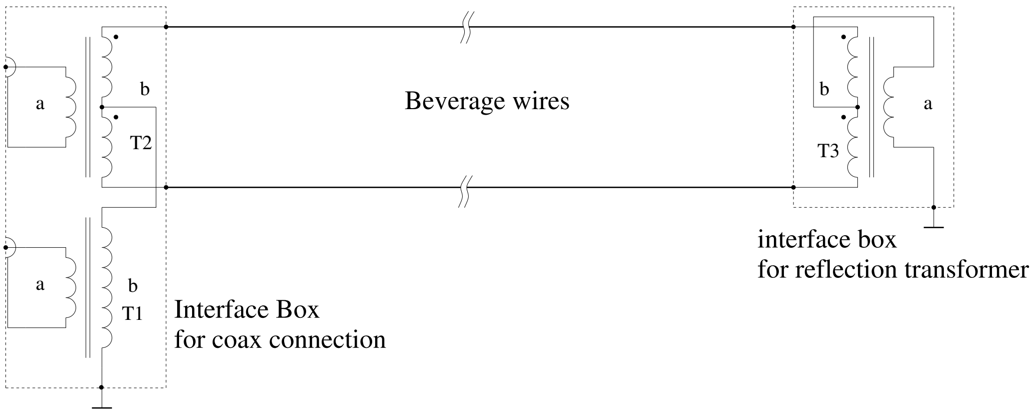

Figure 4: connection of the transformers to the beverage wires and coax feed points

As the antenna wires actually carry both the desired and the unwanted signals that are solely distinguished by their different modes (common resp. balanced), common mode suppression is the most crucial quality of the transformers. To avoid additional reflections they must provide a fairly good match into the coaxial feedline. Optimal cores are made of ferrites with a permeability factor $\mu_r$of 2000 - 5000 (e.g. EPCOS N27 or N30, Amidon/Fair-Rite 73 or 77), either as toroids, or beads or as binocular cores with their particularly favourable magnetic properties.

Important: To minimize leakage inductance and to obtain a broad frequency range the length/diameter-ratio should be as high as possible.

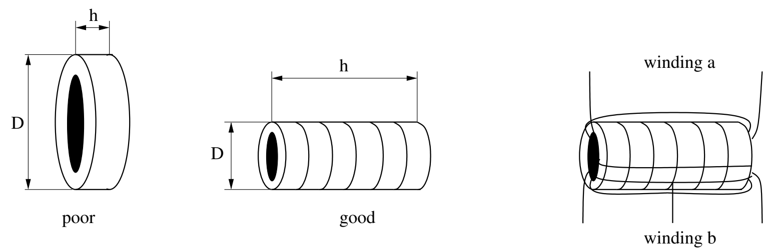

Figure 5: impact of core geometry on leakage inductance

The following formulas can be used to calculate the required number of turns.

T1:

$$\frac{n_b}{n_a} = \sqrt{\frac{Z_{Bev}}{Z_{Coax}}}$$

T2:

$$\frac{n_b}{n_a} = \sqrt{\frac{Z_{TL}}{Z_{Coax}}}$$

T3:

$$\frac{n_b}{n_a} = \sqrt{\frac{Z_{TL}}{Z_{Bev}}}$$

n_a : number of turns on winding a,

n_b : number of turns on winding b,

Z_{Bev} : characteristic impedance of the Beverage antenna

Z_{TL} : characteristic impedance of the two-wire line

Z_{Coax} : characteristic impedance of the coaxial feedline.

To achieve good common mode suppression in T2 and T3 winding (b) should be bifilar resulting in an even number of total turns. For effective transformation the inductance of a winding should be at least five times the respective impedance ($\omega L \geq 5 \cdot Z$). The easiest way to calculate inductivities is to use the A_{L}- factor as to be found in the manufacturer's data sheets. When stacking several cores you can multiply the single-core $A_{\mathrm{L}}$with number of cores in the stack. A_{L}values for most of the common cores can be found in ref. [6, 8].

On a stack of two FB73-6301 ferrite beads just two turns will do for a 50Ω winding. An extra third bead might reduce the loss by a few tenths of a dB.

4.3 A practical example

For a contest site a Beverage system had to be planned to cover all directions mainly on 160 m and 80 m, but the system should work on 40 m as well. The local situation favoured an arrangement as shown in the illustration.

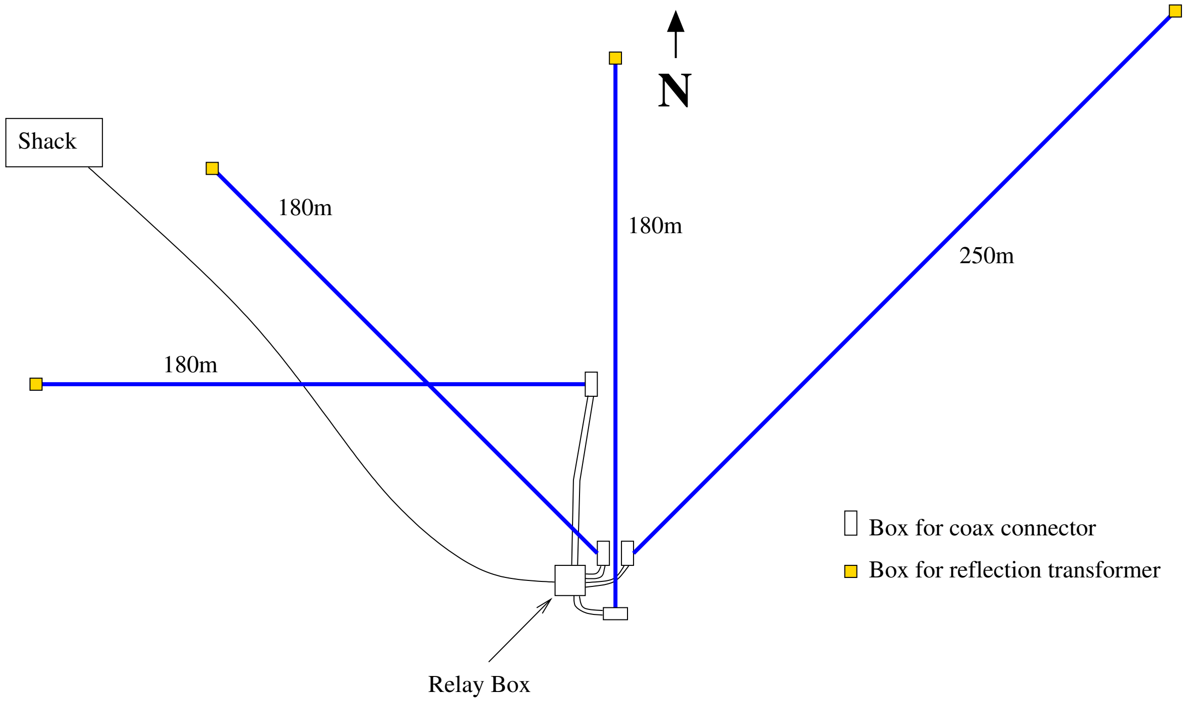

Figure 6: Beverage system of a contest site

The wire lengths of 180 m and 250 m were chosen for a good F/B-ratio. As there was more room to the NE, this Beverage could be made a bit longer. Crossing the different Beverages is not harmful as long as the angle exceeds 45 degrees and the distance between the wires is at least 30 centimetres.

With supports of 2 m and the sagging of the wires of 1.8 mm diameter spaced 6 cm the average height was about 1.80 m. From these physical dimensions (h = 1800mm, S = 60mm, d = 1.8mm). The impedances can be calculated as

$Z_{Bev} = 69\,\Omega \cdot \log_{10}\left[\frac{4\cdot 1800}{1{,}8} \cdot \sqrt{1 + (\frac{2\cdot 1800}{60})^2}\right] \approx 371\,\Omega$ and

$Z_{TL} = 276\,\Omega \cdot \log_{10}\left(\frac{2\cdot 60}{1{,}8}\right) \approx 503\,\Omega$. Now we can design the transformers:

For T1 the ratio $\frac{n_b}{n_a}$ amounts to $\sqrt{\frac{371\Omega}{50\Omega}} \approx 2.72$. Choosing 11 turns for n_b and 4 turns for $n_a$the ratio is 2.75 and the Beverage impedance of 371 Ω is stepped down to $371\Omega \cdot \left(\frac{n_a}{n_b}\right)^2 = 49\,\Omega$ (SWR=1,02).

For T2 the ratio $\frac{n_b}{n_a}$ amounts to $\sqrt{\frac{503\Omega}{50\Omega}} \approx 3.17$. Choosing 6 turns for n_b and 2 turns for $n_a$the ratio is 3 and the 503 Ω of the two-wire line (with 60 mm spacing) is stepped down to $503\Omega \cdot \left(\frac{n_a}{n_b}\right)^2 = 56\,\Omega$ (SWR=1.12).

For T3 the ratio $\frac{n_b}{n_a}$ amounts to $\sqrt{\frac{503\Omega}{371\Omega}} \approx 1.16$. Choosing 8 turns for n_b and 7 turns for $n_a$the ratio is 1.14 and the 503 Ω of the two-wire line (with 60 mm spacing) is stepped down to $503\Omega \cdot \left(\frac{n_a}{n_b}\right)^2 = 386\,\Omega$ (SWR=1.04). The 8 turns (n_b) result from 4 bifilar turns.

For all transformers a stack of three FB73-6301 ferrite beads was used.

In this example the calculated values hit the target very closely. For practical purposes a deviation of about 20 - 30 % is well tolerable, especially as the calculated values for the impedances of the Beverage antenna and the two-wire line may slightly differ in a real environment.

Before practical use the transformers should be tested. This can easily be done with an SWR-analyser. After terminating winding (b) with a resistor representing the impedance of Z_{Bev} or $Z_{TL}$the analyzer should read an SWR below 1.5 on all frequencies between 1.5 and 7 MHz when connected to winding (a). T3 can be tested when connected to T1 as shown below. Make sure that T1 has been checked for proper operation first.

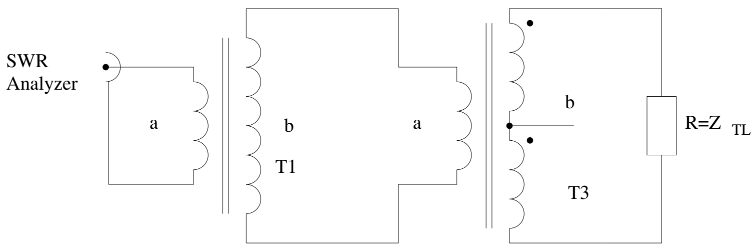

Figure 7: Test of transformer T3

You can check the transformers even if you do not have an SWR-analyser. You can use a simple SWR-meter and a small amount of RF (< 5 W) as long as the resistors can stand the power.

4.4 Hints for building

When building the Beverage make sure that the wires keep the direction and the distance to ground. At both ends the wires can slope down to the ground from a distance of up to 40 m (see Fig. 8).

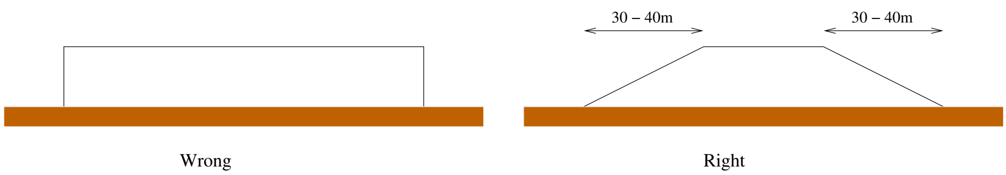

Figure 8: sloping ends improve directivity

By that both terminal boxes can be mounted at ground level doing away with the necessity of vertical down leads that might deteriorate the pattern.

Hammering posts of more than 2 m length into the ground is quite a feat. You can do without a ladder, if you use a small earth drill. The distance between supports should be chosen for a reasonable amount of sagging. In most case 20 - 30 m will be adequate. Wooden posts appear to be most suitable, those made of metal require insulators (e.g. those used for electric fences) to suspend the two wires.

To reduce sagging the wires can be kept under tension. In any case the terminal points must be free of any strain. This can most simply be accomplished by breaking the wires with insulators and attaching the ends to the ground posts.

5 Results and Future Plans

The Beverage-system described here has been in use for about a year. The original versions didn't have sloping ends and the spacing between the wires was wider. By adding these corrections last year the F/B-ratio was improved from 10 to about 20 dB. Once the receiving problem was used, we had a new one. If we wanted to work the stations we could hear now we had to do something on our antennas for transmission.

Nevertheless, what can be done to further improve such a receiving system? At the moment we can use the system on 160m, 80m and 40m, but only on one of these bands at a time. We aim at using the Beverages simultaneously on *any* band for *any* direction from *several* rigs. A suitable matrix to accomplish the switching has already been designed [9]. We are still looking for a termination device that works properly on a selected band while showing high impedance on the other bands.

My time window regrettably doesn't allow me to cover all aspects of designing Beverage antennas. Those who would like to learn more about them will find a selection of books and sources on the Internet in the bibliography below. Azimuth and elevation plots of the Beverages discussed here were obtained using the EZNEC modelling programme. If you want to do some modelling yourself, you'll find the files in the Internet [12]. Finally I'd like to express my gratitude to those who helped me to build the Beverages or to prepare this lecture: Uli, DJ2YA, Ingo, DJ5CL, Volker, DJ8QP, Hans, DK3YD, Jörg, DL4RDJ, and Ben, DL6RAI.

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