HF OPERATORS

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MAGNETICS:
FERRITES, BEADS and BALUNS

by

John White

VA7JW

What's the Problem ?

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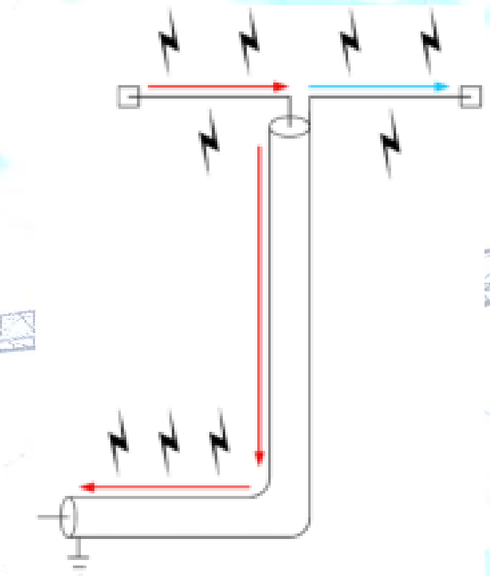
- **HF Dipoles and coaxial cables have a nasty compatibility problem**



- **Dipoles are balanced structures**
- **Coax is an unbalanced feed line**
- **Connecting an unbalanced "circuit" directly to a "balanced" circuit leads to undesired effects**
- **Performance properties of the coax and antenna are compromised**

The Unbalanced Dipole

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- **Dipoles are ideally balanced due to their symmetry, *but***
- **Real dipoles are rarely symmetrically oriented in space with respect to ground and thus become unbalanced due to asymmetrical coupling effects**
- **Nearby objects reduce symmetry and upset balance even more**
- **Antenna currents not balanced due to these effects, and radiation pattern suffers**
- **The coax feed line braid is at ground potential.**
  - **The side of the antenna connected to the coax braid is connected to ground in the shack; Leads to RF in the shack …**

The Issues

-.-. --.- -.. . ...- . --... -. ... .-.

- **Radiation pattern is altered because the coaxial feed line becomes an antenna in itself due to RF currents induced on the outside (braid) of the coax**

- **RF conducted into the shack – posting on QRZ.COM**
  - **…I put up a 40 meter inverted V dipole, and I am getting a mess of RF in the shack. My transmit audio is so distorted that it is useless. I reconnected all the grounds (tuner and radio) and moved the antenna a bit, this reduced the problem but I am still being told that my audio sounds over driven.**
    HELP !!!!!

- **Receive noise rejection is compromised because the coax is "open" to noise currents induced on the outside of the coax at the antenna connection point**

- **Remedies - yes**

Requirements

–•–• ––•– –•• • •••– • ––••• –• ••• •–•

- **Convert unbalanced feed line to match a balanced feed point**
- **Force balanced currents into the antenna feed point to compensate for local unbalancing effects**
- **Keep RF signal INSIDE the coax thus eliminating RF currents from the coaxial feed line that will radiate.**
- **Restore radiation patterns to that of the antenna alone**
- **Suppress noise currents on outside of coax from entering the coax and being part of the received signal**
- **Some required background on Magnetics …**

MAGNETICS

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- **The remedy to our problems relies on magnetic devices**
- **Need an understanding of some basic “magnetic” properties**
- **The only useful magnetic material for us is Iron (Ferric, Fe)**
- **Ferric materials respond strongly to a magnetic field, others less so, but they are important in determining the magnetic material “mix”.**

Iron **Nickel** **Zinc** **Manganese** **Cobalt**

- **These elements can be combined to form a variety of magnetic materials with varying properties**

Magnetic Flux B

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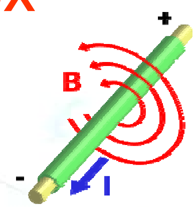
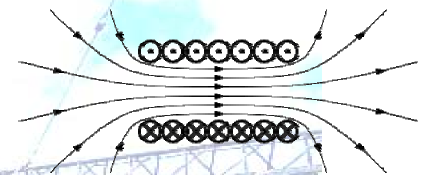
- **Current flowing through a wire develops a magnetic field around it**
- **Magnetic lines of force are referred to as FLUX**





- **Coiling the wire concentrates the magnetic field thus increasing the Flux Density, intensifies the magnetic field strength**
- **Magnetic field strength B measured in Teslas or Gauss (an old term)**
- **Flux Density can be further intensified by placing a magnetic material, a CORE, inside the coil.**

- **Flux density can be further increased by winding more turns, increasing the number of turns per inch, or decreasing the coil diameter**

Inductance

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- **Wires, straight or coiled, with or without and cores, have Inductance due to the presence of a current & magnetic field**
- **Type of material, the number of turns, the frequency of operation and core selection all determine design of the inductor**
- **Inductance is inherent in Transformers, Beads and Baluns**
- **The challenge is to tailor the magnetic component the application**
- **Reminder: inductive reactance. This is an impedance to the flow of AC currents, frequency dependent, & increases with frequency**

Permeability μ

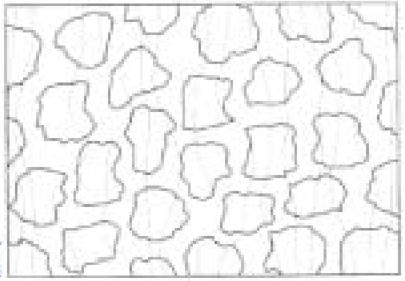
– • – •   – – • –   – • •   •   • • • –   •   – – • • •   – •   • • •   • – •

- **Flux Density can be increased by inserting different cores, that is, magnetic materials inside the coil**
- **The ability of a material to intensify a magnetic field is referred to as PERMEABILITY, symbol of "μ "**
- **Cores come with many different permeability's**
- **Range from μ = 1 (air) to 10,000 + for RF cores**
- **The higher the Permeability, the higher the inductance**
- **High permeability is needed to meet the low-frequency requirements for inductance i.e. at 160 m / 1.8 MHz**

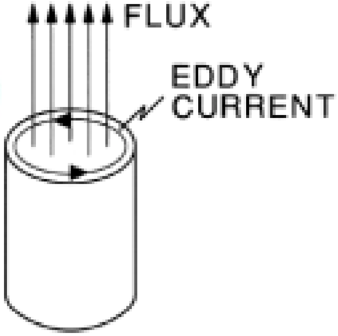
Core Losses

- Cores exhibit losses when an alternating current is applied
- Losses in core material increase with
  - Increasing frequency
  - Increasing flux density

Magnetic “domains” align in ferric material which creates magnetic properties



- Hysteresis
  - Cycling magnetic domains takes energy
  - Higher the frequency, the more energy is required
  - Energy is dissipated as heat in the core
- Eddy currents
  - Core materials are conductive metals
  - Changing magnetic field causes circulating currents to flow in the core material
  - Core materials are not great conductors
  - Heat is generated in the core since $P = I^2 R$



Loss Reduction

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- **Have to reduce hysteresis and eddy current losses**
- **Losses increase significantly with increasing frequency**
- **Cores are not "solid" as in a permanent magnet construction**
- **Low frequency cores are made of sheets of magnetic steels that are stacked on top of each other (Addendum 1)**
- **Higher frequency cores are solid & molded using small particulate, as in dust, magnetic material**
- **Insulated, particulate magnetic materials impede eddy current flow**
- **Small particulate, magnetic domains, take less energy to cycle**

Core Saturation

- **Flux density increases with increasing power, voltage or current**
- **Cores can only support flux densities to a specified level**
- **A “saturated” core cannot increase flux density any further, *and***
- **Inductance collapses, component no longer functions as a magnetic structure**
- **Driving core to high levels of flux density and towards saturation drives up core losses and creates core heating**
- **An overheated core will lose its magnetic properties, and μ will rapidly decrease if the “Curie” temperature is exceeded.**
- **Note that Air does NOT saturate and is lossless**

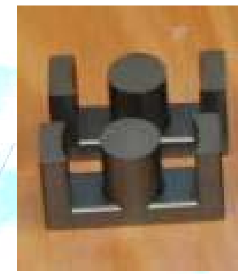
RF Materials

- **Core material has to be carefully chosen for the application**
- **Frequency is the greatest consideration**
- **High efficiency = low losses & minimal heating**
- **Three Choices:**
- **Magnetic Steel cores – 60 Hz thru audio < 20 kHz   Not for RF**
- **Iron Powdered Iron cores - audio thru HF +   Possibly RF**
- **FERRITE core – audio thru UHF …   YES for RF**

Ferrite Material

– • – • – – • – – • • • • • • – • – – • • • – • • • • • – •

- $MO\text{-}Fe_2O_3$ Metal oxide-Ferric oxide
  - Fe, iron, is as always, the main component
  - MO refers to oxides of Zinc, Nickel and others ..



- Different Ni & Zn & Fe_2O_3 "Mixes" are formulated to optimize various magnetic properties
- Raw, powdered dust mixtures are compressed & formed to shape, then "fired" under heat forming a ceramic material referred to as Ferrite
- High conductive resistivity, very low eddy current losses

Choice of Shapes

- **Lots of geometries**

- **Rods**
- **Toroid**
- **Sleeves**
- **Pot cores**
- **E – I Structures**
- **Others …**
- **Given a shape- choose different sizes**

Core Shielding (coupling)

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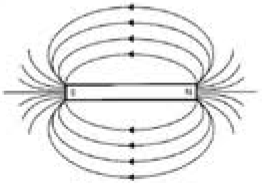
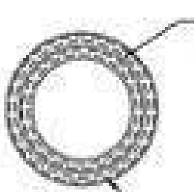
- **Open magnetics – i.e. Rods**
  - **The magnetic path consists of ferrite core + external air**
  - **Saturation does not occur but total permeability ❍is low**
  - **Inductances are low**
  - **Flux is not captured and can radiate**
  - **Core is susceptible to the influence of external fields**



- **Closed magnetics – i.e. Toroids**
  - **The magnetic path is enclosed - internal**
  - **Permeability and Inductance is high**
  - **Core can saturate, but the ferrite powders are microscopically separated from each other providing a somewhat distributed air gap**
  - **Core is self shielding from external fields**



RFI Control - Beads

- **Suppress RF currents flowing on wiring**
  - **Strong, near field induction, RF power dependant**
  - **RF radiated from antenna will be picked up by all wiring**
  - **RF conducted in to shack**
- **RF Interference control**
  - **Keep RF out of shack – equipment malfunction / shock hazard**
  - **Suppress interference with home electronics**
- **Create a high impedance to any and all conductive wiring**
  - **Suspect all wires – power, control, signal, ground ….**
  - **Apply at wire entrance to equipment**

Ferrite Suppressors

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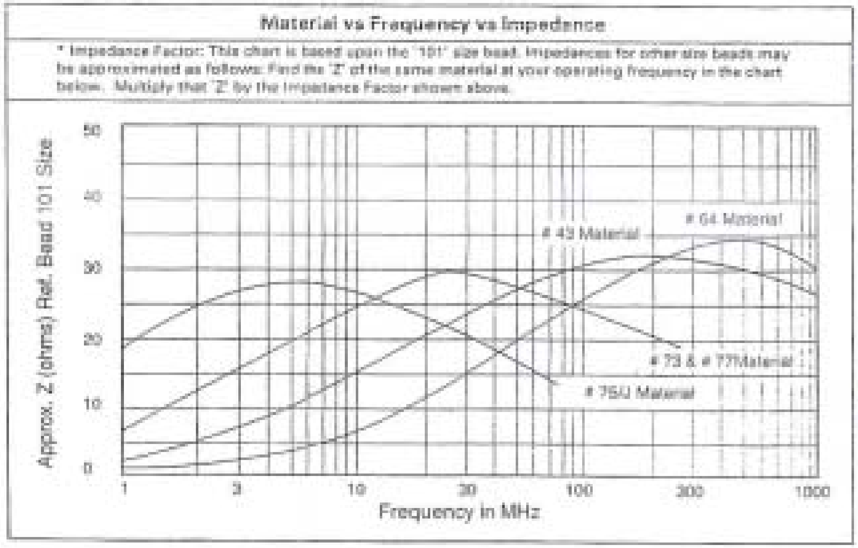
- Beads & Snap on ferrites are used
- Provides impedance to RF flowing on wires
- Sized to fit various wire diameters
- Ferrite material is designed for suppression service; will have a recommended “mix #” by manufacturer

- Typically Mix 31 & 43 used and available various sizes and forms. Other mixes available

Suppressor Properties

- Typical impedance performance - 1 bead with single wire passing through is a 1 turn inductor



- To increase impedance effectiveness, wrap more wire turns on bead and/or string more beads on wire/coax as needed

Beads for RFI

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- **RFI problems generally result from transmitted signal radiated from close-by antenna**
  - **"Fundamental Overload" conditions**

- **RF antenna action along any and all nearby conductors**
  - **RF flows along conductors, especially house electrical wiring**
- **Conducted inside radio sensitive equipment on any or all leads and causes a malfunction**
  - **Your station equipment or various home electronics**
- **Place a snap-on choke(s) on leads until interference is suppressed**
  - **Try AC power leads first, then others**

Alarm System RFI

- **Example**
- **Ferrites on Alarm sense leads**

- **Ferrites on 'phone and power lines**
- **Required to prevent false trips**

Beads on Power leads

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- **Be aware that snap on chokes placed over AC or DC power leads can suffer flux saturation due to high current flows**
- **To ensure saturation does not occur, ensure that the NET CURRENT through the choke is ZERO**
- **On AC power cord, choke is around the complete cord**
- **DC power leads, both the Pos and Neg leads must pass through the choke to ensure net current / flux is zero**
- **If core saturates, inductor action is destroyed**

AC Power Cord

DC Power

Sources of Supply

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- **DX Engineering, Mix 31,**
  - **DXE-CSB - .275 for RG-58, RG-8X smaller coax**
  - **DXE-CSB - .525 for RG-8, LMR-400 for larger coax**
- **RF Parts, FERCKE, Mix 31**
  - **- E for smaller coax as above**
  - **- M for larger coax as above**
- **Check their web pages for cost & stock**
  - **Typical cost $3 for small, $6 for large**
- **Check manufacturers web pages for technical detail**
- **Fair-Rite & Amidon & others**

BALUNS

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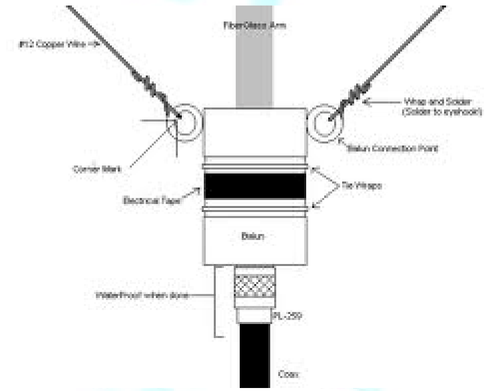
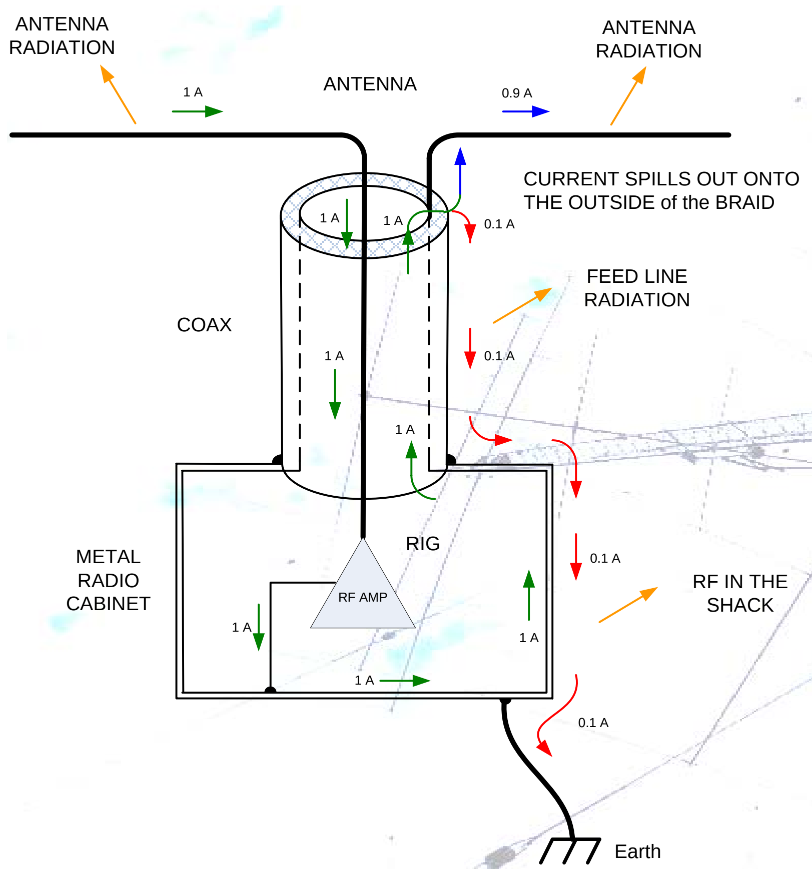
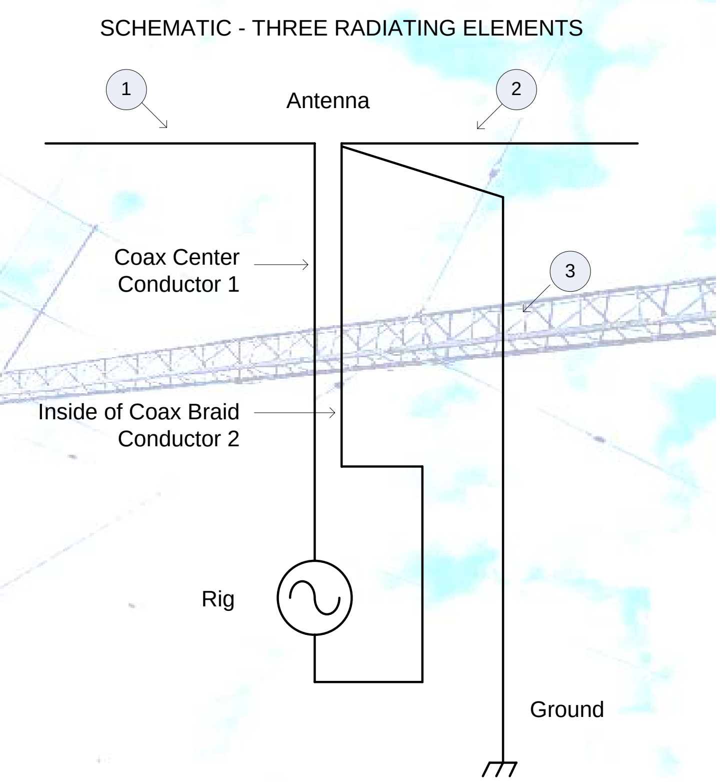
- **Balun is derived from BALanced to UNbalanced**
- **Balanced refers to the antenna**
  - **Symmetrically fed, i.e. dipoles are balanced**
  - **Verticals non symmetrical, typically unbalanced but can be used for matching**
- **Unbalanced refers to coaxial cable feed line**
- **Baluns typically connected between the coax feed line and the antenna, at the feed point**
- **Balun may also connect coax to balanced (ladder) line that then goes to the antenna feed point**



Why use a Balun ?





Radiating Feed Lines

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- **Skin effect – RF flows on SURFACE of conductor**
- **Coax as a 3-conductor model**
  - **Center conductor**
  - **Inside surface of braid**
  - **Outside surface of braid**
  - **Desired RF exists between center conductor & inside surface of the braid – RF signal is contained, except at the end**
- **Three radiating elements**
  - **Left side of antenna**
  - **Right side of antenna**
  - **Outside of the Coax braid - to rig - to ground - or anything else in the shack**

Impedance

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- **Current exits coax BRAID at antenna**
- **Free to flow to antenna AND outside of coax on braid**
- **Impedance of these two paths determines division of current**
- **The lower impedance hogs the current**
- **Antenna 25 – 100Ω ? ? thereabouts**
- **Coax braid + equipment + ground impedance – uncontrolled**
- **Could be High or Low**
  - **path length = multiples of quarter wave = Hi Z**
  - **Path length = multiples of half wavelength = Low Z**
  - **Given a fixed length of feed line, problem of RF in shack could be very dependent on operating frequency**

Consequences

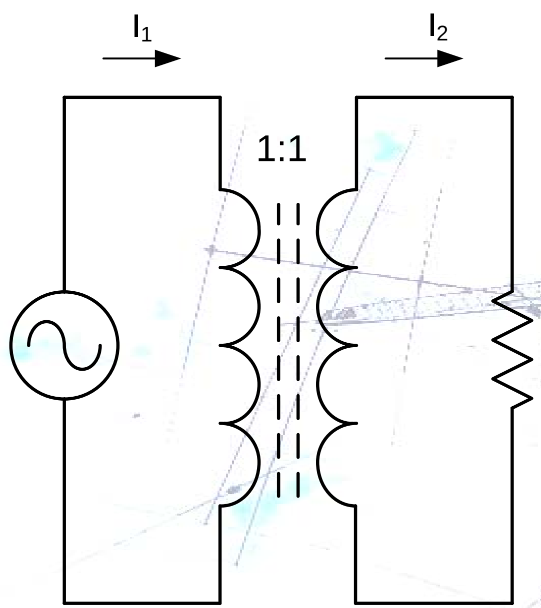
- **Radiation from feed line will alter antenna radiation pattern**
  - **Effect of coax radiation is indeterminate**
  - **Antenna system radiation patterns not as designed**

- **RF in the shack**
  - **RF is conducted down coax, into the shack**
  - **Flows on surface of equipments**
  - **Equipment malfunctions**
  - **RF “bites”**
  - **Frequency dependent**

- **Undesirable – keep RF INSIDE THE COAX !**

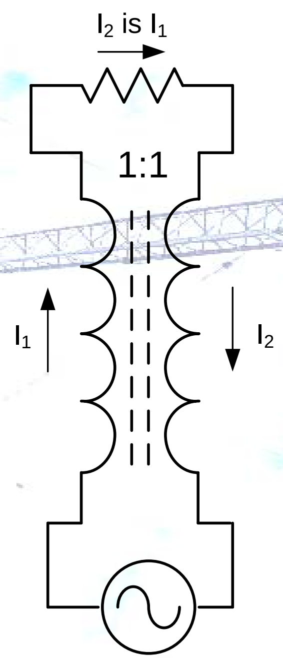
Transformers

Conventional Transformer



Secondary Turns = Primary Turns this Example
and so PRI and SEC Currents MUST be equal

Transmission Line Transformer - TLT



Secondary Turns = Primary Turns
Currents MUST be equal

TLT - Current

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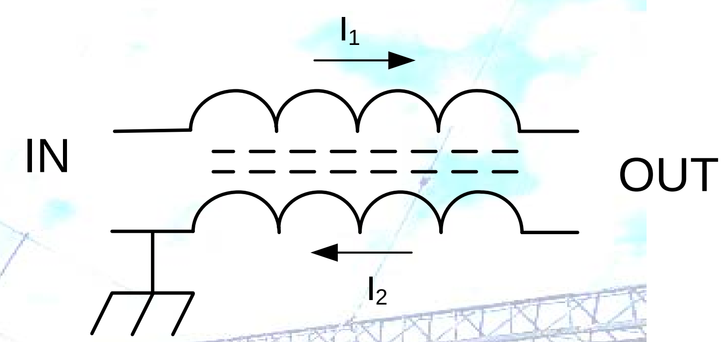
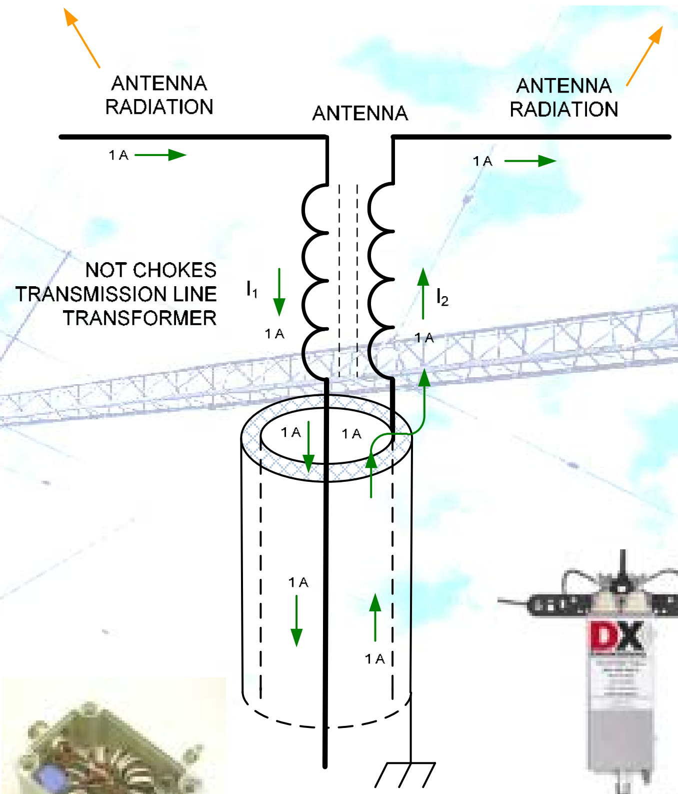
- **FERRITE Toroid Core**
- **Two identical windings**
- **Wound Side x Side**
- **Current 1 must equal Current 2**
- ***Windings look line a transmission line***
- **Balanced output currents**
- **Net flux in core = 0**
- **Core Losses near zero as currents are balanced (no flux)**
- **Input ground is isolated, choked, from Output, antenna, due to the reactance of windings W1 and W3**



Current Balun - TLT

- **TLT forces BALANCED CURRENTS, that is, INSIDE BRAID CURRENT equals the CENTER CONDUCTOR CURRENT**
- **There is no current "available" to flow on outside of braid**
- **Choking action of coil inductance provides isolation of coax grounded braid from antenna**
- **As well, currents are forced into antenna regardless of how unbalanced antenna is in reality**



Current Balun - Beads

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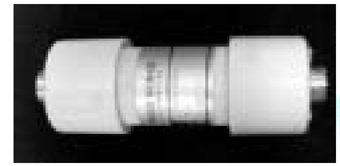
- Chokes off current flow on outside of the Braid
- Coax - Single Turn inductor

- 1 may do – need more inductance? Add more beads
  - Place large heat shrink over beads to fix in place or
  - Use tie wraps at each end to act as "stops"
- Presents a high Z on outside of coax
- Has no effect on RF inside the coax
- Palomar Engineers sells bead stacks
  - BA-8 $20 & BA-58 $10, kits

LONG - Lots of beads needed to develop high Z at 160 m

Unun's

- **UNbalanced to UNbalanced**

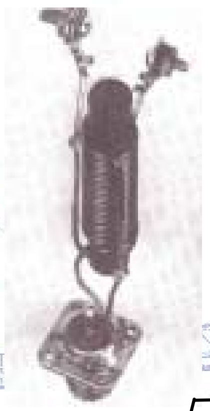


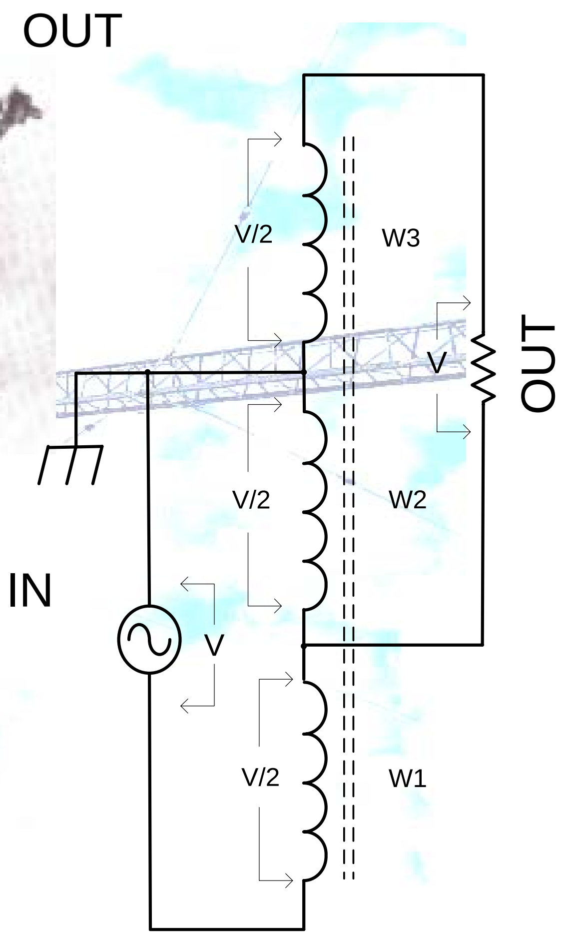
- **Insert In-Line where coax is used**
- **No Balancing feature – Just a choke, like the Beads**
- **Use with**
  - **Vertical Antennas, to decouple coax from ground plane radials**
  - **Long wire antennas and remote tuners**
- **Helps suppress RF in the shack**
  - **RF feedback in Audio**
  - **RF shock**
  - **Station equipment malfunction**

TLT - Voltage

- **FERRTIE ROD Core**
- **Three identical windings**
- **Wound Side x Side**
- **Windings are transmission line style**
- **Balanced output voltages**
- **Output voltage = Input voltage**

- **Input ground is isolated, choked, from Output, antenna, due to the reactance of windings W1 and W3**





Voltage Balun - TLT

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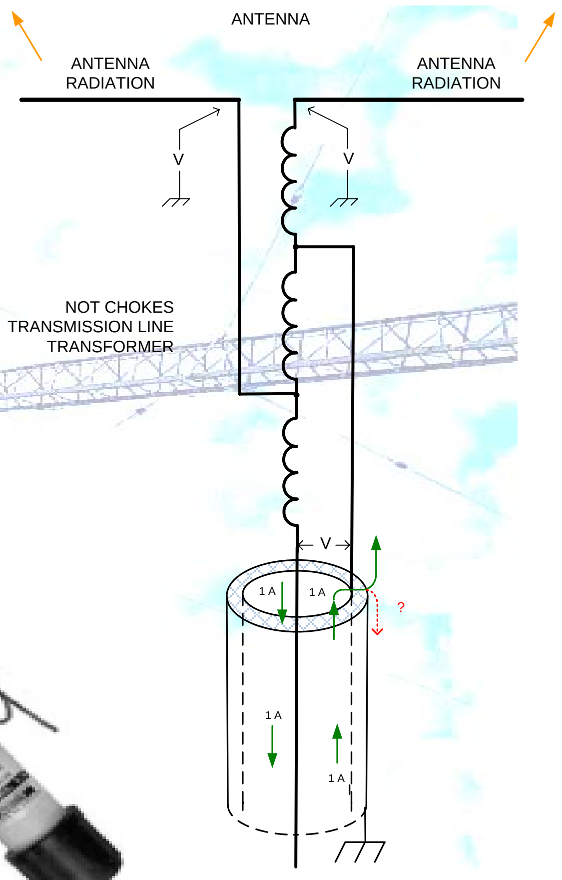
- **Equal voltage forced to each leg of dipole at antenna feed point**
- **Antenna is isolated from ground by choking action of TLT**
- **Performs the Unbalanced to Balanced requirement, but**
- **There is NO choking off of current flow on outside of coax braid**
- **Current baluns are superior in this very important respect**



Ferrite rod core

Coaxial Balun

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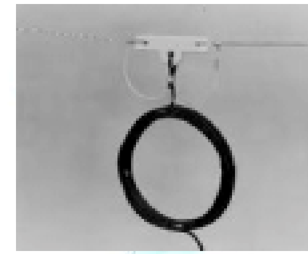
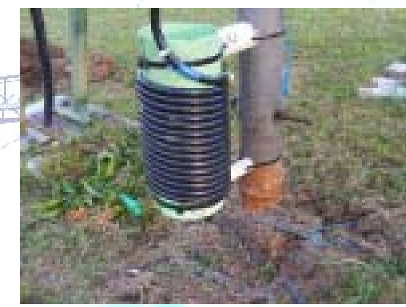
- Simple & Least expensive – cost of coax
- Wind a length of feed line into a coil
  - Makes an RF choke
  - Keeps RF off outside of coax
  - Hang at feed point
  - Coil does NOT affect RF inside the coax (the signal)
- Issues
  - Heavy
  - Inductance is low
    - choking at low frequencies 160, 80 40 m is compromised
  - Capacitive coupling between loops bypasses choking action
    - Choking at higher frequencies 20 thru 10 m is compromised





Coaxial Balun Performance

- **Notice narrow band effectiveness of coil**

- **Improved performance with ferrite**

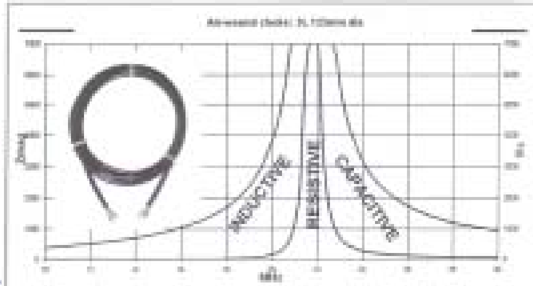


FIGURE 2: Performance of an air-wound choke: notice the very sharp resonance at 21MHz.

PHOTO 1: Clockwise from left: low-bands ferrite choke, mid-bands choke, high-bands choke, the ferrite cores.

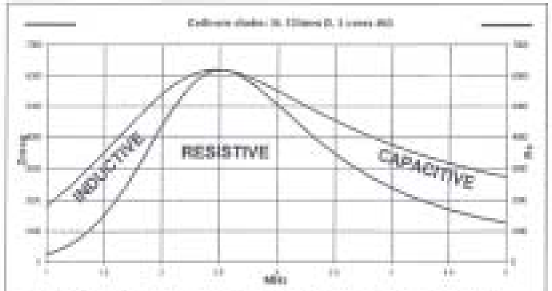


FIGURE 3: Performance of the low-bands choke with three ferrite cores.

Impedance Ratios

– • – •   – – • –   – • •   •   • • • –   •   – – • • •   – •   • • •   • – •

- **All Baluns described to this point are 1:1 impedance ratio**
- **50 ohm antenna feed point to 50 ohm coax**
- **Other ratios are available with TLT's to match 50 ohm coax to other antenna feed point impedances.**
- **1:4 very popular – 50Ω to ladder line or folded dipoles**
- **Others: 1:2 1:8 1:9 1:16**
- **Not continuously variable – limited to discrete values**

What about Receive ?

-.-. --.- -.. . ...- . --... -. ... .-.

- **Bead Balun**
  - **Choking action can be expected on receive preventing noise signals picked up on outside of coax from <u>entering</u> coax**
  - **Receive noise levels could be lower compared to that of no balun**
- **Current Balun**
  - **Receive currents from antenna are forced equal regardless of the reality of an unbalanced antenna**
  - **Noise currents on outside of coax braid are rejected**
  - **Quieter**
- **Voltage Balun**
  - **Does not offer coax noise rejection**
- **Coax Balun**
  - **Limited noise rejection, narrow-banded**

Summary

- Current baluns
  - Install ferrite beads on coax at antenna to choke off radiating line current
  - Purchased Balun may cost about same and provides a support eye
- Voltage Balun will not suppress RF currents on feed line
  - Provides balancing function
- Coiled coax will provide some choking on feed line
  - least expensive but can be heavy and difficult to support
- Ferrite Suppressor beads useful for reducing RFI problems
  - Place on leads of susceptible equipment to choke off RF
- If Balun is not described as Current or Voltage, don’t buy
- No balun?   Then GET ONE.

References

–•–• ––•– –•• • •••– • ––••• –• ••• •–•

- **“Some Aspects of the Balun Problem”. Walter Maxwell W2AU, QST, Mar 1983**
- **“Baluns, What they Do and How They Do It”. Roy Lewallen W7EL, ARRL Antenna Compendium, Volume 1, 1985. Page 157 ff**
- **“Transmission Line Transformers”. Jerry Sevik, W2FMI. Published by ARRL.**
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Some Balun Links

–•–• ––•– –•• • •••– • ––••• –• ••• •–•

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- http://w2du.com/r2ch21.pdf

Addendum 1

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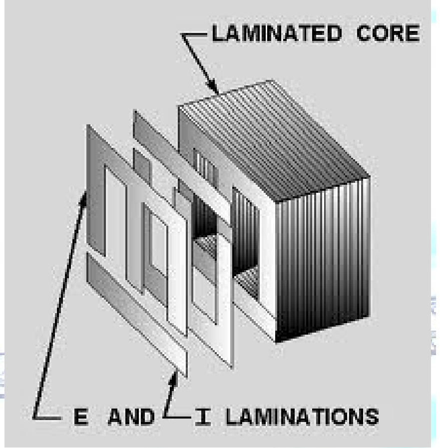
- **MAGNETIC STEEL CORES**
- **TRANSFORMER CONSTRUCTION**
- **POWER TRANSFORMERS for 60 Hz**

Magnetic Steel Cores

–•–• ––•–– –•• • •••– • ––••• –• ••• •–•

- Special alloys of silicon and steel
- Magnetic Grain oriented
  - Hysteresis losses controlled
- High Permeabilities (10,000’s +)
- Eddy Current Controlled
  - Silicon steel is very poor conductor
- Flat lamination construction
  - Core sizes can be built to power handling requirements
- Low frequency, low cost



Transformer Construction

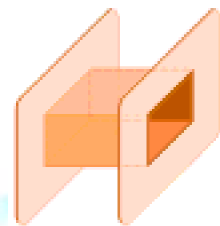
–•–• ––•– –•• • •••– • ––••• –• ••• •–•

- **Wire Winding**
  - **Wind primary on bobbin**
  - **Insulation layer**
  - **Wind secondary overtop**

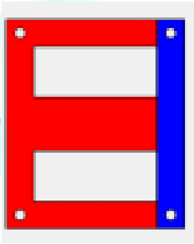
- **Core Construction**
  - **Core material silicon steel**
  - **Ferromagnetic sheets**
  - **Stacked**
  - **Isolates one sheet from the other**
  - **Reduces losses**

- **Stack laminations into bobbin**

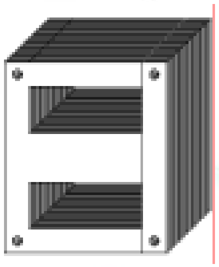
- **Chokes same construction**



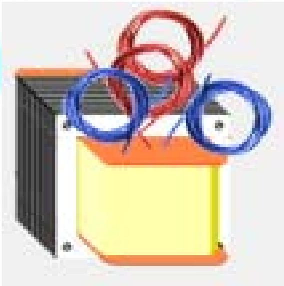
bobbin



E I lamination



core stack

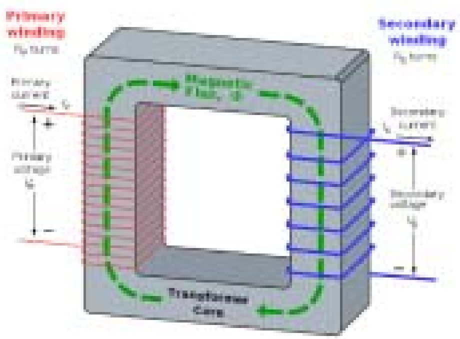


finished transformer

60 Hz Power Transformer

-.-. --.- -.. . ...- . --... -. ... .-.

- **60 Hz low frequency applications characterized by**
  - **Large cores**
  - **Large inductances**
  - **Large number of turns**
  - **Heavy & Big**

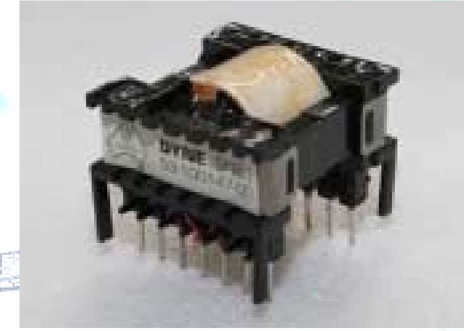


- **Linear Power supplies**
  - **AC line to low voltage**
- **Chokes**
  - **Smoothing rectified AC to DC**

100 kHz Power Transformer

–•–• ––•– –•• • •••– • ––••• –• ••• •–•

- High frequency applications characterized by
  - Small cores
  - Fewer turns
  - Small and light



- Switch Mode Power Supplies
  - Transformers and chokes
- As frequency is increased, the core cross-sectional AREA decreases. 2 x freq. requires 1/2 area
- Smaller transformer cores can be used for same power throughput.

Addendum 2

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- **POWERED IRON CORES**

Powered Iron Cores

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- **Iron powders**
  - **Proprietary combinations, iron + other ingredients to optimize desired magnetic properties**
  - **Flux density, temperature, permeability, frequency range choices**
- **Also described by "Mix" – pick for application**
- **Distributed Air Gap**
  - **Powder particles have minute space between them – acts as an air gap**
  - **Air gap allows for higher flux densities (15,000 G) before core saturates**
- **Permeability's up to 100**
- **Frequency range usually to 1 MHz**
- **Depending on application, an be used into HF region.**
- **Cost is low to moderate**

Addendum 3

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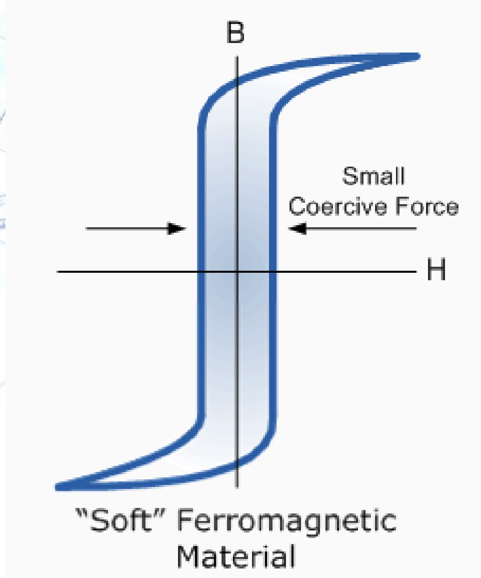
- **HARD and SOFT MAGNETICS**
- **B AND H**
- **MAGNETIC UNITS**

B-H curve



Hard & Soft Magnetics

- **HARD magnetic material**
  - **Iron, easily magnetized**
  - **Retains a magnetic field**
  - **Permanent magnets (PM)**
  - **Will attract other magnetic material**
  - **Used where PM is needed, motors, speakers, etc**

- **SOFT magnetic material**
  - **Exhibits magnetic properties under magnetic field influence**
  - **Does not retain a magnetic field**
  - **Used in electronic applications; inductors, transformers, baluns, beads .. etc**

B and H

Magnetic Induction vs. Magnetic Field

Magnetic induction and magnetic field are often used synonymously. In many cases it is easy to conclude from magnetic induction to magnetic field and vice versa.

The magnetic field H describes the field generated by a free current only, the magnetic induction B describes the field generated by a current plus the effect of magnetization of a material. Materials can decrease or increase the magnetic induction. They are then called paramagnetic or diamagnetic materials.

The relation between magnetic induction and magnetic field in vacuum as well as in air or any other nonmagnetic environment is constant:

$$B = \mu_0 \times H.$$

The proportional factor μ_0 is called constant of permeability and has a value of $4\pi \times 10^{-7}$ Vs/Am or 1.256×10^{-6} Vs/Am in SI[1)] units.

The relation is extended in magnetic materials to

$$B = \mu_r \times \mu_0 \times H,$$

where μ_r is a positive number. μ_r equals 1 in vacuum or air and can reach values above 1000 for soft magnetic materials.

Magnetic Units

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QUANTITY	SYMBOL	SI UNIT	SI EQUATION	CGS UNIT	CGS EQUATION	CONVERSION FACTOR
Magnetic induction	B	tesla (T)	$B=\mu_o(H+M)$	gauss (G)	$B = H+4\pi M$	$1\ T = 10^4\ G$
Magnetic field strength	H	ampere/meter (A/m)	$H = N\times I/lc$ (lc - magnetic path, m)	oersted (Oe)	$H = 0.4\pi N\times I/lc$ (lc - magnetic path, cm)	1 A/m = $4\ \pi\times10^{-3}$ Oe
Magnetic flux	Φ	weber (Wb)	$\Phi = B\times Ac$ (Ac - area, m^2)	maxwell (M)	$\Phi = B\times Ac$ (Ac - area, cm^2)	1 Wb = 10^8 M
Magnetization	M	ampere/meter (A/m)	M=m/V (m- total magnetic moment, V- volume, m^3)	emu/cm^3	M=m/V (m- total magnetic moment, V- volume, cm^3)	1 A/m = 10^{-3} emu / cm^3
Magnetic permeability of vacuum	μ_o	newton/ampere^2	$\mu_o= 4\pi\times10^{-7}$	1	-	$4\pi\times10^{-7}$
Inductance	L	henry	$L=\mu_o\mu N^2Ac/lc$ (Ac- area, m^2, lc - magnetic path, m)	henry	$L=0.4\pi\mu N^2Ac/lc\times10^{-8}$ (Ac-area, cm^2, lc - magnetic path, cm)	1
Emf (voltage)	V	volt	$V=-N\times d\Phi/dt$	volt	$V=-10^{-8}N\times d\Phi/dt$	1

Note: in the above equations: N- turns, I - current (in amps)