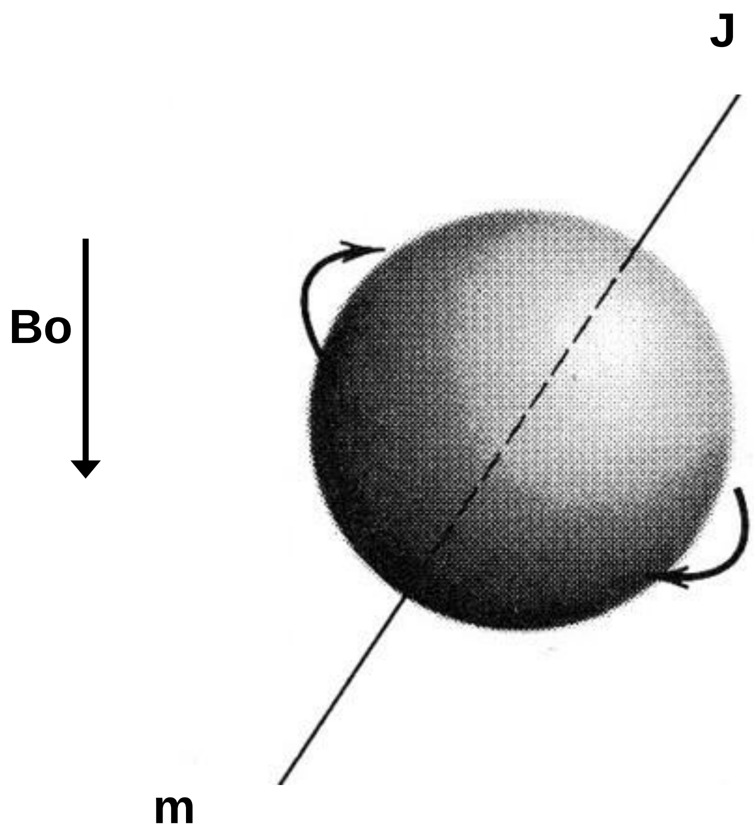
Ferrites

VE3KL

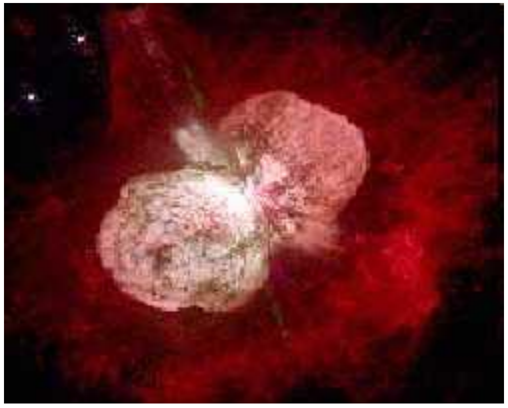
A spinning electron works like a gyroscope
Gyro frequency tells all



Presentation Outline

- **Review of magnetic terms: H, B , M and Gyro frequency**
- **Ferrite materials, samples and measurements**
- **Ferrite Applications**
- **Ferrites with no applied magnetic bias**
- **Ferrites with an applied magnetic bias**
- **Description of an experimental test bed**
- **Further reading**

Gyro Frequency



Fo = 28000*Bo [MHz]

If Bo = 0.1 [T]

Fo = 2.8 GHz

Earth's Magnetic Intensity	Bo = 50 uTesla
Small Bar Magnet	Bo = 0.01 Tesla
Sunspot	B0 = .15 Tesla
Strong Lab magnet	Bo = 10 Tesla
Magnetar	Bo = 100,000,000,000 Tesla

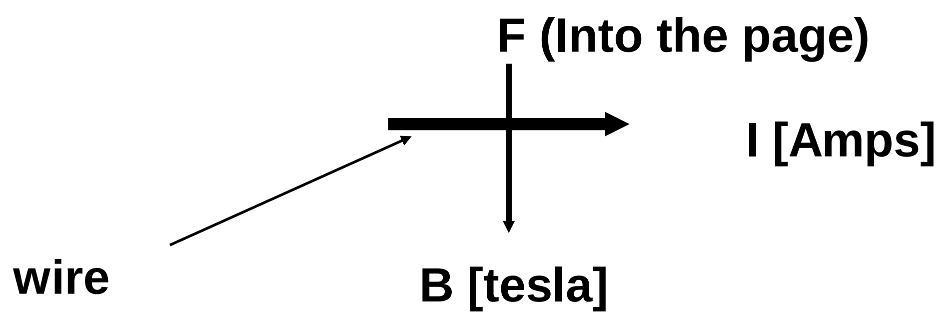
http://en.wikipedia.org/wiki/Magnetar

Magnetics

F = I dl X B

A force is applied to a current that is in a field B. This equation defines B. This is how motors work.

Units of flux density B: Tesla in MKS units

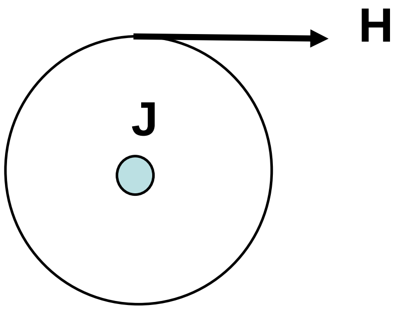


Magnetics

Magnetic Intensity H [A/m] defined by:

Curl H = J [A/m²] **..static case**

Magnetic intensity depends only the current….NOT ON THE MATERIAL



Magnetics

Magnetization **M [A/m]**

Similar to H but currents are internal to the material due to spinning electrons

Magnetics

Relationship Between B, H, M
Here is where the material plays a role.

$$B = \mu(H + M)$$

μ can be a constant… $\mu o = 4\pi \times 10^{-7}$ H/m
μ can be a complex number…mix #43 ferrite
μ can be isotropic… unbiased ferrites
μ can vary with direction…(Faraday Rotation)
μ can be nonlinear…(saturation)

Magnetics

Magnetic Units

Physical Quantity	SI UNIT (MKS)	Factor	Gaussian (cgs)
B (Magnetic Flux)	tesla (T)	10^4	gauss
H (Magnetic Field)	A/m	$4\pi x10^{-3}$	oersted
M (Magnetization)	A/m	10^{-3}	magnetic
Inductance	henry (H)	10^9	abhenry

The Factor is the number of Gaussian units required to equal one SI unit.

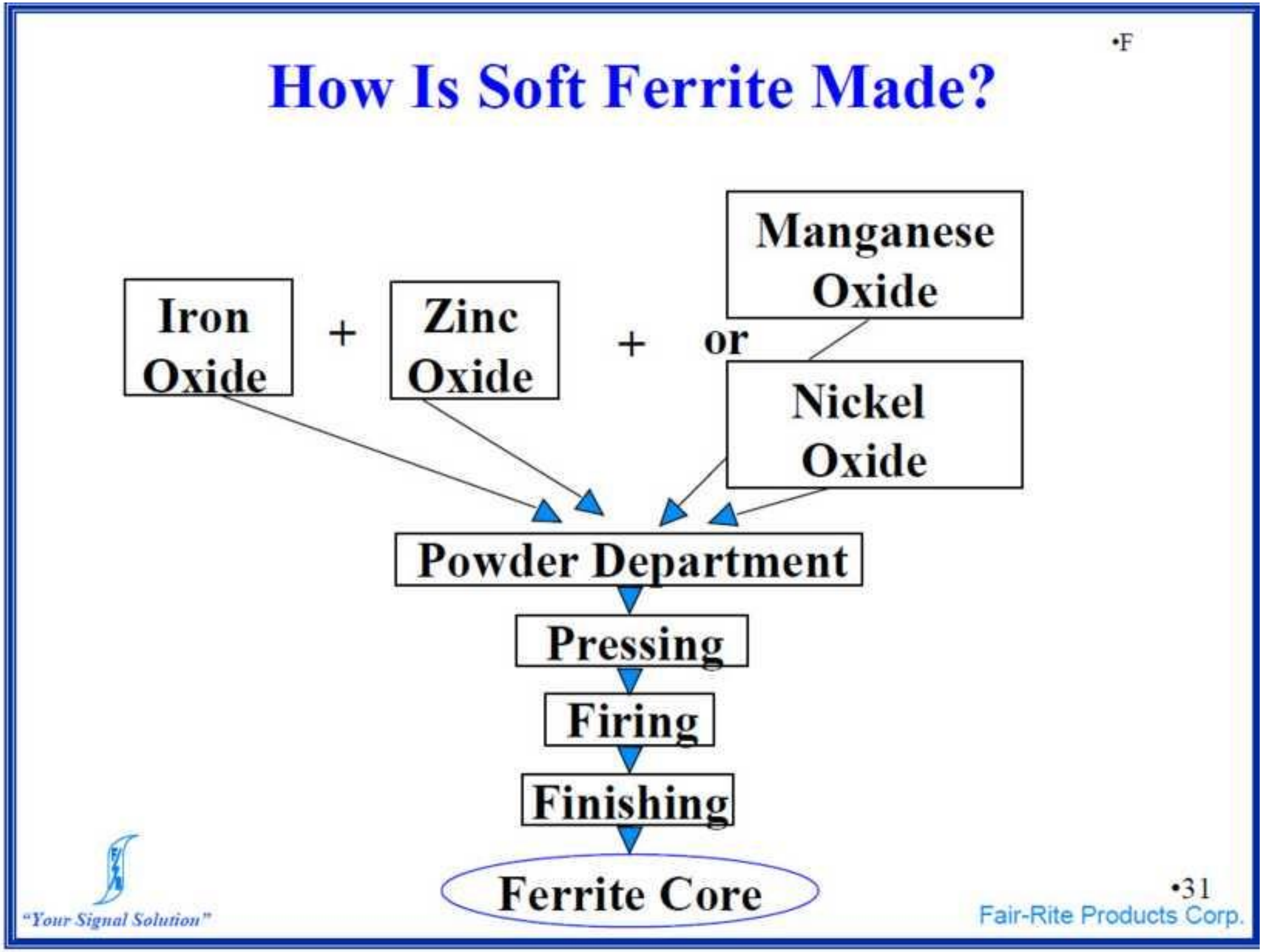
To convert tesla to gauss multiply by the Factor 10^4

What is a soft Ferrite

- An engineered ferrimagnetic ceramic material
- Soft ferrites do not retain a permanent magnetization
- Contains bounded spinning electrons
- High dielectric constant
- High permeability
- High resistivity
- Can be biased to orient spinning electrons
- Many forms and chemical composition

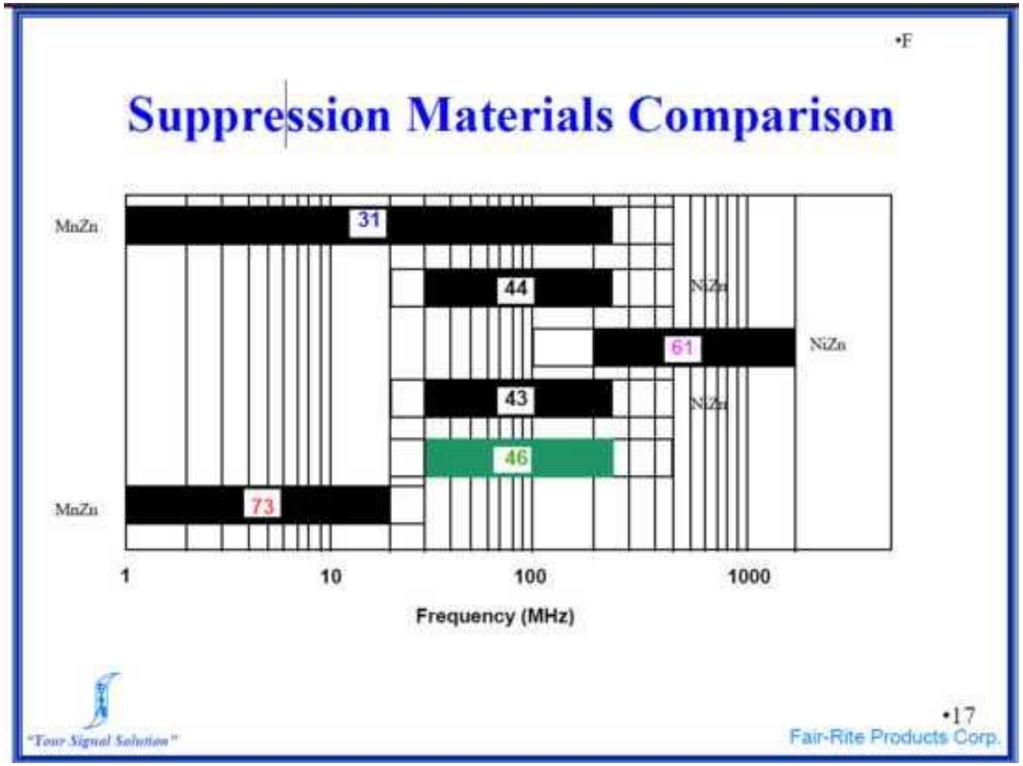
Ferrimagnetic Material
Soft Ferrite

- **Spinning electrons not aligned when Ho = 0**
- **Spinning electrons have a large magnetic moment**
- **B = μH where μ can be very high.**


•F
How Is Soft Ferrite Made?
Iron Oxide
+
Zinc Oxide
+
or
Manganese Oxide
Nickel Oxide
Powder Department
Pressing
Firing
Finishing
Ferrite Core
"Your Signal Solution"
•31
Fair-Rite Products Corp.

Ferrite Samples

EMI Suppression Materials
Ho = 0

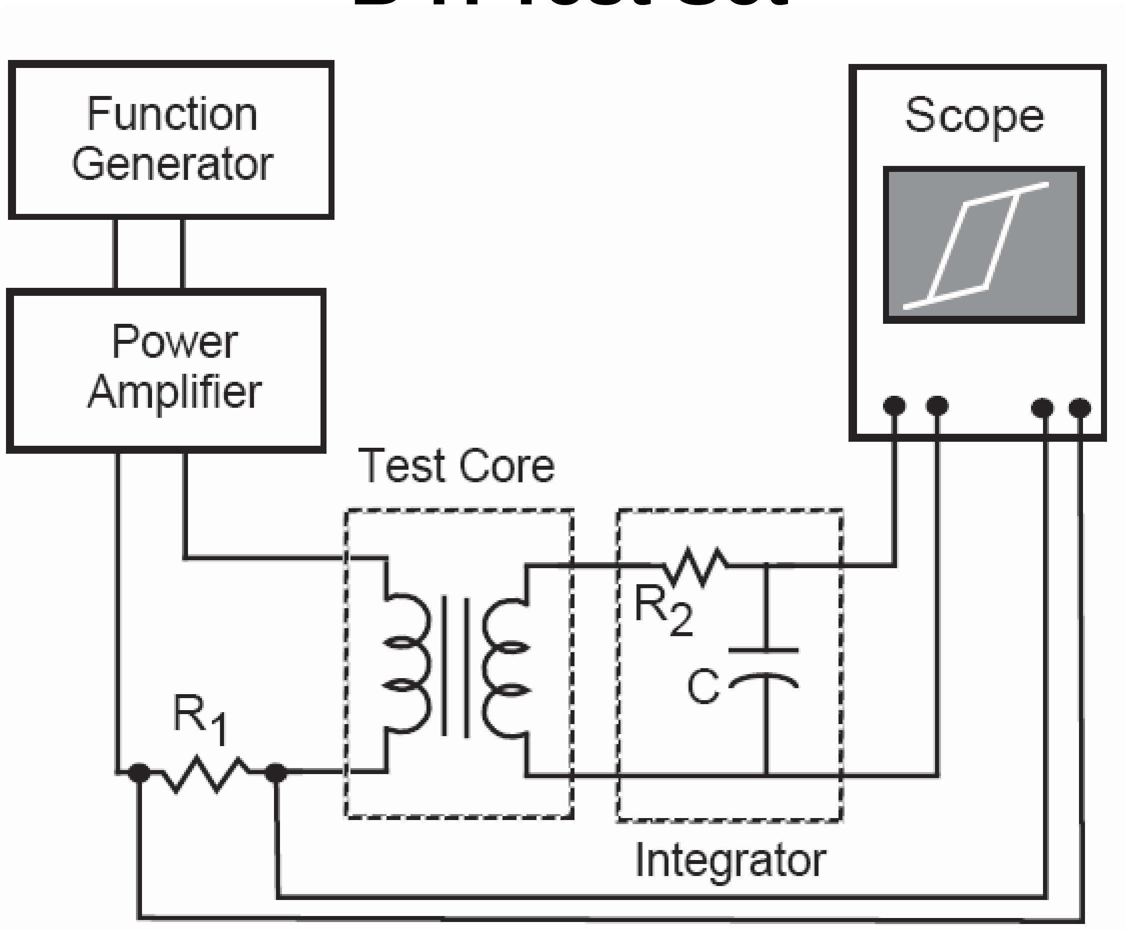


Note: For Balun's there are different charts..
#61 material can be used at HF for high power Guenalla Balun

Ferrite Applications

- **Waveguide Phase Shifters and Isolators**
- **Microwave Circulators**
- **Antenna Baluns**
- **RFI Common Mode Chokes**
- **Antenna Common Mode Chokes**
- **Transmission Line Transformers**

Magnetics
B-H Test Set



See http://www.cliftonlaboratories.com/type_43_ferrite_b-h_curve.htm

Special Cases
Case 1…Small Signals
No applied DC Magnetic Field

Mix #43
μ = 800 (relative) at low frequency
μ is complex

$$\mu = \mu' + j\mu''$$

- **Spinning electrons not aligned**
- **Spinning electrons have a large magnetic moment**
- **B = μH where μ can be very high.**
- **μ does not depend on direction (isotropic material)**

Mix #43 from Fair-Rite Products

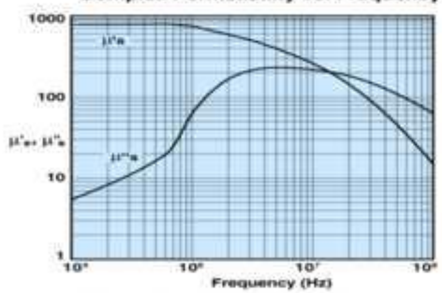
This NiZn is our most popular ferrite for suppression of conducted EMI from 20 MHz to 250 MHz. This material is also used for inductive applications such as high frequency common-mode chokes.

EMI suppression beads, beads on leads, SM beads, multi-aperture cores, round cable EMI suppression cores, round cable snap-its, flat cable EMI suppression cores, flat cable snap-its, miscellaneous suppression cores, bobbins, and toroids are all available in 43 material.

43 Material Characteristics:

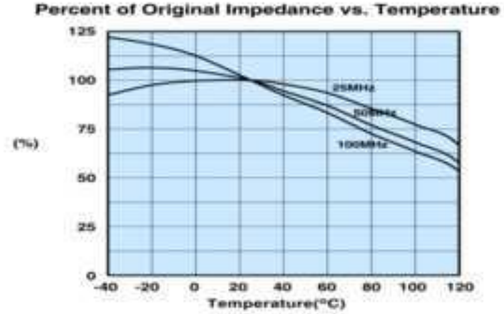
Property	Unit	Symbol	Value
Initial Permeability @ B = 10 gauss		μ_i	800
Flux Density @ Field Strength	gauss oersted	B H	2900 10
Residual Flux Density	gauss	B_r	1300
Coercive Force	oersted	H_c	0.45
Loss Factor @ Frequency	10^{-6} MHz	$\tan\delta/\mu_i$	250 1.0
Temperature Coefficient of Initial Permeability (20 -70°C)	%/°C		1.25
Curie Temperature	°C	T_c	>130
Resistivity	Ω cm	ρ	1×10^5

Complex Permeability vs. Frequency



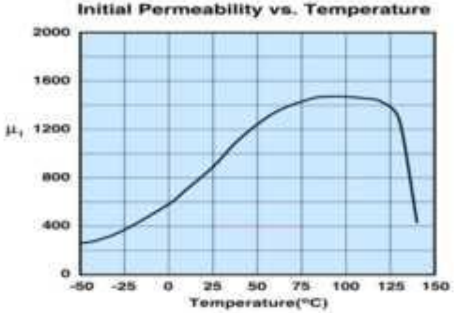
Measured on a 17/10/6mm toroid using the HP 4284A and the HP 4291A.

Percent of Original Impedance vs. Temperature



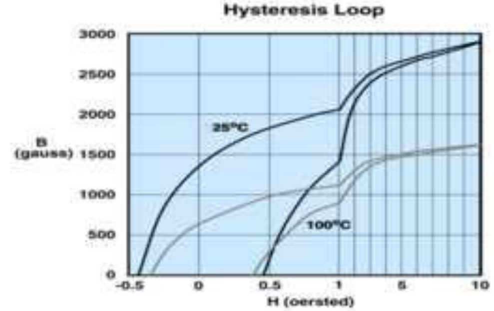
Measured on a 2643000301 using the HP4291A.

Initial Permeability vs. Temperature



Measured on a 17/10/6mm toroid at 100kHz.

Hysteresis Loop

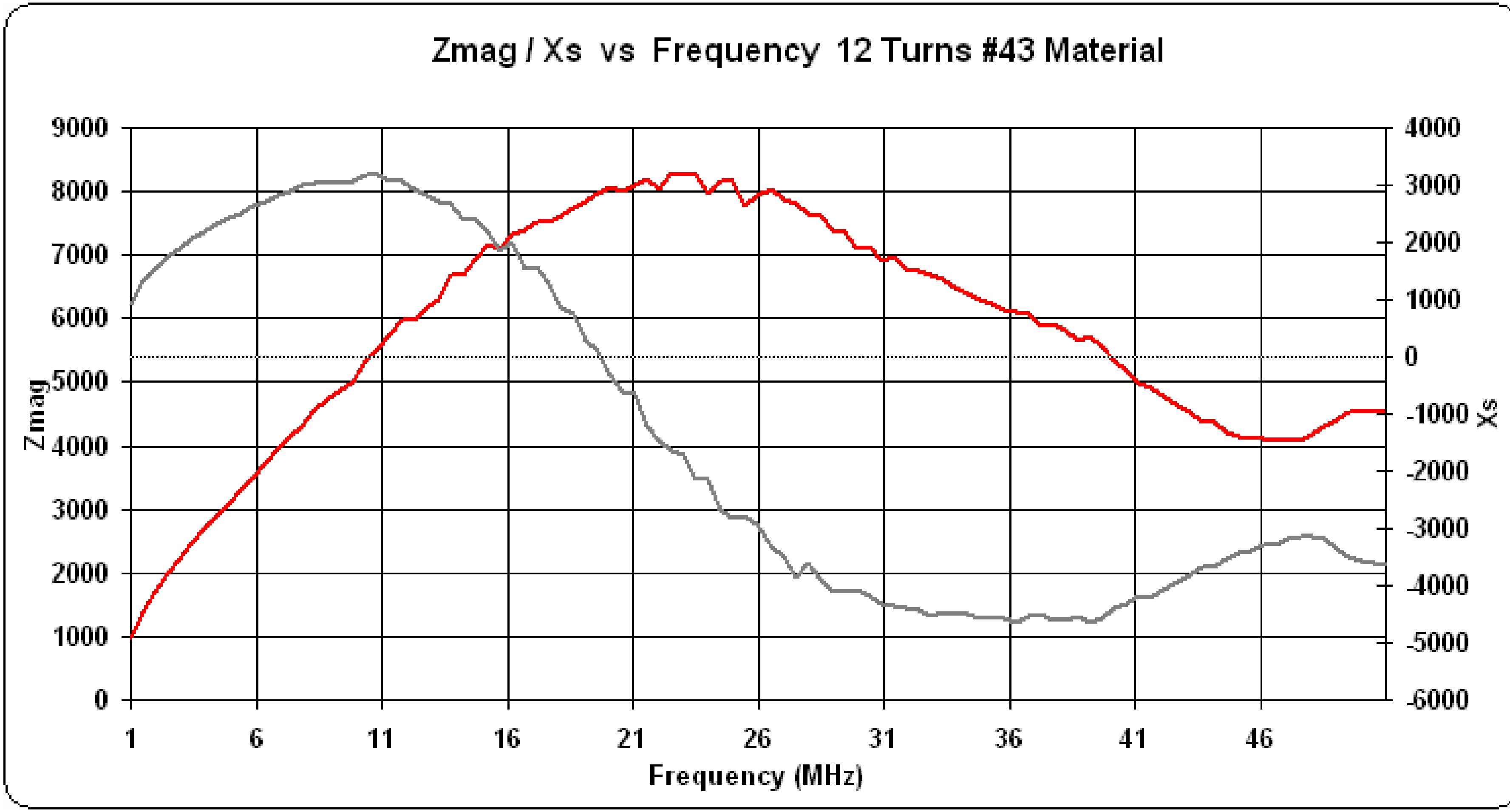


Measured on a 17/10/6mm toroid at 10kHz.

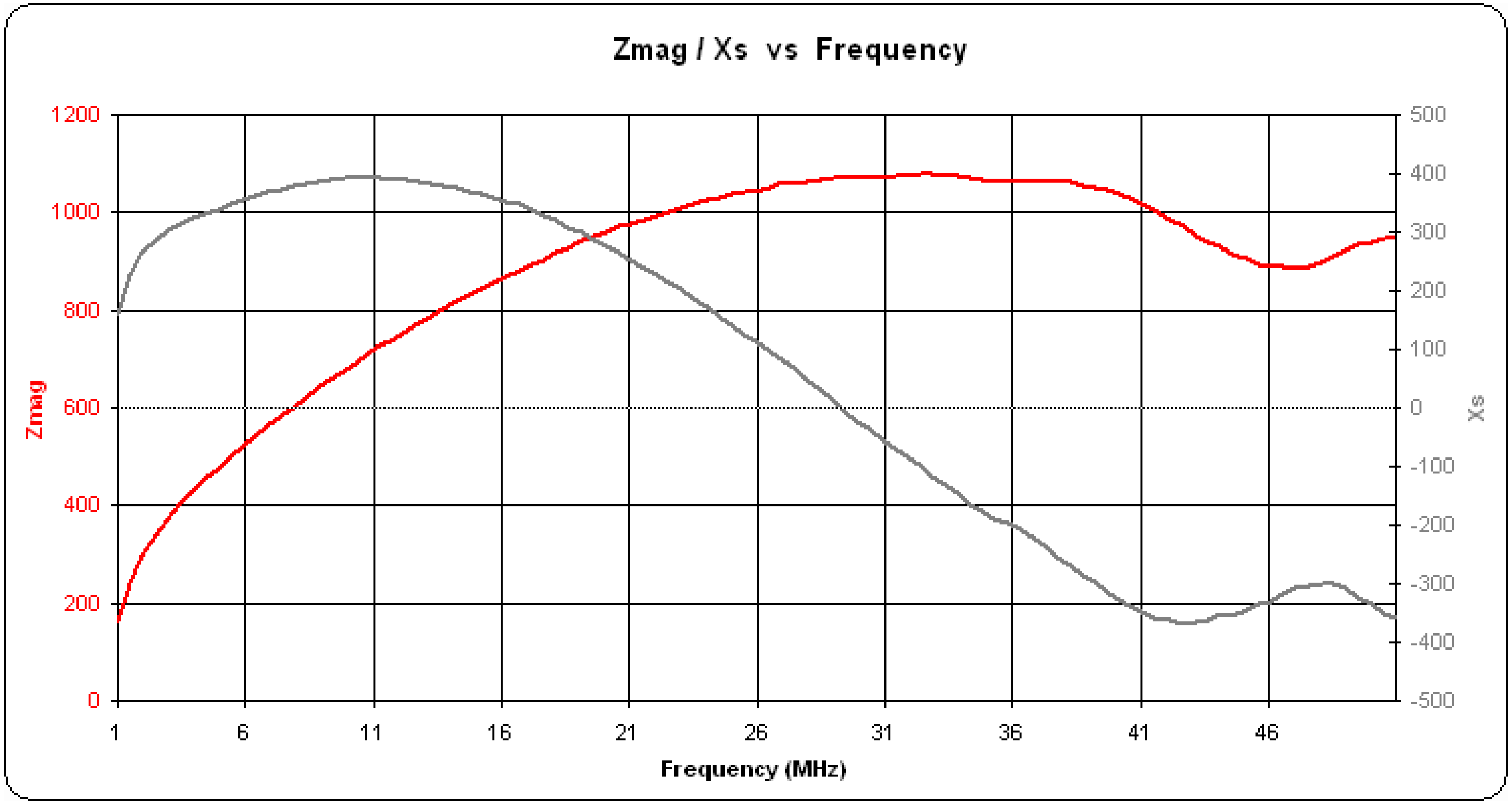
Case 1 Ho = 0 No Bias

- **Ordinary modes exist….**
- **Supports TEM and other waves**
- **μ does not depend on direction (isotropic material)**
- **Applications include EMI chokes and RF inductors**
- **Used extensively in all of our radios**

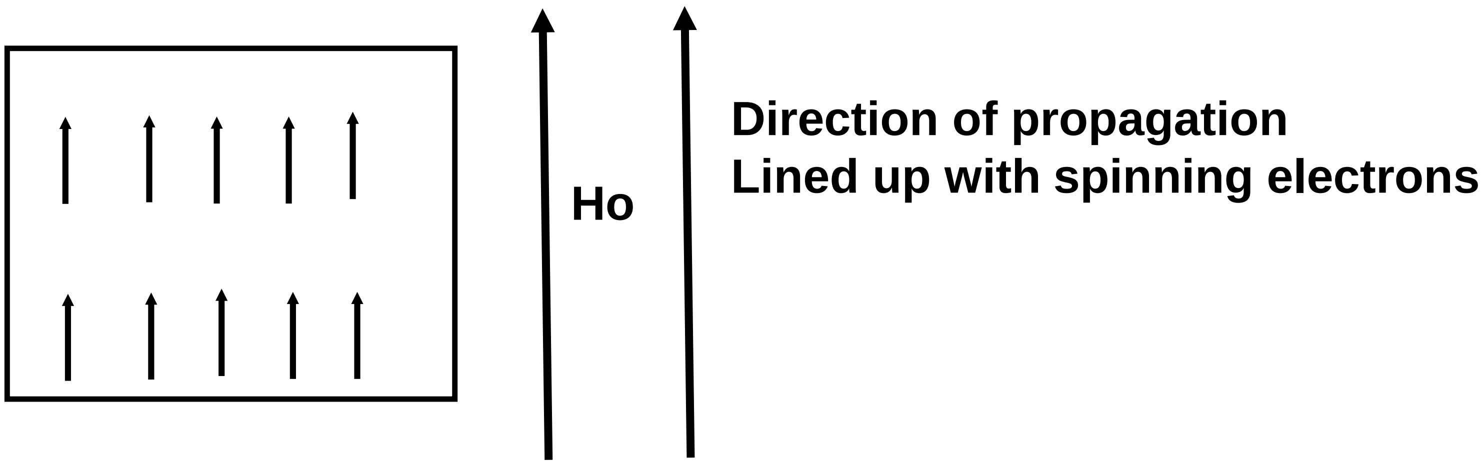
Amidon FT-114A-43 Toroid 12 Turns



#43 EMI Fair-Rite Round Chokes
5 Chokes in Tandem   #2643540002

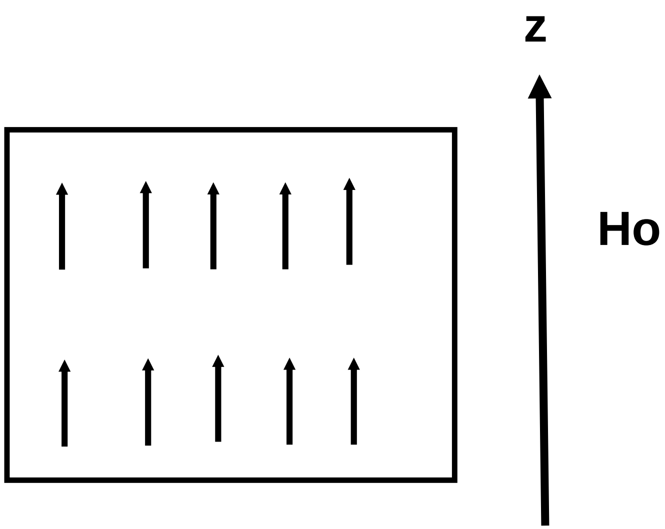


Special Cases
Case 2…Large Ho Bias (Saturation)



- **Spinning electrons aligned**
- **No longer Isotropic**
- **u depends on direction. (not a constant)**
- **Wave propagation depends on direction**
- **High precession frequency….microwave region**
- **We expect big interaction with circularly polarized waves**
- **(RHP different from LHP)**

Permeability, μ, under Bias (Ho) (Assume Saturation)



$$\begin{vmatrix} B_x \\ B_y \\ B_z \end{vmatrix} = \overbrace{\begin{vmatrix} k1 & k2 & 0 \\ k3 & k4 & 0 \\ 0 & 0 & \mu_o \end{vmatrix}}^{\mu} \begin{vmatrix} H_x \\ H_y \\ H_z \end{vmatrix}$$

K1, K2, K3, K4 depend on Ho

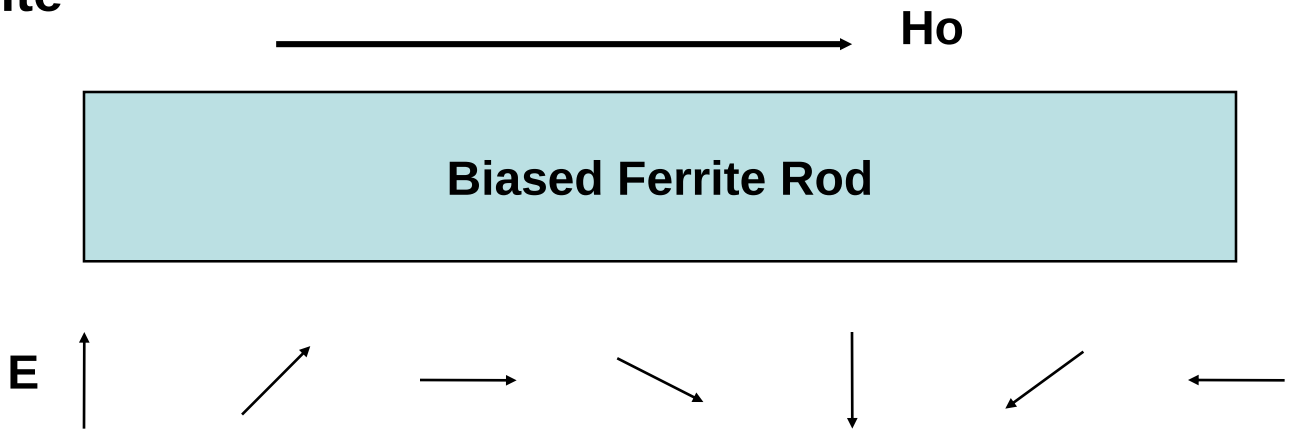
Case 2
Propagation in Direction of Ho

- Solve Maxwell’s equations assuming M is saturated in the z direction
- No solution for a TEM wave
- Circularly polarized waves can exist……RHP + LHP
- RHP and LHP travel at different velocities
- This leads directly to Faraday Rotation.
- A frequency near the ferrite precession frequency reacts strongly
- Many interesting things occur such as stop bands

Faraday Rotation

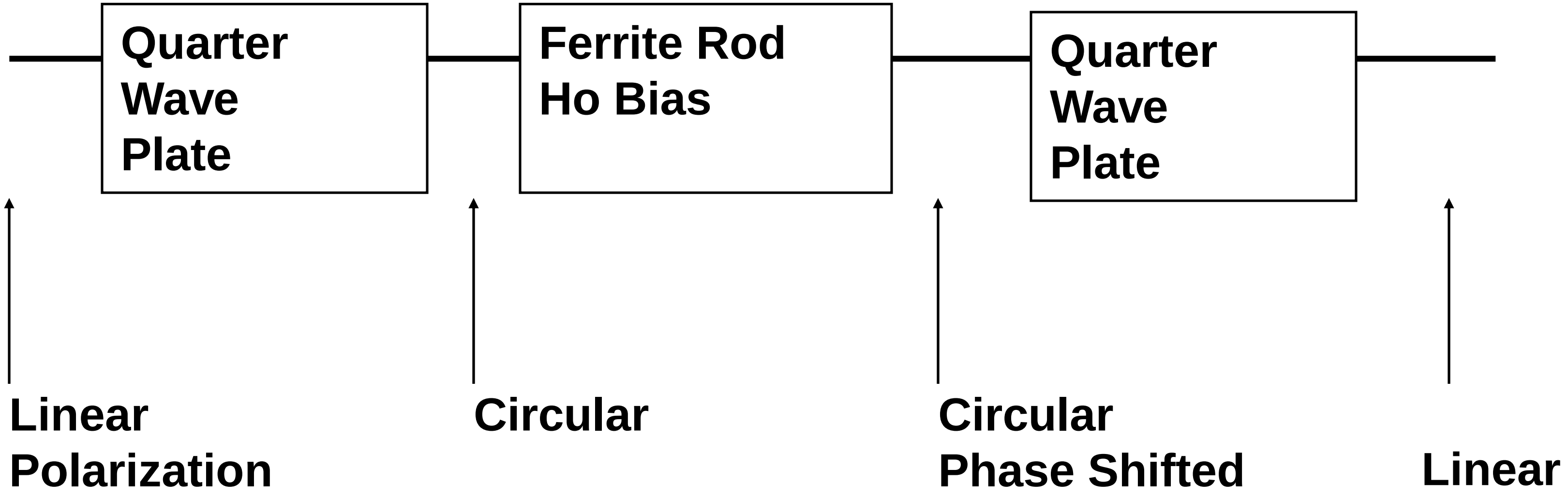
- A linearly polarized wave can be decomposed into RHC + LHC wave
- RHC and LHC waves propagate with different velocities

- This produces a rotation of the wave as it propagates through the ferrite



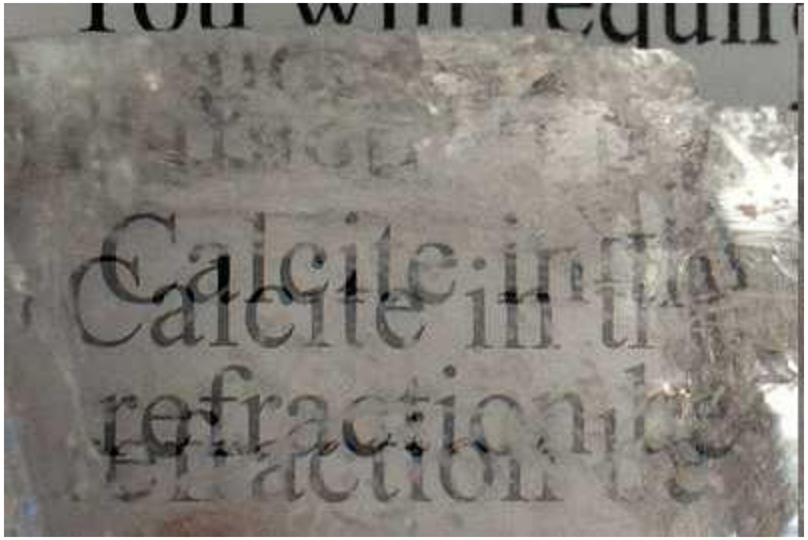
Faraday Rotation Phase Shifter

- Create a RHC wave with a quarter wave plate
- Phase shift it by applying a bias Ho to a ferrite rod
- Convert back to a linearly polarized wave
- See Pozar page 569 for drawing



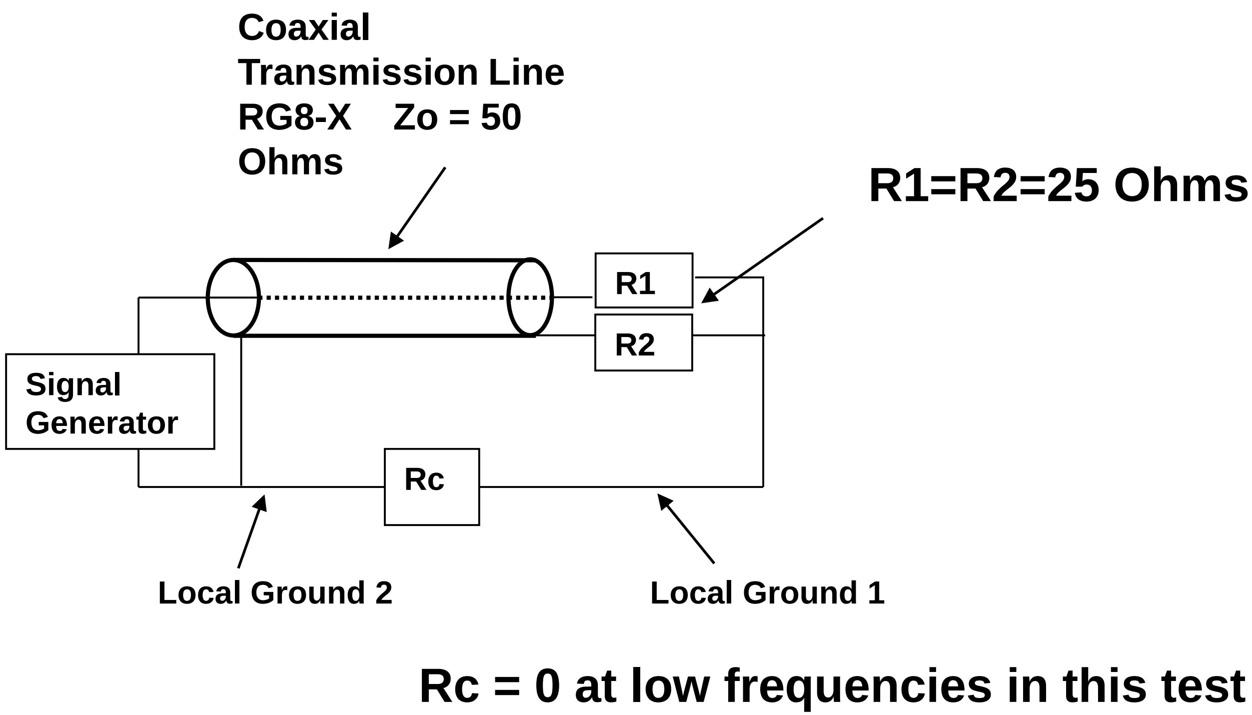
Case 3
Propagation Perpendicular to Ho

- Two plane waves: ordinary and extraordinary
- Waves have different velocities and even stop bands
- This is called birefringence
- Applies mainly to optics and the ionosphere

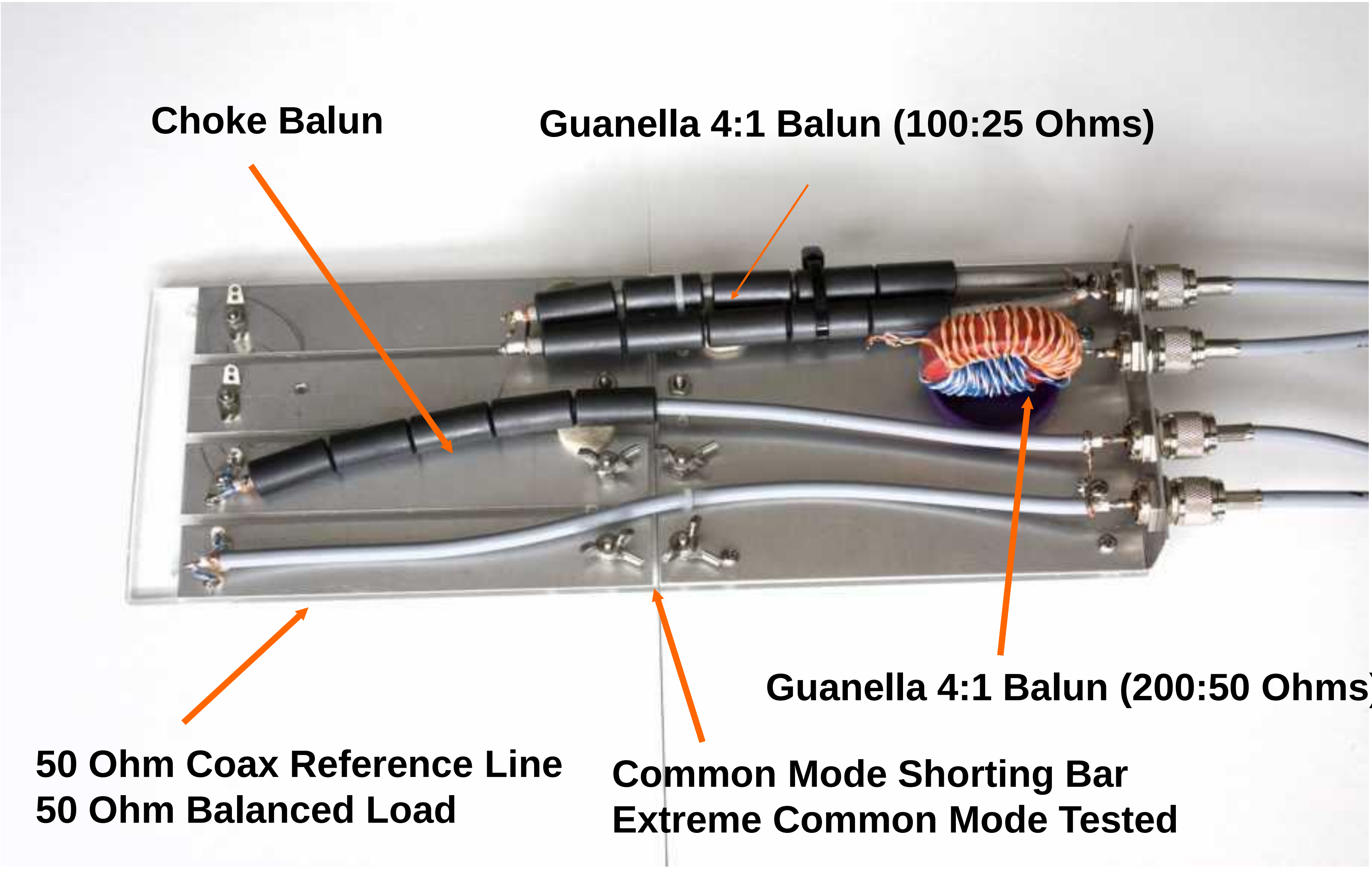


Birefringence in Calcite

EMI Demonstration Block Diagram

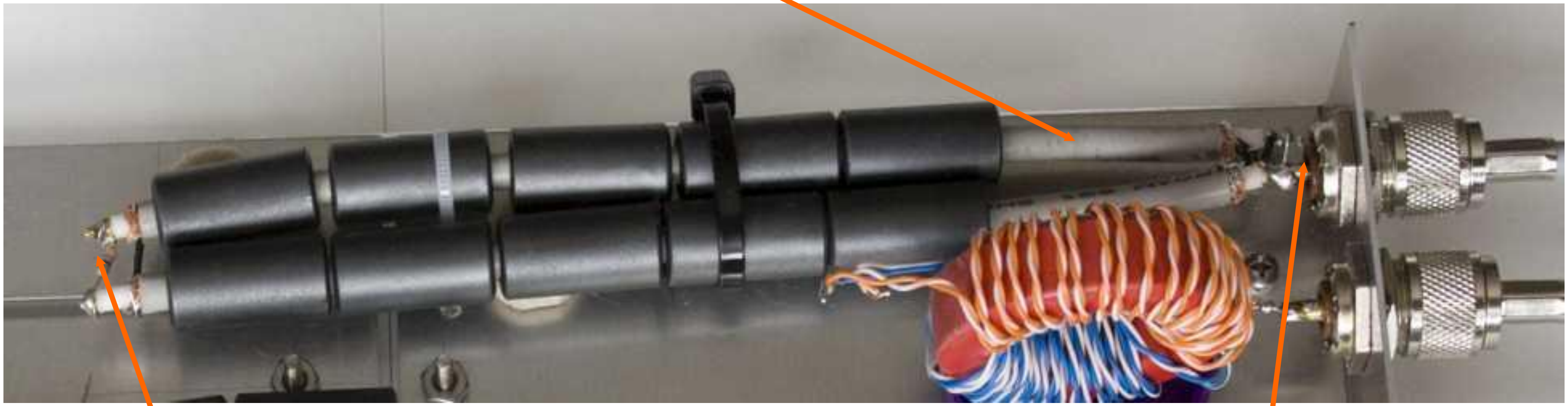


The Test Bed


Choke Balun
Guanella 4:1 Balun (100:25 Ohms)
Guanella 4:1 Balun (200:50 Ohms)
50 Ohm Coax Reference Line
50 Ohm Balanced Load
Common Mode Shorting Bar
Extreme Common Mode Tested

Guanella Balun   4:1 100: 25 Ohms

Uses 50 Ohm Coaxial Line…..not a transformer



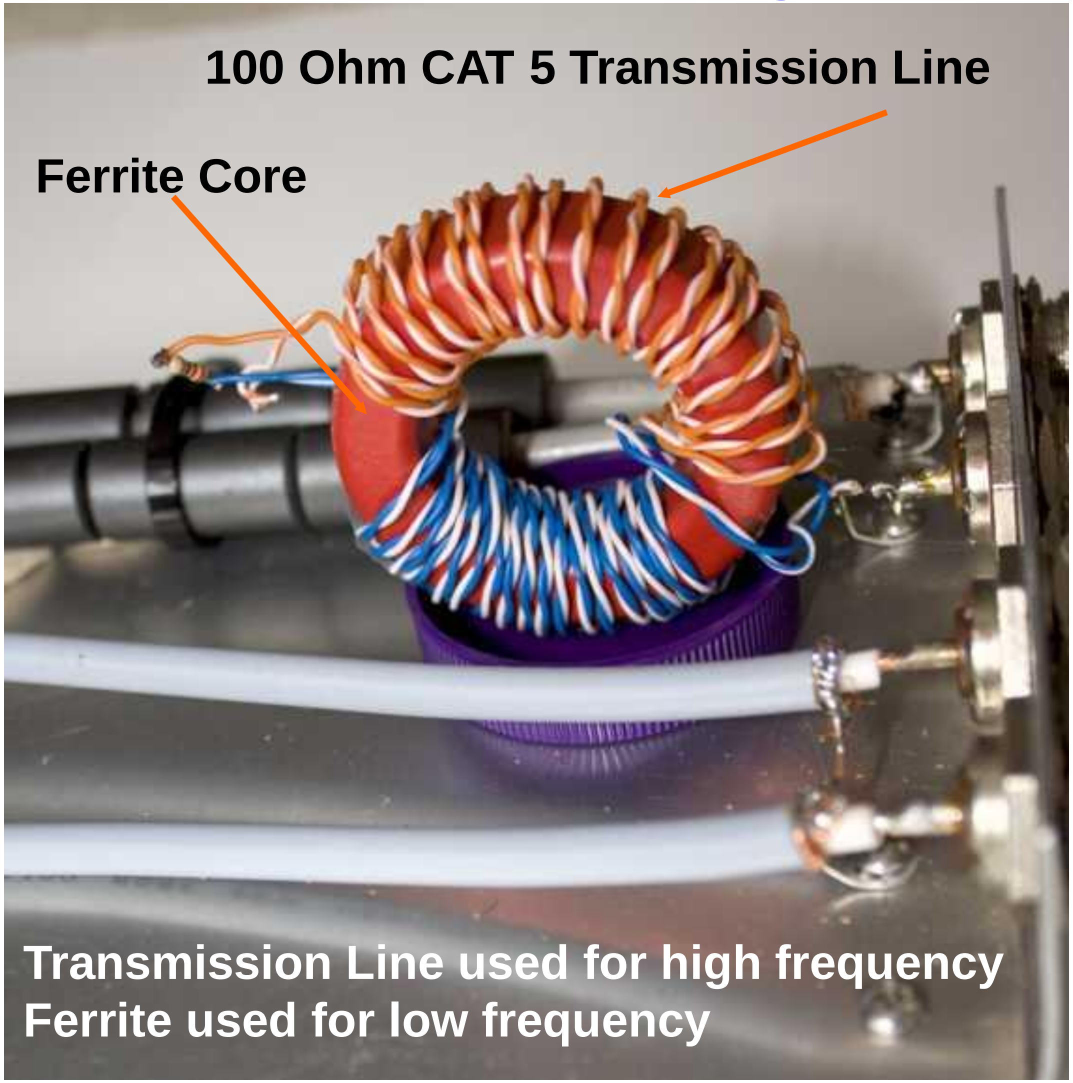
100 Ohm Load

DC short at near end

Ferrite sleeves prevent common mode currents
Easy to simulate using new version of LTSPICE

Guanella 4:1 Balun Using CAT5 Cable

200:50 Ohms



Further Reading

- Hyper Physics Web Site
- Fair-Rite Catalog
- ARRL handbook
- Transmission Line Transformers, Sevick, ARRL
- Microwave Engineering, Pozar, Adison-Wesley
- Fields and Waves in Communication Electronics: Ramo Whinnery Van Duzer: John Wiley
- Clifton Labs: http://www.cliftonlaboratories.com/type_43_ferrite_b-h_curve.htm

Conclusions

- **Soft Ferrites can be biased or unbiased**
- **EMI filters and inductors**
- **Guenalla current Baluns**
- **Microwave Phase shifters and other components**
- **Same theory used to describe wave propagation in the Magnetosphere**
- **Test bed used to study performance of EMI components**

73 Dave VE3KL