WHY YOU NEED A CURRENT BALUN

INTRODUCTION

It is common practice to use a balun when connecting a coaxial cable transmission line to an antenna. There are three electrical requirements to be met. Of these three, two are generally well known, but the third, maybe not so much. Addressing all three issues with the correct type of balun will lead to the successful integration of the antenna and feedline.

REQUIREMENTS

1. Requirement #1 - Preserving Balance: The word BALUN is derived from the fact that this device connects a **BAL**anced antenna feed point, such as a dipole, to an **UN**balanced feed line, commonly being coax. Coax is unbalanced because the braid is connected to “ground” at the rig. Balanced and unbalanced circuits should never be connected together as the electrical properties of both circuits will be seriously compromised. The balun is the intervening item that transforms the unbalanced to the balanced.

2. Requirement #2 - Impedance Matching. The balun will commonly match a 50 ohm feed line impedance to feed point impedances of 50 ohms or 200 ohms, depending on the antenna design thus achieving a low SWR.

3. Requirement #3 - Suppressing RF on the feed line. This is the not so well understood issue that often results in RF problems in the shack. The use of the correct balun will alleviate many of the problems associated with RF on the line.

ANTENNAS

The half wave dipole model is used to demonstrate the properties of a balanced antenna and the ways and means to properly feed it. The dipole antenna operates without a connection to an Earth ground, and so the feed point is a good example of a balanced circuit, which needs to be connected to a balanced feed line. Coax is not a balanced feed line and therein lies a problem.

Verticals on the other hand are operated against an Earth ground which is a good example of an unbalanced circuit. The vertical can be directly fed with an unbalanced coaxial feed line. This style of antenna may make use of impedance matching networks at the feed point, but they are impedance matching networks, not baluns.

GROUNDS

Antennas and grounds go hand-in-hand, and it is important understand the role of ground as will be seen later in this article, (Figure 4).

Earth Ground means an electrical connection made to the soil through use of a grounding conductor such as a rod, plate, or wire etc. Our stations are Earth grounded as soon as the AC line cord of the rig is plugged in to the AC wall socket. The AC line cord contains the green wire safety ground conductor as required by the Canadian Electrical Code. This is to prevent shock hazard occurring should there be an insulation failure in AC power connected equipment. The green wire connects the rig chassis to Earth ground in the electrical service entrance panel in the residence. The consequence is that the station is mandatorily grounded to Earth.

Electrical Ground is taken to be the common voltage point in an electrical system. This would be the ground bar in the shack to which all equipment in the shack is connected with a ground wire. This is a safety ground to ensure that no hazardous voltage can exist between equipment. This ground bar is to be connected to the service entrance Earth ground.

Note that these grounds are Safety grounds. They are NOT Signal grounds or RF grounds.

Note - RF Ground does not exist. Quote: “The idea that earth ground electrodes provide a zero impedance sink that we can use to absorb or otherwise make unwanted signals or noise go away can’t possibly be true”. It is a total myth, pure and simple, having no basis in reality in this universe”[1]

FEED LINES

The antenna is connected to the rig by the feed line. The feed line is not part of the radiating or receiving system. The antenna is the radiator/receiver. The purpose of the feed line is to transport TX RF from the rig to the antenna without radiating, and conversely, to transport RX signals to the receiver without picking up extraneous signals.

Coax is an unbalanced feed line with a center conductor insulated from a surrounding, conducting braid which is the “return” circuit. The coax connector on just about every rig is a SO-239 bolted to the chassis and so the coax braid is always grounded in this connector system. TX and RX signals are propagated up and down inside the coax, like water in a pipe, and that means they are totally contained within and totally isolated from the “outside” world, neither radiating nor picking up signal. Thus coax is a shielded line. Also worthy of note is that the signal current on the center conductor is equal and opposite to the signal current on the braid. Since the two opposing currents are very close together in the coax, and the fields surrounding each conductor are opposing, they would cancel at a distance, and no radiation takes place. These equal, opposite, close together signal currents are referred to as Differential Mode currents. One more thing - while the construction of coax lends itself to an intuitive understanding of shielding, there is one other very important property that clinches coaxial cable shielding effectiveness, and that is the Skin Effect on the braid. If unfamiliar with skin effect, please read the Sidebar now.

Balanced feeders consist of two wires placed side x side, commonly known as Ladder Line. There is no shield. However, the line does not radiate because the signal currents in each of the two wires are also equal and opposite and close to each other. These are Differential Mode currents as well, and as such the electromagnetic fields developed around each wire will be opposing, and cancelling, this also means no radiation of signal takes place at a distance from ladder line.

Since the line is not shielded, the two conductors are vulnerable to extraneous signal induction. However, the induced currents will be equal in each wire as both wires “pick-up” equally well, being close together. Since they flow in the same direction in both wires, this is called a Common Mode current, quite different from the Differential Mode current flow. Common mode fields do not cancel and unwanted signal will be transported to the rig or antenna.

Circuits that terminate either end of the balanced line need to be balanced in themselves so as to reject common mode currents. Retaining line balance is essential for balanced line operation as grounding of one side will allow unwanted common mode signal current to flow in to the receiver. The SO-239 unbalanced, grounded, coax connection for the antenna feed line is unusable for balanced line connection.

PRESERVING BALANCE

Use of a proper balun can provide RF isolation between the grounded rig and unbalanced coax to the balanced requirement of the antenna. In other words, an unbalanced coaxial feed line can be coupled to a balanced antenna as long as there is an intervening balun. The balun can be placed anywhere in the coax feeder if ladder line is connected to the balanced side of the balun leading to an antennas’ balanced feed point. Requirement #1 addressed.

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[1] Keith Armstrong. Cherry Slough Consultants, Stafford, UK. “Fundamentals of EMC Design” page 113, para 7.7. Interference Technology 2012

ANTENNA IMPEDANCE MATCHING

Coaxial cables typically have a 50 ohm characteristic impedance, which turns out to be close to the radiation resistance at the feed point of a dipole antenna. Using a balun that offers a one to one (1:1) transformation ratio means that the 50 ohm unbalanced impedance of the coax on the primary side of the balun will match the 50 ohm balanced impedance of the dipole on the secondary side, while preserving the balance of the dipole.

Different styles of dipole-like antennas can have differing impedances which the balun must be matched with. Most commonly, baluns are offered with the ratio of 1:1 intended for basic dipole configurations as well as 4:1 for other dipole-like antennas such as Off Center Fed or Folded dipoles where the feed point Z is higher, such as 200 ohms.

Note that a balun is NOT an antenna tuner device; it can only match certain fixed impedance ratios. Requirement #2 addressed.

RF ON THE FEEDLINE

The “RF-in-the-Shack” experience is mostly due to RF flowing on the OUTSIDE of the coax feed line entering the radio room. This commonly manifests itself as RF voltage causing “tingles and bites” on conductive surfaces such as the key or mic when transmitting, or TX audio distortion due to RF feeding back in to the audio circuits, or unexplained computer behavior, and other RFI effects. Use of baluns that solve problems #1 and #2 will not solve problem #3 if the wrong type of balun is used. Requirement #3 remains to be resolved.

RIG – COAX – ANTENNA SCHEMATIC

Figure 1 represents the electrical circuit for a transmitter connected to a feed line and then to an antenna where the antenna is represented by a 50 ohm feed point Impedance. The Tx and Rx signals flow inside the coax as differential mode currents.

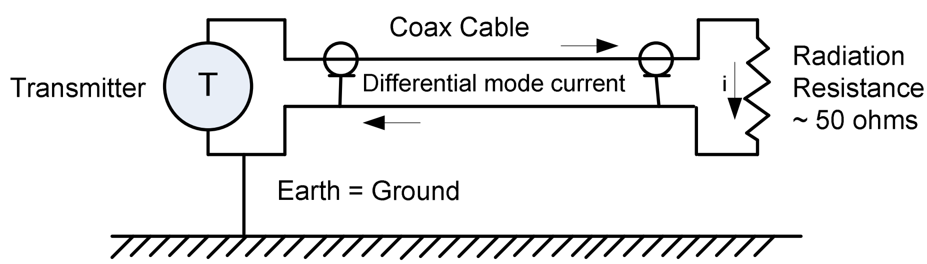


Figure 1

Note that while the transmitter chassis is connected to Earth ground, no current flows in that connection because there is no complete circuit from ground to anywhere else. The RF currents are wholly contained within the loop.

VOLTAGE DISTRBUTION on a DIPOLE ANTENNA

Figure 2 is the classic view of the voltage distribution along a half wave dipole.

The solid line waveform represents the standing wave voltage along the antenna at the peak of one-half cycle, where the electron flow in the wire is from right to left. On the second half cycle, as the current reverses, so does the voltage, as illustrated by the dotted line.

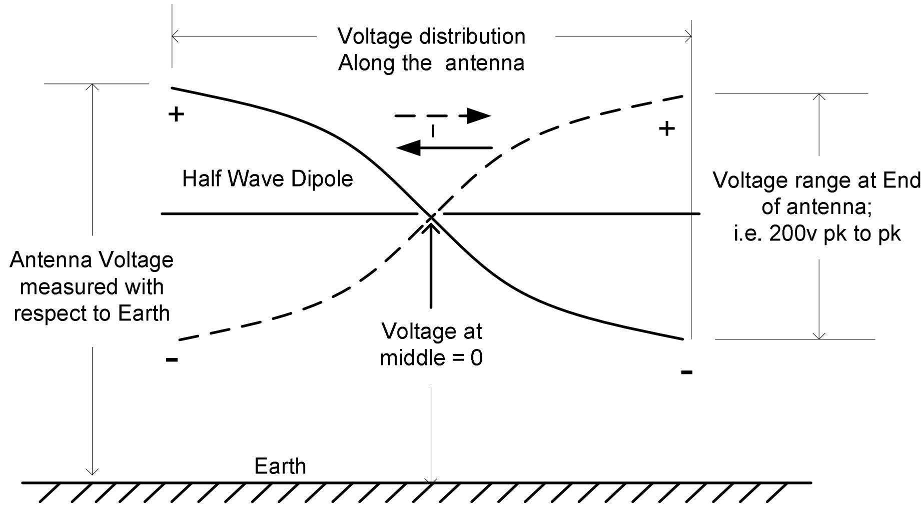


Figure 2

The voltages on the antenna are measured with respect to Earth. At all points along the antenna there is a voltage with respect to Earth. The highest voltages will be measured at the ends of the antenna because the antenna is "open circuit" there. The magnitude of the voltage at the ends will depend greatly on the transmit power and can easily reach 100's of volts or more.

Only at the center feed point does the voltage remain at zero with respect to Earth.

THE OFF CENTER FED (OCF) DIPOLE ANTENNA

Figure 3 is an Off-Center-Fed antenna, perhaps better known as a Windom. This class of antenna is known for multiband capability. As with the dipole, the same standing wave voltage is developed along its length. The only difference is the location of the feed point with respect to Earth. Note that the voltage "**V**" on the antenna at the feed point is not zero[2] as seen in Figure 2.

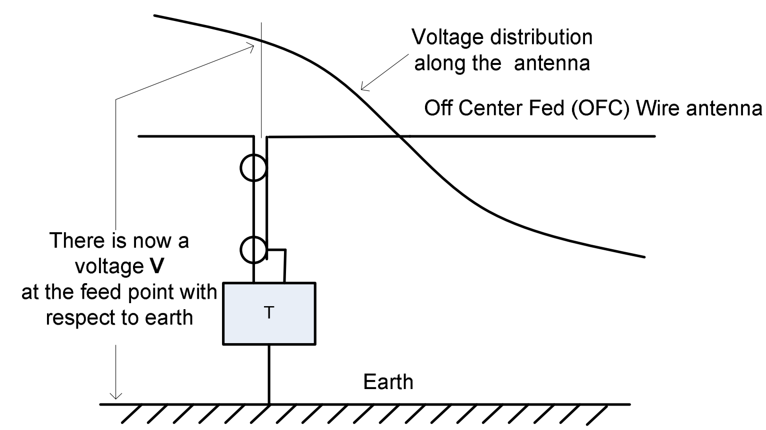


Figure 3

The feed point impedance is not 50 ohms as it rises as one moves away from the center where higher voltages and lower currents prevail (Ohms law). Typically the feed point distance from center is chosen to have an impedance of about 200 ohms where a 4:1 balun would be used.

[2] Radcom. November 2013. "Moving On" by John Welsh G0NVZ

Figure 4 is a redrawn as a “block” diagram of Figure 3.

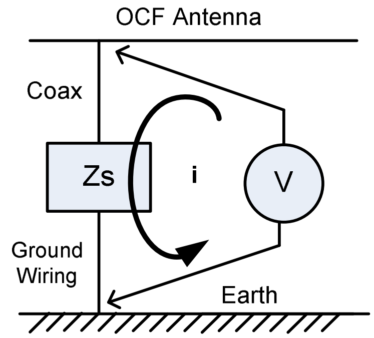


Figure 4

The voltage source **V** is the antenna voltage at the feed point with respect to Earth ground. The feed point is connected to the coax, the braid being a conductor, which in turn connects to the station labelled as “Zs”. “Zs” represents the rig and all other connected equipment, and wiring, in the shack and it is an indeterminate series impedance in the circuit. In turn “Zs” connects to Earth ground through the green wire safety ground of the AC line cord at the very least.

This circuit forms a bonafide loop, that is, a voltage source at the feed point with respect to Earth drives a current down a conductive path consisting of the coax, station equipment, and ground wiring retuning the current Earth end of the voltage source.

RF current is driven by this voltage and flows on the OUTSIDE of the coax braid. This is by definition a common mode current because the current flows in a large loop and the opposing currents are NOT close to each so radiating fields develop. Radiating feed lines will distort the radiation pattern of the antenna system.

Differential signal currents inside the coax are not affected due to the shielding effect of the coax braid. It is the common mode RF current reaching the station that flows ON the surface of conductive equipment and wiring, and then to Earth. Since the impedance Zs of this circuit is indeterminate, the amount of current flow is not predictable. However, a clamp-on RF ammeter such as an MFJ-854 will give an indication of the amount of current actually flowing.

The cure for Problem #3 is to insert a high value impedance Zx that should be much greater than Zs to reduce the unwanted (series) current to very low value, such as a few mA.

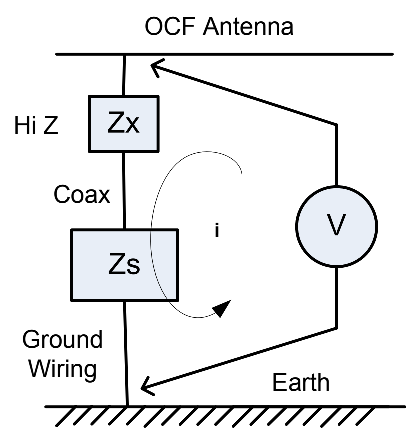


Figure 5

Zx of the Current Balun, by design, has an inherently a high impedance, and effectively chokes off common mode current on the coax.

Consequently the current balun will meet the requirements of items #1, 2 and 3.

TWO TYPES of BALUNS

There are two types of baluns; the Voltage balun and the Current balun. Both types of baluns can look outwardly identical to each other but they are of quite different designs. The voltage balun has no common mode choking capability and is not the right product to use for suppressing RF on the feedline. Because it is impossible to visually differentiate between these two packaged products, ensure the product you buy is clearly labelled as a Current Balun for this application.

AND TWO TYPES of CURRENT BALUNS

The Current balun is commonly implemented using two different techniques. One achieves a high common mode impedance, Zx, using ferrite beads, Figure 6, and the other uses a transmission line transformer for the same purpose, Figure 7. Both of these implementations result in a high common mode impedance able to choke off RF currents on the feed line.

Ferrite beads, Figure 6A are a lossy magnetic material useful for increasing the inductance of a wire, cable, AC line cord etc. to discourage RF currents flowing on such cables. They are often used to control RFI problems. As seen in Figure 6B, the beads are threaded on a piece of coax contained within a PVC pipe per Figure 6C. This construction can only provide a 1:1 impedance ratio as there is no mechanism available to transform impedance since the coax is connected "straight" through. This form of current balun is the simplest and least expensive of the two designs.

Ferrite Beads (A) Ferrite Bead Balun (B) Packaged Implementation (C)

Figure 6

Figure 7 shows the other popular implementation of a current balun where a transmission line transformer is wound on a toroidal ferrite core and is housed in an outdoor rated plastic enclosure.

Figure 7

Conventional transformers, such as used for AC power and audio have the primary winding wound on a magnetic core which generates a magnetic flux, which in turn couples energy to the secondary winding also wound on the core. Significant flux levels are developed in the core to transfer energy from the primary to the secondary and in doing so, the core incurs magnetic losses which result in overall heating of the transformer.

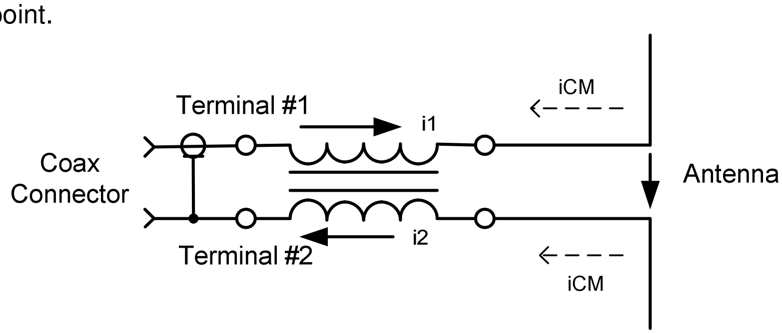
This type of operation is not suitable for RF applications where very low loss is required. To achieve these objectives, the construction, winding techniques and core materials for RF are very much different from the conventional transformer[3]. Interestingly, the cores in transmission line transformers operate at zero flux and so loses are near zero. This is achieved by placing the primary and secondary (insulated) wires tightly together, side x side, as they are wound on the core. This technique is referred to as a bifilar winding, which essentially emulates a balanced line. Hence the transmission line transformer. Careful inspection of the wires in Figure 7 show this but are more easily seen in Figure 8.

Bifilar Winding Technique
Figure 8

There is zero flux in the core because the differential mode signal currents, being closely coupled, equal, and opposite in direction, produce no net flux in the core. Should one current decide to differ from the other, a net flux does develop which forces the currents back to equality due to the 1:1 winding ratio. No flux, no loss, no heat, and the signal is transferred unimpeded through the structure.

The antenna feed point voltage will drive a common mode current down both wires in the same direction. This looks like just one wire wound on a magnetic core and will result in core flux being developed which is nothing more than a RF choke. Hence the current choke aspect of the balun is realized.

The schematic of a current balun is shown in Figure 9, in circuit, between the coax and the antenna feed point.



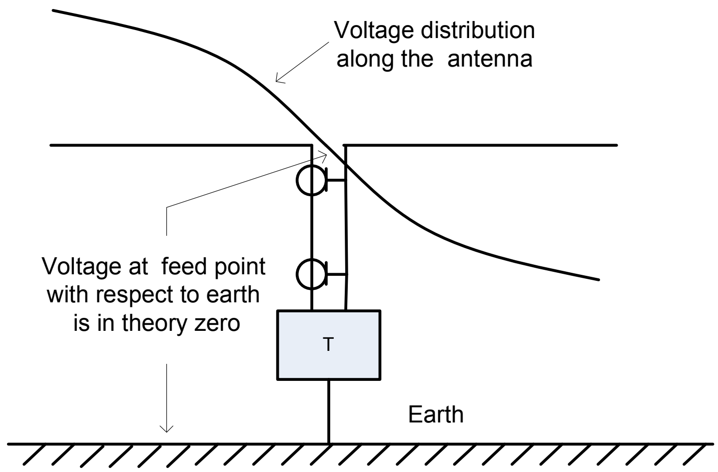
Transmission Line Transformer Balun
Figure 9

[3] Refer to “Transmission Line Transformers” Jerry Sevick, W2FMI (SK) . An ARRL Publication

The bifilar transformer having an equal number of turns on both windings provides a 1:1 turns ratio. This would be a 50 ohm to 50 ohm application. For a 4:1 ration, the windings are more complex and not described here.

BACK to the CENTER FED DIPOLE

Many of us, author included, have simply connected coax directly to our dipole and operated happily ever after. One now ought to understand how we could get away with little to no problems with "RF-in-the-Shack". Quite simply, referring to Figure 10, the voltage at the feed point is practically zero, and so little common mode current is driven down the feed line in to the shack.



Coax to Dipole - Direct Connection
Figure 10

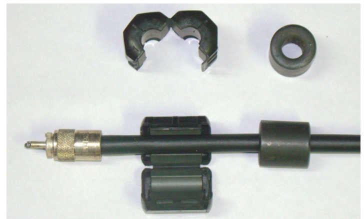
While good luck and ignorance played a major role in this success, the reality is that dipole antennas are rarely balanced in practice. We are typically limited to where and how we can support the antenna. There are many and various non-symmetrical, environmental variations such as houses, trees, soils, aluminum gutters, house wiring etc. which tend to unbalance the antenna's electrical impedances either side of the physical feed point center. This will shift the antenna voltage off the zero point away from the physical center thus causing a voltage to exist at the feed point and start driving a common mode current down the feed line.

Good practice says that a current balun at the feed point is always well advised.

RF STILL IN THE SHACK?

Even with a good current balun on the feed line, there can still be RF flowing on the outside of the coax due to direct radiation from the antenna. This cannot be helped. If there are remaining problems with RF, one can continue to raise the coax impedance further reducing common mode current flow by installing Snap-On[4] ferrite chokes Figure 11, on the feed line. These chokes will further reduce unwanted current. Typically one might put one or two ferrites in series on the coax at the bottom of the tower, another pair about middle of the coax run and another pair where the coax enters the shack, as needed. Note that non-opening beads need to be threaded on before connectors are installed!

[4] A web search for snap-on beads will reveal many sources. Bead performance depends on bead materials called the MIX . Look for a Mix that has the highest impedance ratings for bands of interest HF, VHF etc.



Threaded & Beads and Snap On Ferrites
Figure 11

Another remedy is to coil up a few turns of the coax feed line which will act as an inductor and can be quite effective in preventing RF conduction down the feed line. The coil can be installed at the feed point but this places a weight burden at that point which can prove difficult if the dipole is suspended only at the ends. The coil need not be there as an impedance can be inserted anywhere along the feed line. Note that the baluns and ferrites have greater broadband performance than the coils which tend to show a narrower range of suppression, perhaps effectively covering only 2 to 3 bands at a time.

For additional information please visit: http://www.nsarc.ca/hf/currentbalun.pdf

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Sidebar – Skin Effect

At DC, current flow is distributed equally throughout the cross section of the wire. With AC currents, the flow migrates outwards from the center of the conductor and crowds towards the surface with increasing frequency. At radio frequencies, most of the current is flowing near the surface since the current density decreases exponentially towards the center of the conductor.

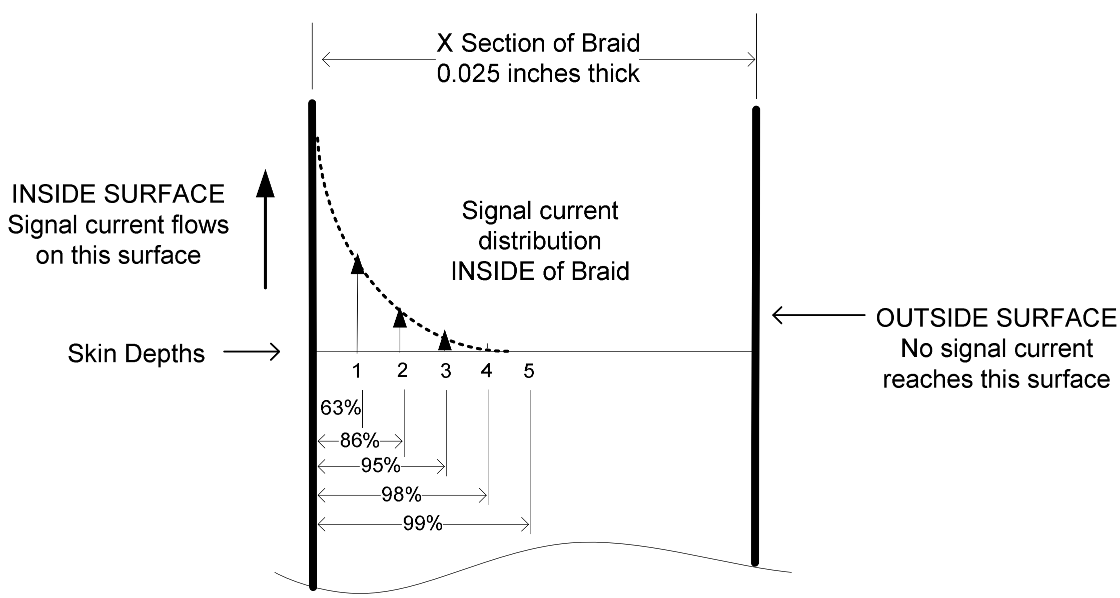

Figure A

Braid thickness on a piece of RG-8 was measured at about 0.025 inches. One skin depth at 1.75 MHz is about 49 micrometers or ~ 0.002 inches and 63% of the total current is flowing within that 0.002 inches. Adding the next 0.002 inches of skin depth, now 0.004" accounts for 86% of all the current. When 5 skin depths are taken in to account, about 0.010 inches, 99.3 % of the total current is flowing in this thickness which is less than half the thickness of the braid.

If the frequency is increased to 30 MHz, the thickness of the 99% current "sheet" becomes thinner and is only about 0.060 micrometers / 0.0024 inches thick.

An on-line calculator, Figure B, can be found is at: http://www.siversima.com/rf-calculator/skin-depth-calculator/#

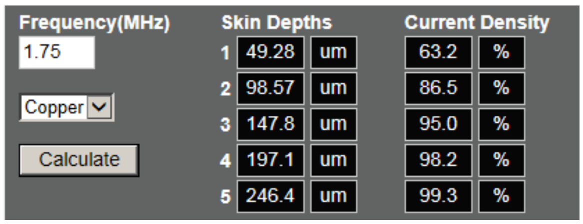

Figure B

As a consequence of this phenomena, we have transmit and receive signal currents flowing on the inside surface of the braid which do not appear on the outside of the coax braid (no radiation), and at the same time, undesired currents flowing on the outside surface of the braid do not penetrate to the inside surface of the braid. Effective shielding is achieved.

Referring to Figure C, current on the center conductor flows over the entire circumference of the conductor. One might think that ought to be true with the braid with current flowing on both the inside and outside surfaces.

Figure C

Examination of the cross section of the coax shows that the electric fields associated with the current flow terminate on surfaces of the center conductor and the inside surface of the braid. Since the skin effect governs the depth of current flow, the braid carries the current on its' inside surface only and cannot penetrate to the outside surface.