IMPEDANCE MATCHING A BEVERAGE ANTENNA TO A RECEIVER

A941-5

NICHOLAS HALL•PATCH AND JOHN H. BRYANT

BRYANT:

Ever since I first read of Beverage antennas and their almost magical attributes, I have lusted after a Beverage. Every time that failing propagation caused an elusive catch to disappear unlogged, I would swear to construct a Beverage "next weekend." Although I read every technical article ever published in English on Beverages, "next weekend" never arrived. Finally, in 1986, I happened to be in Edmonton, Alberta and arranged to spend an afternoon with Don Moman, Executive Secretary of CIDX and certainly one of the more experienced Beveragers in North America. Don patiently answered my numerous "practical" Beverage question and stiffened my backbone. The winter of 1986-87 was spent planning a DXpedition with fellow FTers Allen and Sams and in acquiring 2000' of wire plus assorted accessories. In the early spring of 1987, the expedition was ON! We planned to go about 30 miles out on the true prairie in western Oklahoma....at least 5 miles from the nearest man-made electricity, and give the thing a weekend trial. Calmer heads suggested that we string the Beverage up first at my semi-rural home to "make sure that we had all the kinks out" before going out 15 miles past the last flush toilet to stay for the weekend. We decided to test everything, including running the business end of the Beverage to my van and operating our radios on 12 volts.

The trial date arrived; after two hours of huffing and puffing, the Beverage was up and the moment had arrived to introduce the end of the wire to the back of my NRD-525! The NRD folks were even nice enough to provide two antenna ports, one for coax and one for wire antennas. As I hooked it up, I noticed the wire antenna port was labeled "High Z" (!!???).

As it turned out, even though the Beverage ran under two power lines (at about right angles), the directional and other special characteristics of the antenna allowed it to ignore all that potential noise; it proved to be an almost totally quiet antenna. Very quickly, we decided not to leave the flush toilets, refrigerator or the water bed behind to DX in a cow pasture. We had the DXpedition in my back yard!

The Beverage was everything I'd been led to believe. Our first night, we hit very fortunate propagation and logged both Europe and Japan (with multiple loggings) ON MEDIUM WAVE. Further, every band below 4 MHz was alive with superb DX! Later, I learned that if we'd been less greedy and only put up 1200', the Beverage would have worked for us up to at least 5.5 mHz! Well, when the DXpedition was over, I was not about to go back to my 'old' antennas and give up that Beverage. THAT'S WHEN THE WORDS ON THE BACK OF THE NRD "HIGH - Z" HIT ME BETWEEN THE EYES. All the reading came flooding back... "Z" means "impedance" and Beverages have characteristic impedances of from 300 to 700 ohms. The unfortunate part was that the nearest point to the shack that I could bring the Beverage — in a straight line — was over 70' from the shack. If I ran a bare wire lead-in (at about 90° to the Beverage) to the Shack, the directional characteristics of the Beverage would be badly compromised. If I ran a 400-700 ohm antenna through 50 ohm coax, I didn't know what would happen, but the words IMPEDANCE MISMATCH kept running through my mind. On the other hand, converting one of the two family cars into a semi-permanent DX shack in the backyard was causing major QRN at the dinner table... What to do?? What to do??

I called several technically proficient friends and they said - "No sweat, the Beverage has plenty of gain — use coax, come in out of the truck, its OK!" I tried that and it was nice to be inside, but now the Beverage seemed to perform as "just another wire antenna", particularly on weak signals. I was sure that I was suffering significant losses due to poor matching. I knew that Beverages were one of the most popular antennas for medium wave DXers and I knew that Nick Hall-Patch, Technical Editor for the medium wave Club IRCA, was technically astute and that he was a shameless Beverager. I contacted Nick and he solved the mismatch problem in a flash...thereby saving the Beverage and probably the marriage. He performed this miracle by introducing me to matching transformers constructed using toroidal shapes made from ferrite (sorta like iron Life Savers).

Looking back over this whole experience I realized that I DID NOT REALLY KNOW WHAT IMPEDANCE WAS!, even though I'd been in and around this hobby for over 35 years. Further, I realized that other DXers might well make the mistake which I did: running a high Z antenna through 50 ohm coax and thus losing a substantial amount of gain. So, I imposed upon Nick once again and asked him to write up what we had done and to begin his article with an explanation of impedance that even I could understand. I'm pleased to say that he has done so. Nick take it away.......

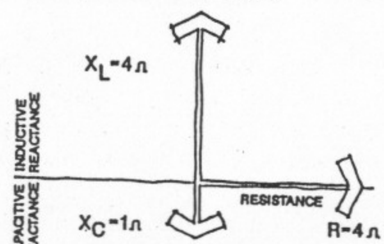
"Impedance" is one of those mysterious electronic terms which I'll attempt to define before we proceed to the body of this discussion. The term "impedance" is obviously derived from the verb "to impede" and impedance is a quality which impedes the flow of electric current. A more common and accessible term is "resistance' which is also a quality which impedes the flow of electric current, and in doing so converts electrical energy into another form of energy (heat, mechanical or whatever). Resistance has a similar effect on electric current whether the current is AC or DC.

However, when we are speaking of AC, more than simple resistance can impede the flow of electric current. An AC electric motor often has negligible DC resistance — a couple of ohms. If resistance of such a motor winding was all that impeded the flow of current, by Ohm's Law (I=E/R), it would pass a current of 30 or 40 amps. But it doesn't. It can be more like one or two amps. The inductance of the motor's winding also impedes the passage of AC by a quality known as inductive reactance (this reactance will also initially impede direct current (DC) but we won't go into that).

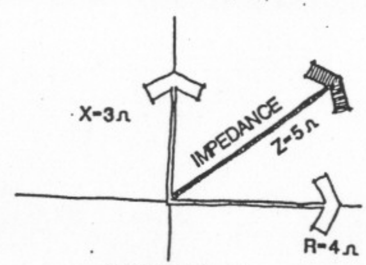
Inductive reactance is also measured in ohms like resistance is, but is dependant on the frequency of the applied AC: $X_L = 2\pi fL$ where X_L is inductive reactance, f is frequency in Hertz, and L in inductance in henries. Virtually no current would flow in our electric motor if RF type AC were applied to it, as its reactance would be so high. Inductive reactance impedes the flow of current, but it does not convert electrical energy to other forms of energy as resistance does; it simply stores the energy.

Another form of reactance is capacitive reactance, which is also measured in ohms and is frequency dependant: $X_C = \frac{1}{2\pi f C}$ where X_C is capacitive reactance in ohms, f is frequency in Hertz, and C is capacitance in Farads, but in this case, increasing the frequency of applied AC lowers capacitive reactance. X_C is usually denoted as a negative value, because capacitive reactance can cancel out inductive reactance when they're in series; this is the basis of tuned circuits. Capacitive reactance also impedes current flow, but stores electric energy rather than dissipating it in non-electrical energy.

So what is impedance then? It is the combination of capacitive and inductive reactance along with simple resistance in a circuit. Although these three qualities are all measured in ohms, they are not the same thing, and cannot simply be added together. Their common quality is that they impede the flow of alternating current, including AC at radio frequencies. Capacitive and inductive reactance can be added together in a series circuit, but the resulting value in ohms can't be then directly added to the resistance value in ohms. We must move into two dimensions to perform this addition, and refer to Sketch 1.



SKETCH 1



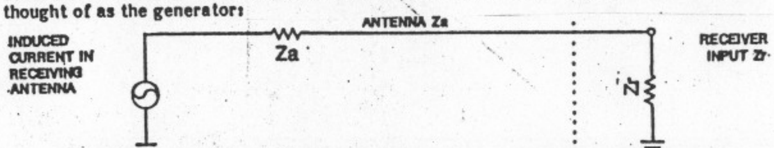
SKETCH 2

Resistance is a positive value on the x-axis of our two dimensional graph, X_L is on the positive y-axis, which X_C is on the negative y-axis. If X_C is 1 ohm and X_L is 4 ohms, then X is 3 ohms (an apparent inductive reactance).

Through the wonders of trigonometry and Sketch 2, we can now find a total value for our impedance (Z) which is 5 ohms. Hence the standard formula: $Z = \sqrt{X^2 + R^2}$, which is the same as the one used for finding the hypoteneuse of a right angle triangle. Note that Z determines what AC current will flow in a circuit for a given voltage, by replacing R in ohm's law with Z: Z = I/E. We won't address phase shifting here, but it can be important.

Now then, antennas are said to have impedance. They have capacitance to ground, and the length of the wire has inductance with itself. These are not large values, but can be significant at MW and SW frequencies. Because reactance varies with frequency, the total impedance of one's antenna will also vary with frequency. At some frequencies (resonant frequencies), the inductive and capacitive reactances of the wire will cancel out, leaving a pure resistive impedance. This resistive impedance is more than simply the resistance from one end of the wire to the other, and is not just a mathematical fiction; a certain RF voltage applied to the antenna at the resonant frequency will only be able to push so much current into the antenna as defined by Ohm's Law and the resistive impedance of the antenna. At non-resonant frequencies the antenna will show a different impedance which has an inductive or capacitive element to it, and once again, only so much current can be pushed into the antenna at a certain voltage as defined by Ohm's Law and the antenna Z.

Maximum power transfer takes place when the impedance of the current generator (usually a transmitter) is the same as that of the antenna. This condition is a desireable one, as maximum power is available for radiation. It is also not a bad condition to have between an antenna and a receiver; in this case, the antenna can be thought of as the generator:



When $Z_a = Z_r$, maximum power is transferred between the antenna and the receiver, even if it is only picowatts, and maximum signal strength will be noted at the receiver. (This condition assumes the Z_a and Z_r are both resistive impedance; if there is reactive impedance at the antenna, it should be cancelled out with an opposing value of reactive impedance at the receiver). However, below 10 MHz or so, note that weak DX signals are usually limited by atmospheric or man-made noise, and you won't hear DX any better by matching impedance between a random wire and a receiver if the DX is buried in external noise already. The receiver signal will certainly be stronger if the receiver and antenna are matched, but so will the external noise. If the random wire is short or close to the ground, or the receiver is insensitive, then impedance matching may allow weaker signals to be heard than would be otherwise (though still stronger than the external moise level) but generally one can say that impedance matching should not be necessary between a good random wire and a good receiver.

IMPEDANCE IN BEVERAGE ANTENNAS

Beverage antennas can be a different kettle of fish however. They are not very efficient, but are quite directional; the antenna will attenuate noise originating from outside its lobes. Also, there can actually be some noise cancellation over the length of the wire even if the noise is originating in the same direction as the desired signal. Therefore our signal to noise ratio may be improved quite markedly over that of a random wire, and in situations where weak signals are poking out of the mud (sunrise DXing for example), we may need every picowatt our Beverage can deliver to our receiver, as there have been cases where a DX signal is actually buried in the receiver noise floor even at medium wave frequencies.

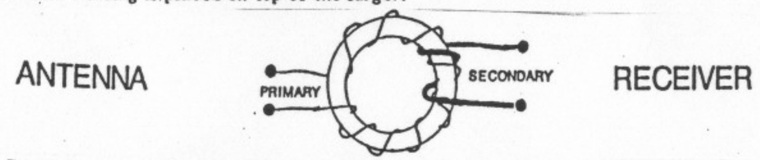
Beverage antennas generally have an impedance in the region of 300 to 700 ohms which is a not unreasonable match to (mostly older) receivers with "high impedance" antenna inputs. Even when using such a receiver, one may want to try to cancel out reactive elements of the antenna impedance using a pi-network coupler (see National Radio Club's Antenna Reference Manual's article by Russ Edmunds "Antenna Tuning Devices for Longwires on the MW BCB" or A DXer's Technical Guide 2nd edition, p. 61, published by IRCA), but that would only be necessary if one felt that potential DX was being buried below the receiver noise floor as opposed to the atmospheric or local noise floor (see "Noise Levels and Useable Receiver Sensitivity" by Chuck Hutton, pp. 6ff in A DXer's Technical Guide, 2nd ed.).

However, most modern receivers have an antenna input impedance of about 50 ohms (again resistive and often independant of the frequency tuned to due to broadbanded front ends), especially above 1600 kHz, and that will mean a fair mismatch to a Beverage antenna—not perhaps important in the vast majority of cases, but that sunrise skip DX from halfway around the world might just need the extra micropicowatt that matching the Beverage to the receiver could give.

Some of us may also need to have a receiver at a location different from the lead-in of our Beverage antenna. The obvious answer is to use coaxial cable between the Beverage and the receiver input, and our 50 ohm receiver input will mate nicely with 52 ohm coax. But, even though losses in coax are minimal at SW frequencies and below, our Beverage will still be looking at a mismatch with 50 ohms, and there is a possibility that electrical noise will be induced onto the coaxial lead-in and/or that the shielding of the coax mav act as an antenna and spoil some of the hard-won directional effects of the

IMPEDANCE MATCHING TRANSFORMERS

So, how do we match a Beverage antenna (approximately 500 ohm Z) to a 50 ohm receiver input? A conventional broadband matching transformer is probably the easiest way to go using a ferrite toroidal core. Such cores are available from Amidon Associates, 12033 Otsego St., North Hollywood, CA 91607. A conventional broadband transformer has a primary winding and a secondary winding; on a toroidal core, the smaller winding is placed on top of the larger:



Because ours will be a step-down transformer, the primary will be the larger winding. First, one takes the impedance of the antenna to be matched, in this case about 500 ohms, and multiplies it by 4 to yield a desired X_L of the primary winding of about 2000 ohms. This X_L will be at the lowest frequency that the transformer will be used, say 500 kHz, if MW DX is anticipated.

$$\text{desired L of winding} = \frac{X_L}{2\pi f} = \frac{2000}{2\pi \times 500\ \text{kHz}} = .637\ \text{mH}$$

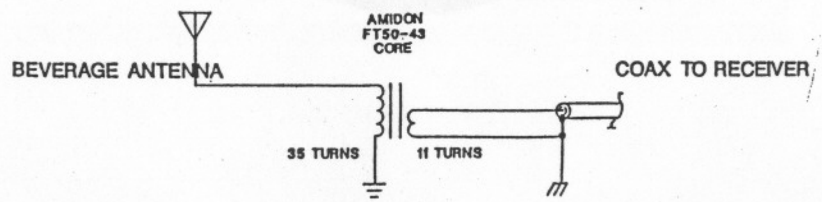
If one choses an Amidon FT-50-43 toroid as the transformer core, Amidon data will yield the following desired number of turns (N) for the transformer primary

$$N = 1000\sqrt{\frac{\text{desired L (mH)}}{A_L\ \text{(mH/1000 turns)}}}$$

A_L for the FT50-43 core is given as 523, so:

$$N = 1000\sqrt{\frac{.637}{523}} = 35\ \text{turns.}$$

The number of turns for the secondary winding can be found using the same process or by knowing that the impedance ratio of a transformer is the turns ratio squared. Either method yields 11 turns for the secondary.



Toroidal cores are a bit trickier to wind than an ordinary cylindrical core. Fortunately, this transformer doesn't have that many turns, so we can use a simple method. Each turn uses about 0.85 inch of wire, so the total wire for our primary winding shouldn't be more than about three feet with plenty of wire left over for leads. As the core is small, wire of #28 or smaller guage should be used. I prefer ordinary magnet wire as its insulation is thin. Take the 3' of wire, tape or knot one end around the core, leaving a couple of inches to spare for a lead. Run the other end of the wire through a darning needle, affix the core carefully in a small vise if necessary, then weave the needle and wire through the center of the toroid until you have the 35 turns. One can also wind the desired wire length around a small flat bobbin thin enough to fit through the toroid center, and play the wire out as you weave it through toroid center. This method is absolutely necessary if many more turns than our 35 are contemplated. The secondary can be wound the same way using about 14" of wire.

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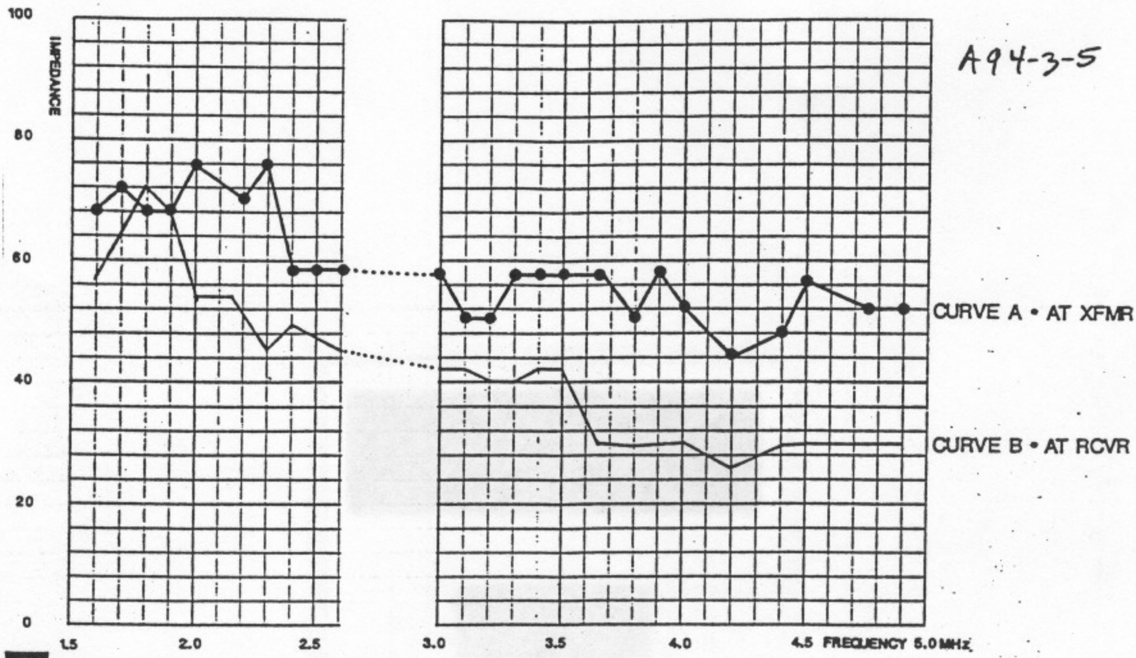

CHART B

Okie Beverage fabricated from 18 ga. wire, mounted at aprox. 8'-0"
Curve A was measured @ the Hall-Patch matching transformer
Curve B was measured at the end of 70' of 50 ohm coax with the transformer connected

IMPEDANCE CURVES • 1200' OKIE BEVERAGE • WITH MATCHING

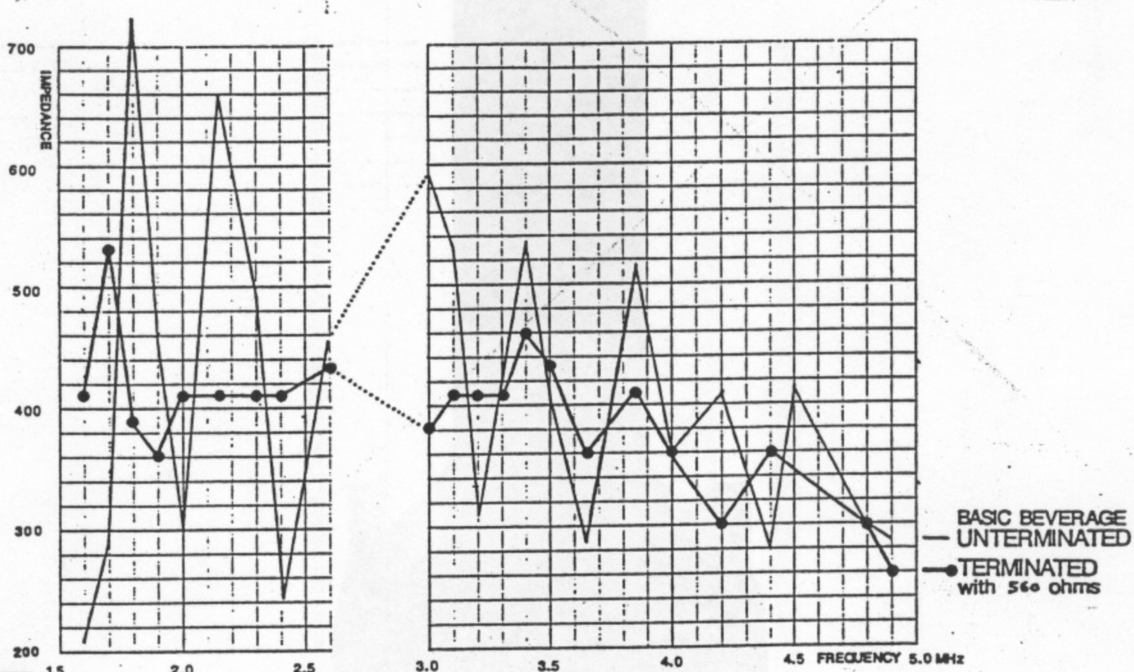

CHART A

Beverage fabricated from 18 ga. wire, mounted at aprox. 8'-0"

IMPEDANCE CURVES • 1200' OKIE BEVERAGE (at Stillwater, OK) • WITHOUT MATCHING

Graph A shows the impedance of the 1200' Okie Beverage as measured by the MFJ 204-B Antenna Bridge. The unterminated Beverage shows impedance swings from 200 to 700 ohms depending on frequency. The characteristic impedance of the wire doesn't really vary so radically with frequency; the bridge is responding to reflections off the far end of the unterminated wire. When the wire is terminated to ground with a resistor (560 ohms) approximating its characteristic impedance, the impedance measurement smooths out considerably with regard to frequency, and becomes a bit more comprehensible. A lower value of termination resistor might approximate the Okie Beverage characteristic impedance even better, but we should regard the apparent wild swings of impedance on the unterminated Beverage as a quirk of the measuring equipment. We won't be using the wire for transmitting, and the bridge is primarily designed to measure transmitting antennas.

BRYANT:

THE PROOF OF THE PUDDING:

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After about six months of testing and use, I have become convinced that the impedance transformer is effective. The comparison tests were all performed with my NRD 525, which has been modified with an outboard 4" diameter electro-mechanical milliamp meter. This meter measures signal strength at the receiver's AGC circuit and is considerably more accurate than the notoriously poor S-meter on the 525. However, this "test instrument" could not be called "laboratory grade" by any means. The tests:

1) Comparing 70' Coax and Impedance Xfmr connected to the Low Z Port with Direct Connection of the Beverage to the High Z Port of the Receiver.

Since the 525 has both High and Low Z antenna ports and since they are switchable, I was able to bring the receiver to the end of the Beverage, lay the 70' of coax out on the ground, hook up both the coax and the end of the Beverage itself to the two antenna ports and compare the two lead-in situations by shifting the switch and one jumper wire. I compared the two lead in methods at mid-day on the broadcast band with S-7 to S-9+10 signals. There was no discernable loss with the coax lead and matching transformer. There could have been the "1 db loss ber 100' of coax" rule of thumb but I couldn't measure it. Using the same method, I also compared the two lead-ins on 90 and 60 meters in the evening. This was naturally more difficult due to fading and QRN. I used the strongest, steadiest signals available - generally around S-8 to S-9. There was no discernable difference between hooking the Beverage directly to the High Z port and using the 70' of coax plus the transformer. I did "feel" however that there was the same 1 to 2 db loss as was probable on medium wave. Basically, the darn matching transformer WORKED and I could come in out of the cold and use the transformer and coax with no meaningful loss of signal strength or directional characteristics.

2) Comparing the 70' Coax Lead-in With and Without the Matching Transformer.

For this test, I "permanently" installed the 70' of lead-in to my Shack, put the 525 on the desk and ran comparisons using: a) the coax directly connected to the Beverage antenna. b) the same hook-up but with the matching transformer between the coax and the Beverage.

The tests were as before: medium wave at mid-day on strong steady signals (S-8 to 9), and in the evening on the best signals available on 60 and 90 meters. Thanks to the assistance of a long suffering spouse, these tests, too, were almost instantaneous.

The result:

NOT HAVING THE TRANSFORMER IN THE CIRCUIT COST ME 2 TO 2½S UNITS (10 TO 12 db) ON EVERY FREQUENCY TESTED.

Until others run the same tests, I cannot claim that my results will be universal. However, I'm willing to wager that anyone using a coax lead with a Beverage and NOT using a matching transformer is giving up at least 10db of useable gain!

IN USE TESTING:

Although I performed no comparison tests using weak, low arrival angle DX signals, I can share the results of two spring Equinoctal seasons hunting Indonesian stations.

Spring 1987: Numerous rare and difficult Indonesians were logged and QSL'ed including RRI Merauke, 3905 kHz. An unsolicited comment from the station manager (who opened the station in 1964) related that my report was only the second correct report from North America in the 23 year history of the station. The first North American report was from Bill Sparks of San Francisco.

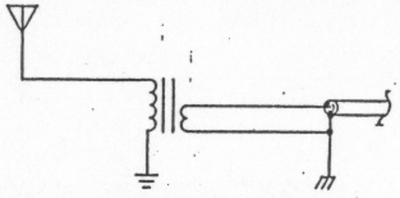
Spring 1988: Again, many rare and difficult Indonesians were logged. This season, a number of the very small "RKPD" stations were "in." Mitch Sams, Kirk Allen and I all three indulged in an orgy of Indo hunting. The Beverage plus transformer clearly outperformed the other DX antennas. There were several instances when Kirk and Mitch could only hear hets and I would have very useable audio. These included RRI Mataram and RKPT2 Manggarai.

CONCLUSION:

A) If you have to use a lead-in with a Beverage antenna, use coax so as not to destroy the directional effects of the Beverage.
B) If you must use a coax lead in with a Beverage, a toroidal core-based matching transformer will probably save you 10 to 12 db of signal loss.

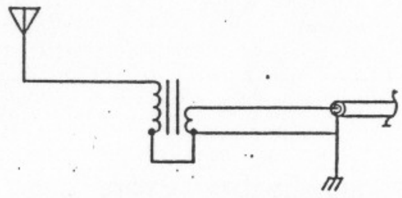
AFTERWORD:

There are at least two possible arrangements useable to connect the transformer into the antenna/receiver/ground circuit. They are:



TWO SEPERATE GROUNDS

CIRCUIT A



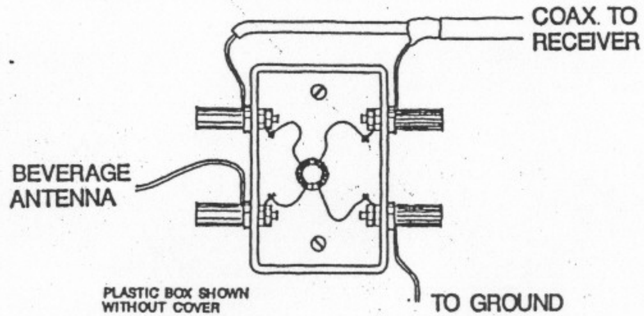
GROUND AT COAX SHIELD ONLY

CIRCUIT B

Nick Hall-Patch and I prefer Circuit A. He feels that it is cleaner and will, theoretically be "lower noise" if there is a good RF ground available. I compared both circuits and found them to deliver equal signal strength on 60 meters and below.

However, careful checking showed that Circuit B caused significant loss of directional characteristics when compared to Circuit A. It would appear that Circuit B should only be used where a good RF ground is not available within 4 or 5 feet of the antenna end.

Finally, the wire used in fabricating this transformer is almost hair-thin. The whole transformer is quite fragile. I mounted the transformer in a small (2" x 3" x 3/4") plastic project box from Radio Shack, fixing the toroidal core to the back wall of the box with a dab of silicon sealant. The wires are then fed out through four binding posts. The top two binding posts are the 50 ohm winding while the bottom two are the 500 ohm primary winding. The two left binding posts are the "hot" side and are red; the right side black posts are the ground side. I have the box mounted on the wall now. (See drawing below). I should note that, with this arrangement, I must scrape the weather - induced corosion off the leads every 60 days. Now that the experimentation is complete, the whole thing will be weather proofed with coax sealant.



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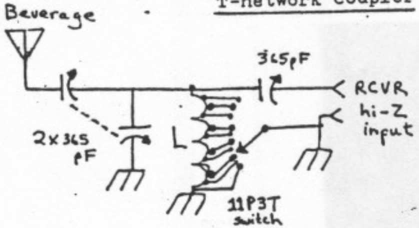
(Since this article was written, I have tried a pi-network coupler with a 1000' Beverage antenna and found that it only works well below about 700 kHz. So I've tried the T-network coupler described below, and found it can give up to 6 dB "gain" through improved matching between antenna and receiver. This was from MW well into the SW bands.)

T-network coupler



(L is about 140 uH. I used a T-157-6 Amidon core with 110 turns, tapped every 10 turns)

If you want to be experimental, you could wind a 50 turn primary, and put taps every 5 turns or so, and use a rotary switch or simple alligator clip to find at which tap signals are strongest on your monitored frequency.

I believe it to be most "sanitary" to use a separate earth ground at the primary rather than connect the secondary ground to it, if you are using a length of coax from the secondary to your receiver, but that may depend on how good an earth ground is available at the site. Separate grounds will help prevent the coax shield from picking up undesired signals or local electrical noise.

Chart B shows the apparent impedance of the Beverage antenna with the aforementioned matching transformer in place. The terminated Beverage measured through the matching transformer (curve A) now appears to have an impedance of between 40 and 65 ohms over the range of 1.5 to 5.0 MHz, with much of the frequency range falling nicely around 50 to 55 ohms. We are certainly a whole lot closer to matching up with our 50 ohm coaxial lead-in and the 50 ohm antenna input terminal, and allowing for margin of error, we probably can't do a whole lot better. Curve B, measured at the receiver end of the coax shows somewhat lower Z values (explanations, anyone?), but are certainly in the ballpark for the frequency range.