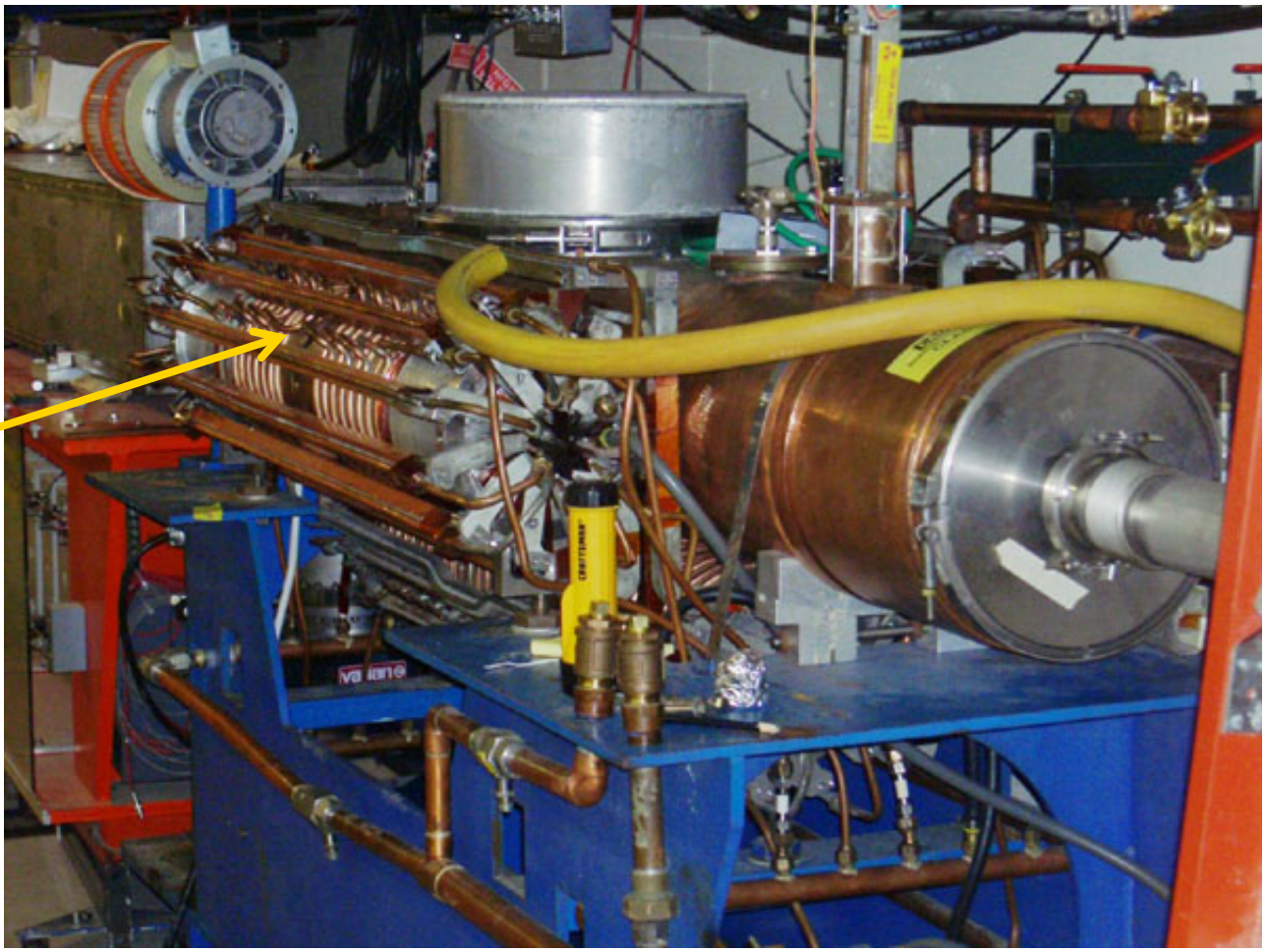
New Ferrite Cores for Booster RF Cavity Tuners (Proton Improvement Plan)

Ralph J. Pasquinelli

Fermilab

November 23, 2011

Ferrites for Booster Tuners



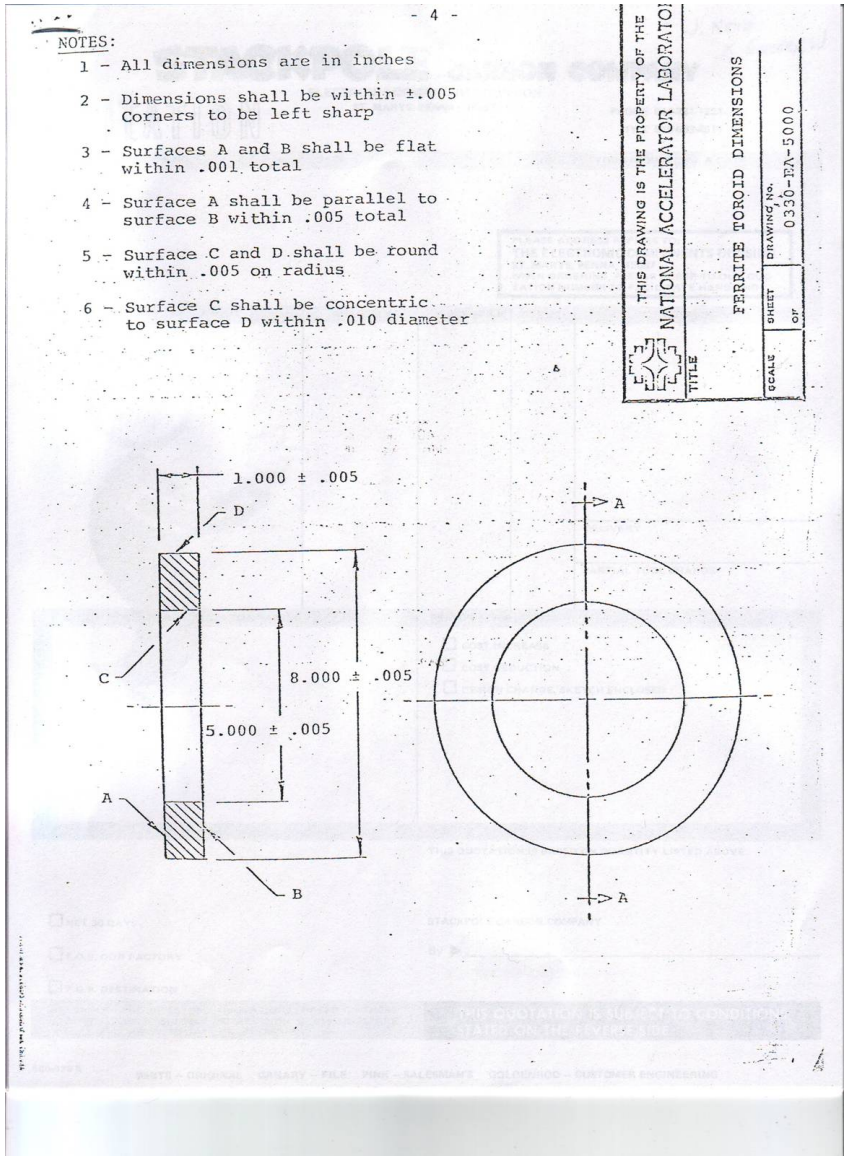
One of Three Tuners

Ferrites for Booster Tuners

Issues with Booster Tuners

- *Booster tuners close to 40 years old*
- *28 cores per tuner, three tuners per cavity*
- *Spare tuners in short supply*
- *All booster cavities to be refurbished over next 18 months*
- *Rebuilds are tedious, cores are succeptible to breakage, water leaks, radioactive*
- *Locate companies that can still produce cores of the required size, permiability, and Q*

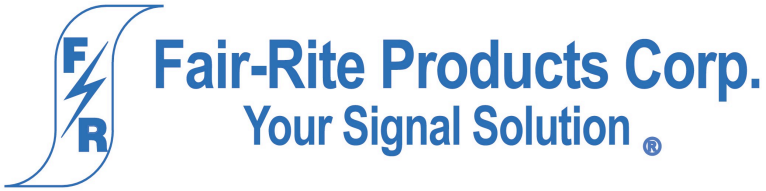
Ferrites for Booster Tuners



Nickel-Zinc
8 inches OD
5 inches ID
1 inch thick
Two values of μ

Ferrites for Booster Tuners

STACKPOLE



TOSHIBA

Ferrites for Booster Tuners

Ferrites for Booster Tuners

National Magnetics Group

Orders for 30 sample cores were placed early June 2011.

First deliveries October 2011 nine cores still outstanding as of November 23, 2011

Ceramic Magnetics, Inc.
A THOMAS & SKINNER COMPANY

Ferrites for Booster Tuners

Ceramic Magnetics, Inc.
A Thomas & Skinner Company

N40 — **High Frequency Ni-Zn Ferrite**

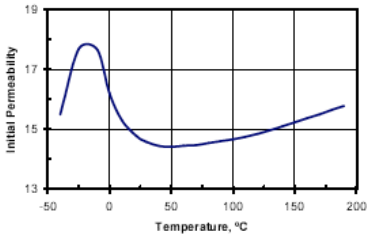
N40 is a Ni-Zn ferrite containing cobalt which has a suitable Q for inductive devices in the 1 to 100 MHz frequency range.

Typical Properties

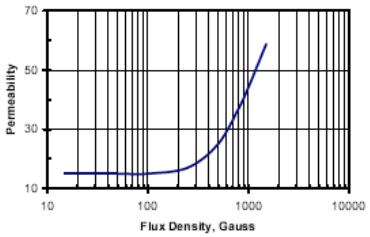
Initial Permeability	15
Saturation Flux Density	2500 Gauss
Remanent Flux Density	950 Gauss
Coercive Force	8.0 Oersted
Curie Temperature	600°C
dc Volume Resistivity	10^{10} ohm-cm
Bulk Density	4.80 g/cc

Unless otherwise specified, all tests were performed at 10 KHz, 22°C
Bs, Br, Hc tested at 1 KHz, 40 Oersted

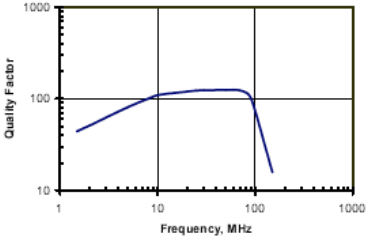
Initial Permeability vs. Temperature



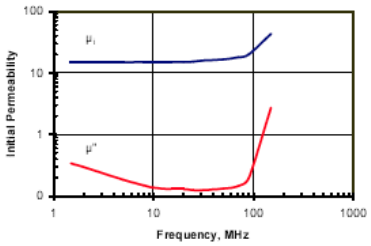
Permeability vs. Flux Density



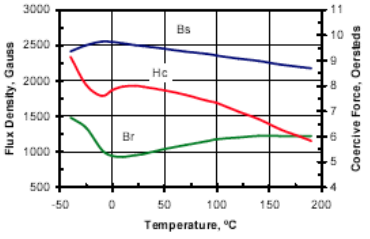
Quality Factor vs. Frequency



Complex Permeability vs. Frequency



BH Loop Parameters vs. Temperature



Upon first delivery
Low Q (<20) due to
Skipped heat treating
Returned and baked
μ is reduced by heat

μ=15
Measured μ=11
Q>800 @ 43 MHz

Can make μ=20
by adjusting formula

Ferrites for Booster Tuners

NATIONAL MAGNETICS GROUP, INC.
MANUFACTURERS OF MAGNETIC AND ADVANCED MATERIALS
AFFILIATE: TCI CERAMICS, INC.

M3

Material

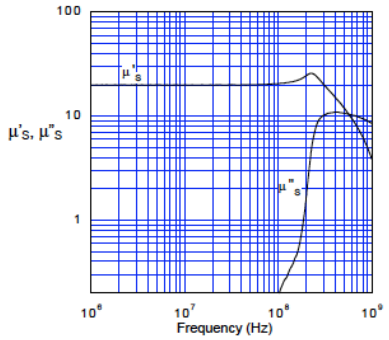
A perminvar NiZn ferrite designed for high frequency applications (up to 100 MHz) including broadband transformers, antennas and high Q inductors.

Specifications

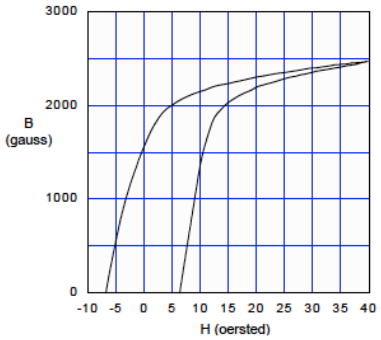
Property	Unit	Symbol	Standard Test Conditions	Value
Initial Permeability		μ_i	Frequency=10 kHz; B<10 gauss	20 ± 20%
Saturation Flux Density	gauss	B_S	H=40 oersted	≈ 2500
Residual Flux Density	gauss	B_r		≈ 700
Coercive Force	oersted	H_C		≈ 7
Loss Factor	10^{-6}	$Tan\delta/\mu_i$	Frequency=100 MHz; B=1gauss	≤ 500
Temperature Coefficient of Initial Permeability (20-70°C)	%/°C			≤ 0.15
Volume Resistivity	Ω cm	ρ		≈ 10^7
Curie Temperature	°C	T_C		> 500

Note: values are typical and based on measurements of a standard toroid at 25 °C

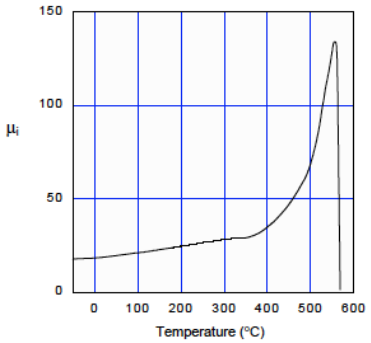
Complex Permeability vs. Frequency



B – H Loop



Initial Permeability vs. Temperature



μ=20

Measured μ=15.5

Q>1000 @ 40 MHz

Ferrites for Booster Tuners

NATIONAL MAGNETICS GROUP, INC.
MANUFACTURERS OF MAGNETIC AND ADVANCED MATERIALS
AFFILIATE: TCI CERAMICS, INC.

M4

Material

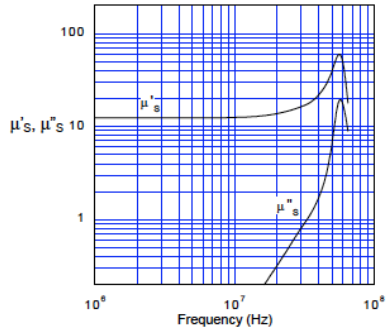
A NiZn ferrite designed for high frequency applications including transformers, antennas and resonant circuit inductors.

Specifications

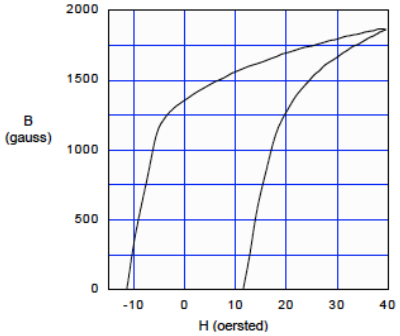
Property	Unit	Symbol	Standard Test Conditions	Value
Initial Permeability		μ_i	Frequency=10 kHz; B<10 gauss	12.5 ± 20%
Saturation Flux Density	gauss	B_s	H=40 oersted	≈ 1800
Residual Flux Density	gauss	B_r		≈ 1350
Coercive Force	oersted	H_c		≈ 12
Loss Factor	10^{-6}	$Tan\delta/\mu_i$	Frequency=10 MHz; B=1gauss	≤ 850
Temperature Coefficient of Initial Permeability (20-70°C)	%/°C			≤ 0.45
Volume Resistivity	Ω cm	ρ		≈ 10^9
Curie Temperature	°C	T_c		> 500

Note: values are typical and based on measurements of a standard toroid at 25 °C

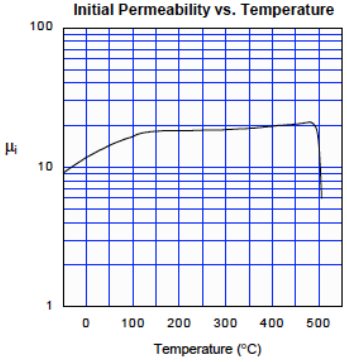
Complex Permeability vs. Frequency



B – H Loop



Initial Permeability vs. Temperature



μ=12

Measured μ=11

Q>280 @ 44 MHz

Ferrites for Booster Tuners

Inductance of a Toroid

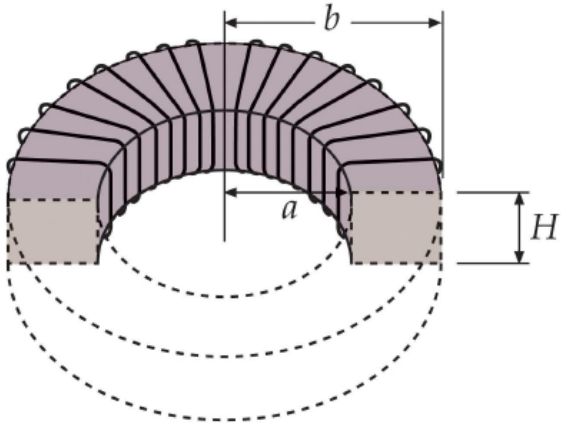
- Total number of turns: N
- Magnetic field inside toroid: $B = \dfrac{\mu_0 I}{2\pi r}$
- Magnetic flux through each turn (loop):

$$\Phi_B = \int_a^b BH\, dr = \frac{\mu_0 INH}{2\pi} \int_a^b \frac{dr}{r} = \frac{\mu_0 INH}{2\pi} \ln \frac{b}{a}$$

- Inductance: $L \equiv \dfrac{N\Phi_B}{I} = \dfrac{\mu_0 N^2 H}{2\pi} \ln \dfrac{b}{a}$
- Narrow toroid: $s \equiv b - a \ll a$

$$\ln \frac{b}{a} = \ln\left(1 + \frac{s}{a}\right) \simeq \frac{s}{a}$$

- Inductance: $L = \dfrac{\mu_0 N^2 (sH)}{2\pi a}$



Ferrites for Booster Tuners

Coaxial Test Fixture + Core
Resonates ~ 40 MHz

Measure Q,L, and μ

Ferrites for Booster Tuners

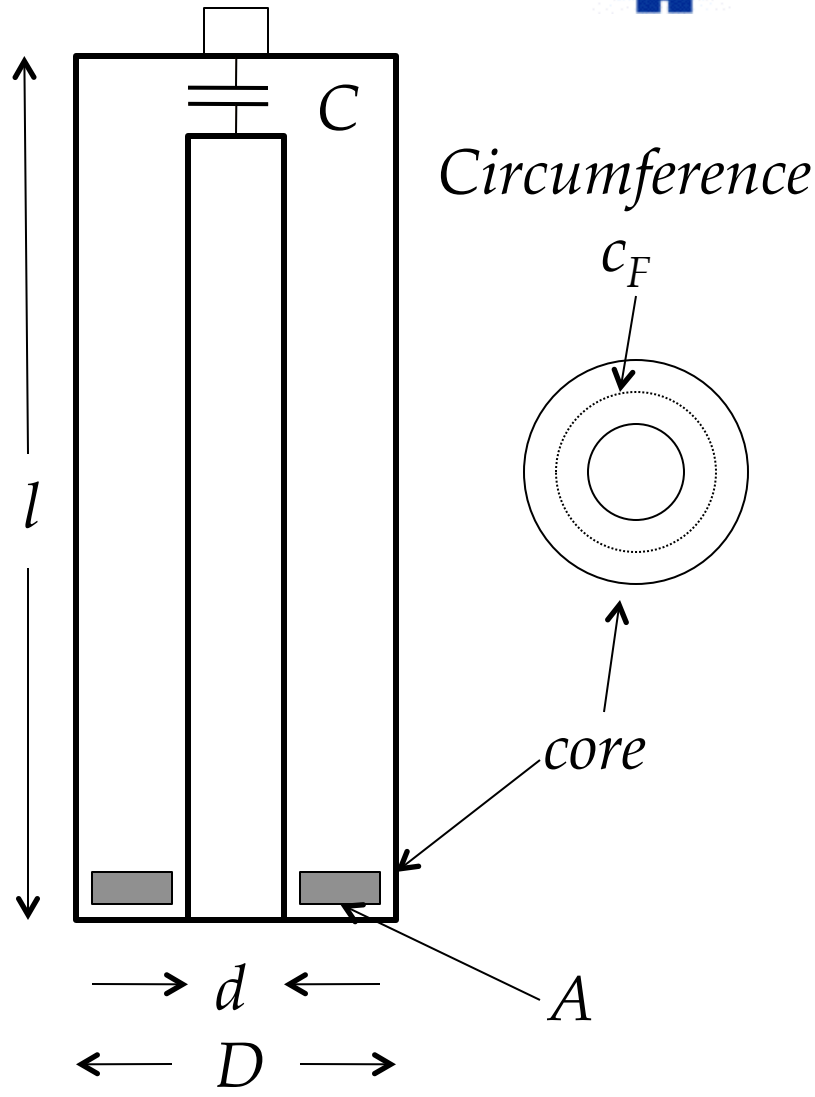
Coaxial Test Fixture

$$L_{coax} = \frac{\mu_o * l}{2\pi} * \ln \frac{D}{d}$$

$$Q = \frac{f_o}{f_{-45} - f_{45}}$$

$$L_F = \frac{1}{(2\pi * f_o)^2 * C}$$

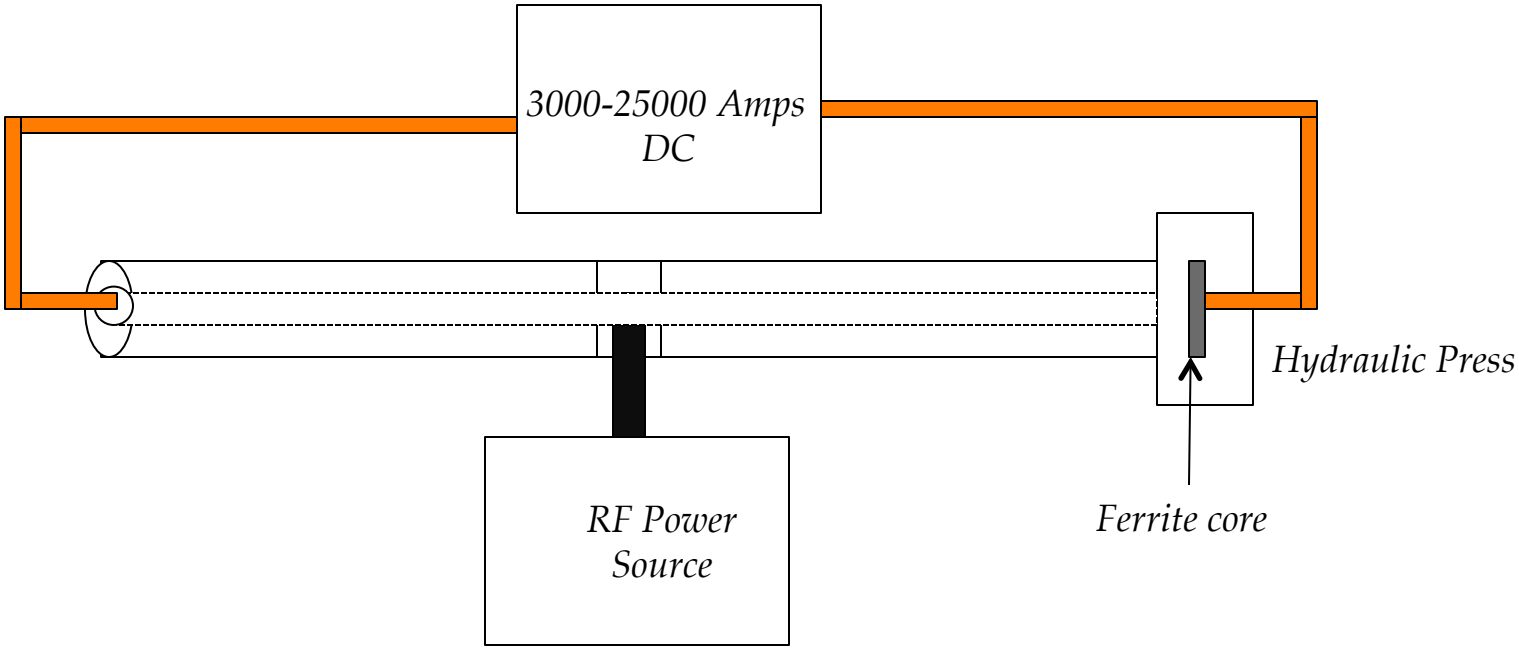
$$\mu_F = \frac{L_F * c_F}{\mu_o * A}$$



Ferrites for Booster Tuners

40 Year Old Biased Core Tester

Ferrites for Booster Tuners



Ferrites for Booster Tuners

Measured with HP Vector Impedance (VI) meter and external synthes											
Core #	Manufacturer	data sheet mu	measured mu	Qo	fo MHz	f low	f high	Zo angle 0 deg	low Z +45 deg	high Z -45 deg	Inductance
1	N40 Ceramic magnetics	15	11.49	767	43.1283	43.1005	43.1567	16000	10200	9900	2.69E-08
2	N40 Ceramic magnetics	15	11.51	847	43.1134	43.0926	43.1435	16200	10600	10900	2.70E-08
3	N40 Ceramic magnetics	15	11.27	866	43.3138	43.2933	43.3433	14900	9680	9850	2.64E-08
4	N40 Ceramic magnetics	15	11.63	947	43.0081	42.9895	43.0349	15600	10200	10800	2.73E-08
5	N40 Ceramic magnetics	15	11.46	823	43.1498	43.1289	43.1813	16500	10800	11200	2.69E-08
6	N40 Ceramic magnetics	15	11.44	1016	43.1705	43.1543	43.1968	16600	10700	11500	2.68E-08
7	N40 Ceramic magnetics	15	11.91	1041	42.7768	42.7613	42.8024	16800	11000	11800	2.79E-08
8	N40 Ceramic magnetics	15	11.88	839	42.8005	42.7814	42.8324	17000	11200	11800	2.78E-08
9	N40 Ceramic magnetics	15	11.26	811	43.3221	43.2997	43.3531	17000	11000	11700	2.64E-08
10	N40 Ceramic magnetics	15	11.61	1044	43.025	43.0092	43.0504	17100	11100	11600	2.72E-08
1	M3 National magnetics	20	15.32	509	40.1985	40.1386	40.2175	22000	14400	14500	3.59E-08
2	M3 National magnetics	20	15.93	1198	39.7838	39.7688	39.802	21000	14000	14480	3.74E-08
3	M3 National magnetics	20	15.63	1102	39.9918	39.9785	40.0148	19300	13600	13920	3.66E-08
4	M3 National magnetics	20	#DIV/0!	#DIV/0!							#DIV/0!
5	M3 National magnetics	20	#DIV/0!	#DIV/0!							#DIV/0!
6	M3 National magnetics	20	#DIV/0!	#DIV/0!							#DIV/0!
7	M3 National magnetics	20	#DIV/0!	#DIV/0!							#DIV/0!
8	M3 National magnetics	20	15.43	1160	40.123	40.1109	40.1455	19400	13700	13900	3.62E-08
9	M3 National magnetics	20	14.47	1063	40.8016	40.7883	40.8267	18800	13300	13300	3.39E-08
10	M3 National magnetics	20	12.45	1001	42.3315	42.3161	42.3584	18140	12500	12220	2.92E-08
11	M4 National magnetics	12	10.95	286	43.593	43.5177	43.6703	4620	3160	3240	2.57E-08
12	M4 National magnetics	12	11.04	286	43.5173	43.4412	43.5931	4600	3140	3250	2.59E-08
13	M4 National magnetics	12	10.88	289	43.65	43.575	43.7258	4660	3160	3250	2.55E-08
14	M4 National magnetics	12	11.11	283	43.4561	43.3798	43.5335	4560	3090	3200	2.60E-08
15	M4 National magnetics	12	11.04	293	43.517	43.4441	43.5924	4620	3180	3240	2.59E-08
16	M4 National magnetics	12	#DIV/0!	#DIV/0!							#DIV/0!
17	M4 National magnetics	12	#DIV/0!	#DIV/0!							#DIV/0!
18	M4 National magnetics	12	#DIV/0!	#DIV/0!							#DIV/0!
19	M4 National magnetics	12	#DIV/0!	#DIV/0!							#DIV/0!
20	M4 National magnetics	12	#DIV/0!	#DIV/0!							#DIV/0!

Ferrites for Booster Tuners

Status & Future Plans

- *First set of sample cores delivered and tested at low level*
- *Refurbish 40 year old biasing test jig and test cores*
- *Build a new tuner using new cores and test*
- *Determine how many new tuners are desired*
- *Procure additional cores for new tuners*
- *Assign appropriate resources (AD & TD) to build and test tuners*