Chokes and Isolation Transformers For Receiving Antennas

By Jim Brown K9YC

Why We Need Them A feedline must be grounded where it enters the shack-for lightning protection; causing the coax shield to behave as a long wire antenna with the base grounded. This makes it a receiving antenna for noise, and even possibly a parasitic element of another antenna nearby. If the feedline is coax, this current flows on the outside of the shield; on 2-wire line, it appears as the difference of currents in the two conductors (which would otherwise be equal and opposite). We call this "common mode" current, as opposed to differential-mode current, which is the current carrying the signal inside the coax from antenna to receiver (or from transmitter to antenna).

Common mode current can couple 1) to circuits at either end of the feedline; and 2) directly to the inside of the coax by a mechanism often quantified as the cable's ***transfer impedance***.

Noise Coupling and Transfer Impedance: Shielded cables have a property often quantified as their ***transfer impedance***, which is the ratio of the differential voltage induced inside the coax as a result of common mode current on the shield. Its units are Ohms, a low value is better, and the lower limit is the resistance of the shield at the frequency of interest. The value of transfer impedance is a property of the cable itself, and is determined by the shield's physical properties – its resistance, overall quality, percent coverage, and uniformity.

Any RF current flowing on the cable shield will induce a corresponding voltage between center conductor and shield, which is added to the signal coming from the antenna. When that RF current is noise, it degrades the signal to noise ratio. When that RF current is a signal off-axis of the receive antenna's desired direction, it reduces its directivity (that is, it fills in the nulls in the antenna's pattern). In a multi-transmitter station, common mode current couples RF radiated by the transmitting antenna that is picked up on the coax shield, which can overload the input stage. In a multi-transmitter station, chokes and/or transformers can reduce crosstalk between transmitters on other bands and the receive antenna.

Transfer impedance can be particularly important because the shield construction of coax we often use for receive antennas is relatively poor on the lower ham bands. We use this cable for good reasons – it's flooded with a gooey material that is self-sealing against penetrations of its outer jacket, protecting the coax from water intrusion; it also helps that varmints don't like the taste of the goo. And because it's sold in very high volume for use in CATV systems, it's dirt cheap (under $100 for a 1,000 ft spool). The downside though, is that the shield is aluminum foil and aluminum braid; this is generally just fine for the CATV systems in which it is designed to be used, but its high shield resistance makes it vulnerable to coupling via its transfer impedance.

The important point here is that common mode current on feedlines is a bad thing and should be avoided. Our two most useful tools for achieving this are 1) Common mode chokes; and 2) transformers.

Effective ***common mode chokes*** are formed by winding multiple turns of a feedline through a suitable ferrite core to form a parallel RLC circuit with a low Q resonance near the operating frequency. In this "near resonance" region, the choke "looks like" a high value of resistance to common mode current, effectively blocking it. We achieve this by choosing a core material (ferrite mix) that's very lossy in the desired frequency range, and by winding the right number of turns around the right size core to place the resonance near the middle of the desired frequency range. The lossy core makes the resonance very broad. Q values of 0.5 – 1 are typical of good chokes.

The differential circuit (the inside of the coax) doesn't see the choke (except as the added feedline length needed to wind it). Table 1 summarizes my work to find the right size core of the right core material for the 630M through 40M bands. These resonances can be clearly seen in plots of measured data for a few representative chokes in the Appendix.

Description		Choking Impedance Rs (Ohms) at Frequency					
Turns	Core	630M	160M	80M	40M	30M	20M
18	1 #75A / 5975001401	3K	**7.7K**	**5.2K**	3.2K	2.5K	
16	2 – #75A / 5975001401	3.8K	**8.2K**	**5.5K**			
17		**5K**	**11K**	**6.3K**	2.9K		
18		**5.8K**	**11.5K**	**6.2K**	2.5K		
19		**6.5K**	**12.5K**	**5.9K**	2.1K		
20		**7.2K**	**12.5K**	**5K**	1.7K		
21		**7.8K**	**13K**	**5.8K**	2K		
16	#75B / 2675821502	4.5K	**6K**	4.1K	2.5K		
18		**5.8K**	**7.2K**	4.6K	2.6K		
20		**7.5K**	**8K**	**4.7K**	2.2K		
22		**9.7K**	**8K**	4.2K	1.6K		
26		**15.6K**	**8K**	3.6K	1.1K		
15	#43 / 5943001601		550	1.7K	3.3K	4.5K	**6K**
27			2.2K	**9K**	**19K**	**8.5K**	1.5K

Table 1 – Receiving Choke Cookbook

The Receiving Choke Cookbook: Table 1 summarizes the results of my measurements of practical chokes wound using one pair removed from good quality CAT6 cable. Higher values of Rs are better; values for recommended chokes are **bold**, and are **red** for optimum chokes. Multiple chokes can be placed in series to increase choking impedance and to cover a wider frequency range. For example, 18-21 turns on two #75A cores in series with 27 turns on one #43 core would provide excellent choking from 480 kHz to 10 MHz (including the AM broadcast band).

The cores for both chokes and transformers are small toroids, typically about 1-in o.d. by about 0.3125-in thick, and are identified by their Fair-Rite part numbers. Cores were chosen on the basis of suitability for the frequency ranges and easy availability at low cost. See "Buying Them," later in this applications note.

Transformers, carefully wound to minimize capacitance between windings, add a very small capacitance (and thus a very high impedance) in series with the common mode circuit, providing an alternate means of blocking common mode current. Transformers used to carry high power (that is, for transmitting antennas) usually have bifilar windings – that is, the primary and secondary are wound in close proximity (nearly touching) to maximize coupling and minimize loss (and excessive heating). Too much capacitance between primary and secondary provides a path for common mode current; for this reason, bifilar transformer windings should be avoided with receive transformers.

With receive antennas the primary concern is signal-to-noise ratio. We are concerned with two kinds of noise – atmospheric noise picked up by the antenna, and circuit noise within the receiver (or its preamp). Most receive antennas are designed to reject atmospheric noise while maximizing pickup of signals in one or more desired directions. A few, like are magnetic loops, have very broad patterns with a pair of sharp nulls that are oriented to reject a single noise source.

From the viewpoint of circuit noise, receive antennas fall into two broad categories – those with relatively high output like Beverages and large loops, and those with relatively low output, like small loops. In this context, size is relative to a wavelength at the frequency of interest. On the lower bands, by the time it reaches our receivers, band noise from high output antennas is usually much stronger than circuit noise within the receiver; a few dB loss (in the feedline or a transformer) can usually be tolerated, but pickup of local noise on the line cannot.

This may or may not be true with small loops – their output may be too low to overcome circuit noise due to losses in the transmission line. In a well designed receiving system, signal to noise ratio for circuit noise is determined at the first gain stage. A good number to remember is that in order to hear the weakest signals, ***noise picked up on the antenna should be at least 10 dB stronger than circuit noise by the time it reaches the first gain stage,*** whether that first gain stage is an outboard preamp or the receiver's input stage. At this level, signal to noise ratio will be degraded by only 0.4 dB. Increasing the ratio to 13 dB makes it 0.2 dB. In practical terms, this means that we should see the band noise rise by at least 10 dB (about two S-units on a well calibrated S-meter) when an antenna is connected to our receiving system; if it doesn't, there's too much loss between the antenna and first input stage, so a preamp should be used. If some of the loss is in the feedline, the preamp should be at the antenna. An excellent tutorial presentation by OH6LIaddressing these concepts is at http://wwrof.org/webinar-archive/receiving-antenna-metrics-with-examples/

If that preamp is at the antenna, feedline loss doesn't matter – but if the preamp is powered via the coax you can't use a transformer (unless you run a separate pair to carry power)!

Total loss will be the loss in the transformer plus the loss in the coax. Measured loss in Commscope F677TSEF, the flooded RG6 often used for receive antennas, is 0.45 dB/100 ft at 2 MHz and 0.5 dB/100 ft at 3.6 MHz. [Loss deviates from sqrt (f) at low frequencies because the center conductor is copper clad steel.] Plots of the measured loss, VF, and Zo for this cable are in the Appendix.

Measured loss data for transformers wound on opposite sides of small cores for three different ferrite mixes is summarized in Table 2. Use this table to choose the core and the number of turns for your application. Loss in the chokes in Table 1 is too small to measure.

Fair-Rite Mix / Part Nr	Loss in dB						
	Turns	0.5 MHz	2 MHz	4 MHz	7 MHz	10 MHz	14 MHz
#61	2½		2.04	1.9	2.5	3.25	4.5
	3½		1.4	1.8	3.1	4.5	
	4½		1.6	2.9	5.4	7.4	
	5½		1.9	3.9	7.2	10	
	6½		2.2	4.7	8.5	10.8	
#75 / 5975001401	3	1.2	1.25	1.6	2	2.6	3.5
	4	0.7	0.8	1.25	2.1	3.1	4.4
	5	0.4	0.6	1.1	2.2	3.4	5.1
#43 / 5943001601	3	2.1	1.5	1.7	1.9	2.4	3.2
	4	1.15	1.1	1.6	2.5	3.7	5.2
	5	0.75	1	2	3.7	5.4	7.5

Table 2 – Loss Data for 1:1 Receive Transformers on Small Fair-Rite Cores

Resonance in Ferrite Inductors Figs 1a and 1b show why high frequency loss increases with more turns – the windings are resonating, as indicated by the peak around 26 MHz for the 5½ turn transformer wound on a #61 core. These are Vector Network Analyzer sweeps with the transformer connected between output and input. The VNA input and output impedances are 50 ohms, the unit can simultaneously measure both gain (loss) and the impedance seen by the generator. The blue curve is the gain (loss) through the transformer, 6dB/div, with zero at the top; the red curve is the impedance seen by the VNWA, 500 ohms/div, zero at the bottom. The sweep is logarithmic from 2

MHz to 50 MHz. The resonant peak in the 2½ turn transformer is much higher in frequency, off the graph.

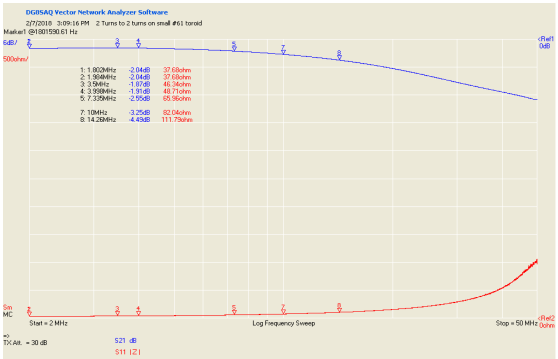


Fig 1a – 2½ turns #61

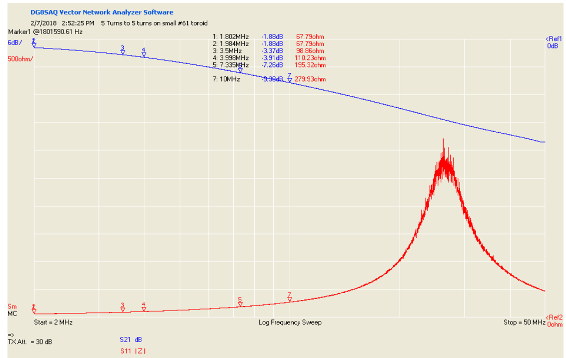


Fig 1b – 5½ turns #61

When a turns ratio other than 1:1 is used (usually to match a high impedance receive antenna to a coax feedline), the winding with the most turns will resonate at the lowest frequency. If wideband response is desired, the number of turns on the high impedance side should be chosen so that the rise in loss due to resonance in shown in Table 2 occurs above the highest desired operating frequency. For example, no more than about six turns should be used on #75 material for an antenna that we want to work well up to 40M. I plan to look at 3:1 turns ratio (9:1 impedance ratio) transformers in a future applications note.

Placement: A choke (or transformer) should always be placed at the antenna feedpoint. One or more additional chokes along the line "break up" the line into non-resonant lengths so that it becomes a less efficient receive antenna for noise, just as guy wires are broken up with egg insulators. I use transmitting chokes to break up the coax feedlines to high dipoles so that they do not act as parasitic elements to my 160M vertical. We also break up feedlines from receive antennas to prevent noise coupling via the coax's transfer impedance.

Choke or Transformer? The "right" transformer can cover the bandwidth of most receiving antennas, while chokes are generally optimum on one or two bands; multiple chokes in series can cover multiple bands. Chokes can pass DC to power a preamp or switch a relay at the antenna, while transformers cannot. Because they are electrically very short, the loss introduced by these chokes is too small to measure – less than 0.01dB.

When NOT to Use a Transformer: Low output antennas (small loops) where feedline loss is a concern, and for any antenna where switched DC on the coax is used to power a preamp or control a relay at the antenna.

When either one works: High output antennas (Beverages, large loops) with no DC on the coax for a preamp or relay.

Buying the Parts: I've found Arrow Electronics to have the best prices for small quantities of Fair-Rite parts that they stock, and shipping is free for orders of $20 or more. These are very inexpensive parts – less than $1 for the #75 cores and about $1.25 for #43. Buy enough to hit the $20 for free shipping, filling your parts stash and sharing with friends.

Part #	o.d. (in)	i.d. (in)	Thick (in)
5943001601	1.225	0.75	0.312
5975001401	1	0.61	0.32
2675821502	1.22	0.748	0.59

Table 3 – The Cores

Building Them: Chokes and transformers should be mounted in a non conductive enclosure and wired to chassis-mounted female F-connectors. (coax connectors mounted to a metallic enclosure would defeat the choke, by connecting the two cable shields). Weatherproof boxes should be used outdoors. Fig 3 shows a 4-in x 4-in x 2-in box with a gasketed screw cover that houses the transformer and termination for a VE3DO receive loop. The wing nuts connect the wires, coax goes to an F-connector on the bottom of the enclosure. I paid about $7 at the local big box store. It's Carlon p/n E989NNJL.

Fig 3 – Outdoor Enclosure

When winding chokes, pairs that are individually molded are strongly preferred. Belden's structured cables (CAT5/6) use this construction; I had some Belden 1872A left over from a project, and used that (Fig 4). [The two conductors in Fig 4 were shorted together for measurement. In use, they are connected as a transmission line.] These cables have a nominal Zo of 100Ω, which is close enough to 75Ω that the short electrical length of the winding that the choke does not add measureable loss. F-connectors with solder tabs can be found from internet vendors. For transformers, use any small diameter (18-26 AWG) insulated solid copper (solid is preferred simply because the windings stay in place better. Fig 5 shows one of the 3:3 turn transformers being measured. The windings are #24 solid copper.

Fig 4 – Receiving Chokes

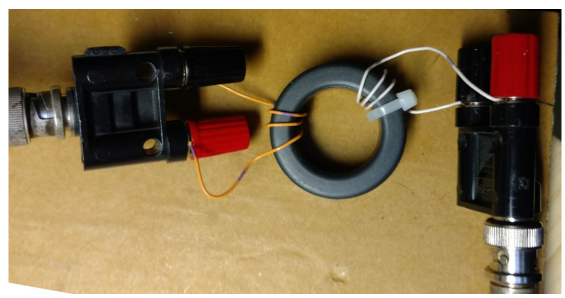


Fig 5 – Receiving Transformer

Series and Parallel Equivalent Circuits A ferrite choke works by forming a <u>parallel</u> resonant circuit, where Lp and Rp are the inductance and resistance coupled from the core and Cp is the stray (parasitic) capacitance between turns and between the windings through the core (the core is a dielectric). Lp, Cp, and Rp can be derived from the measured data using classic circuit analysis. ***For any given choke, Lp, Cp, and Rp are approximately constant with frequency, having values that depend on the core material and the physical arrangement of the winding.*** The parallel equivalent circuit helps us tweak the design of the choke to fit our needs by placing the resonance where we need to kill common mode current.

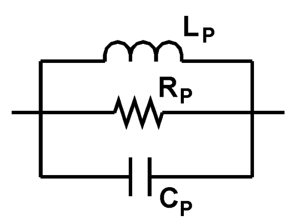


Fig 6a – Parallel Equivalent Circuit

This measured data provides values for the choke's **series** equivalent circuit, Rs + j Xs, and Zmag, where Zmag is the square root of the sum of the squares of Rs and Xs. ***For any given choke, these values are <u>different</u> for every frequency.*** Knowing Rs, however, is quite convenient for our analysis of their usefulness, because it is Rs that always reduces common mode current.

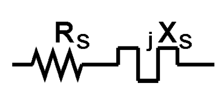


Fig 6b – Series Equivalent Circuit

Understanding the Common Mode Circuit: Consider a simple dipole fed with coax. In the common mode circuit, the coax shield becomes part of the antenna, acting as a single wire connected between one side of the center of the antenna and ground. As a common mode circuit element, its VF is near 0.98 (depending on the diameter of the shield and the outer dielectric). In the common mode circuit, this wire (the coax) has some impedance, (Rs + jXs), by virtue of its electrical length, which is different at every frequency. At some frequencies, Xs will be positive (inductive), at others it will be negative (capacitive).

Because it can be inductive or capacitive, and because the common mode circuit will be inductive at some frequencies and capacitive at others, Xs of the choke can cancel part or all of the Xs of the common mode circuit. This cancellation causes common mode current to increase, which is the opposite of the desired result. But Rs of the choke always adds to the common mode impedance, so a high value of Rs always reduces common mode current.

Fig 7 shows a choke added to a feedline that looks capacitive at some frequency of interest. In this example, the capacitive and inductive reactances partially cancel, adding to 4,040Ω +j 100Ω. Rs and Xs values for both choke and feedline will be different at every frequency, with Xs values sometimes adding and sometimes cancelling, but Rs values always adding.

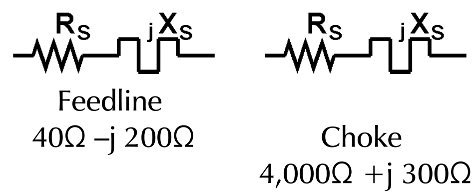


Fig 7

A line that is electrically short at a given frequency (< λ/4) looks inductive; Xs of a choke that looks inductive at those frequencies will reduce current. As the line becomes longer (λ/4 – λ/2) it becomes capacitive, and an inductive choke increases the current. This cyclical relationship repeats as the line gets longer electrically (i.e., longer coax or increasing frequency). A high value of Rs "swamps" the effects of reactance (so that the reactance values don't matter, or can only decrease current), so that a choke with a high value of Rs is effective for any length of coax.

[Note that the coax shield doesn't have to be grounded to unbalance the antenna or to carry common mode current – any wire connected to any point on an antenna becomes part of the antenna and will carry current. The only effect of the connection, or the lack of a connection at the other end, or the length of the wire, is to change the current distribution on that wire (the coax shield).]

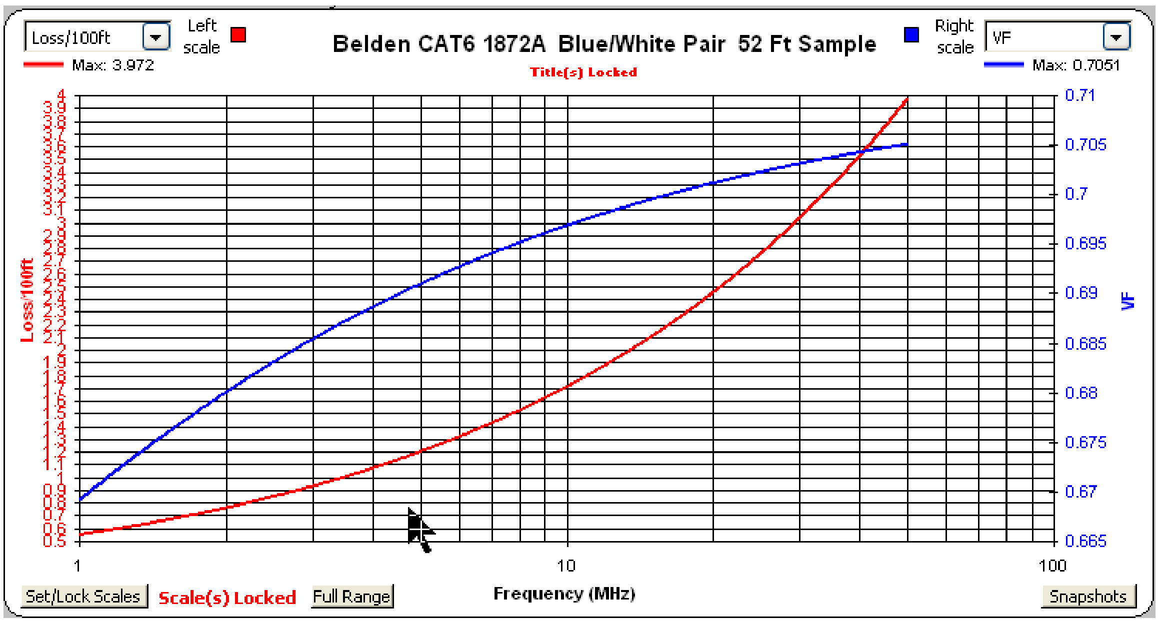
Acknowledgements: Thanks to Wayne Burdick, N6KR, Elecraft co-owner, who provided the ferrite cores used for this work, and for work on chokes for transmitting antennas for the 630m band.

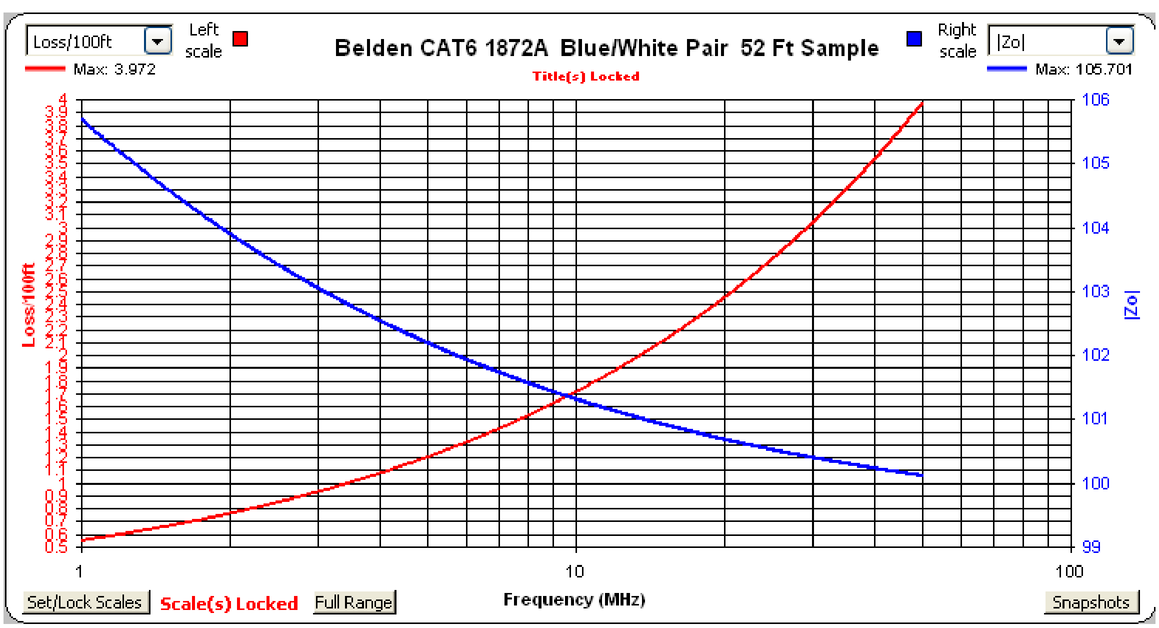
Appendix

Measured Transmission Line Loss Data

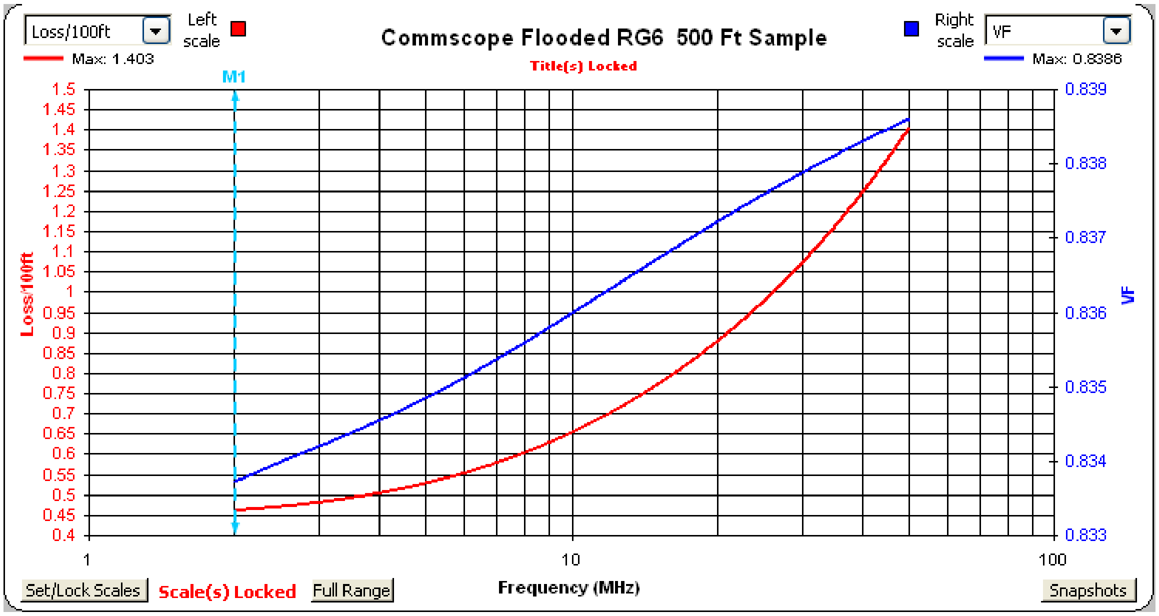
To obtain this data, two S11 measurements were made on known lengths of each cable using a DG8SAQ VNWA Vector Network Analzyer. For the first measurement the far end shorted, while for the second the far end was open circuit. Those data were posted processed using AC6LA's ZPlots Excel spreadsheet to compute and plot Zo, VF, and attenuation over the range of the measurement.

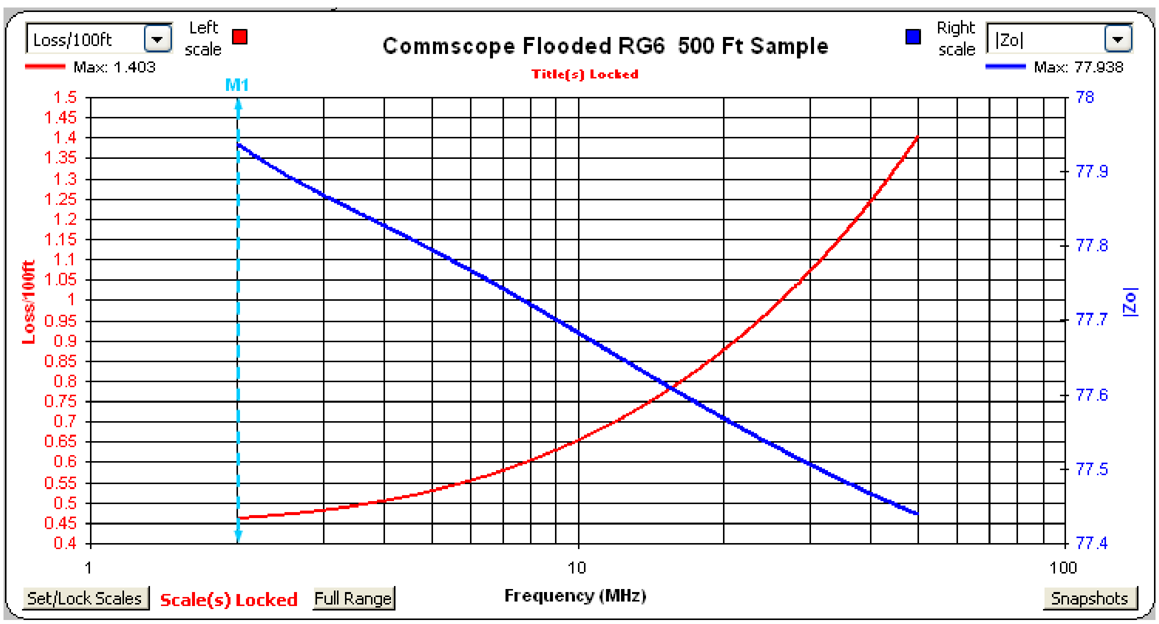
Belden CAT6 1872A: Zo (nom) = 99.15 ohms, = VF (nom) = 0.712, Loss = 0.77 dB/100 ft @ 2 MHz, 1 dB/100 ft @ 3.5 MHz, 1.42 dB/100 ft @ 7.15 MHz [Zo, VF, and attenuation vary with frequency for all practical transmission lines. Nominal values are those to which the line converges (flattens out) at high VHF. Zo (nom) = sqrt (L/C).]





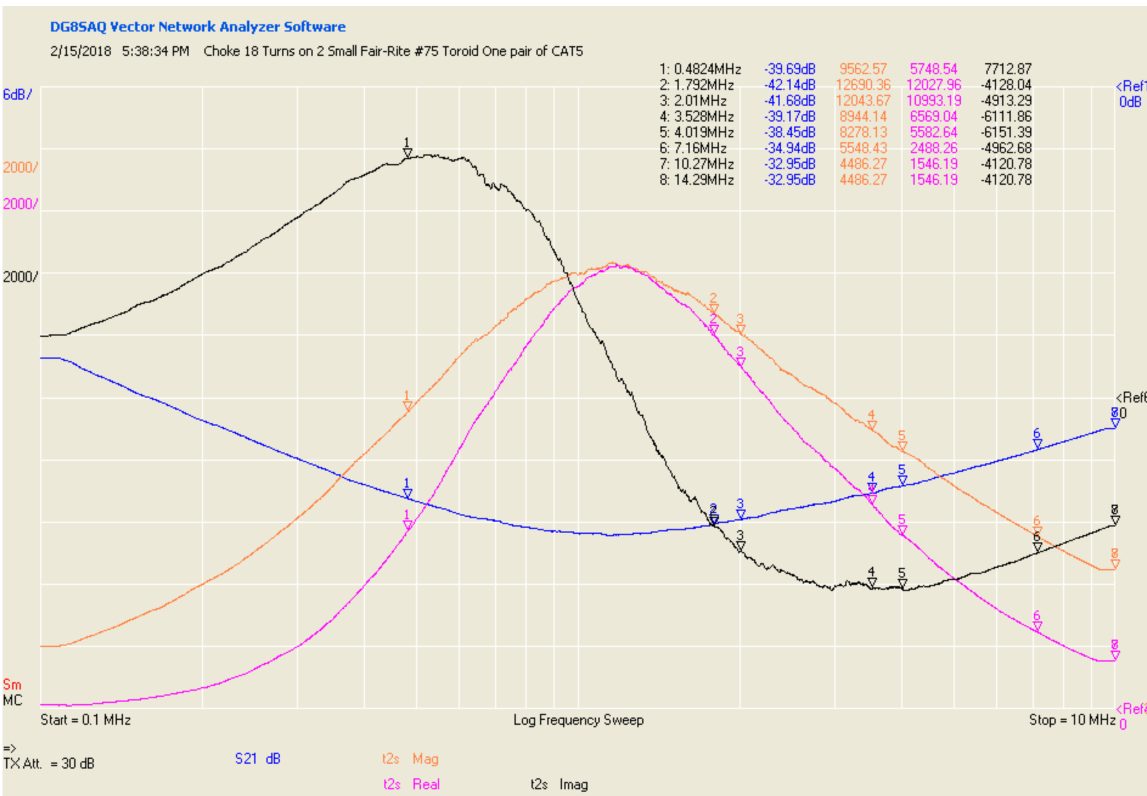
Commscope F677TSEF): Zo (nom) = 77.2 ohms, VF (nom) = .8414, loss = 0.46 dB/100 ft @ 2 MHz, 0.495 dB/100 ft @ 3.5 MHz, 0.583 dB/100 ft @ 7.15 MHz



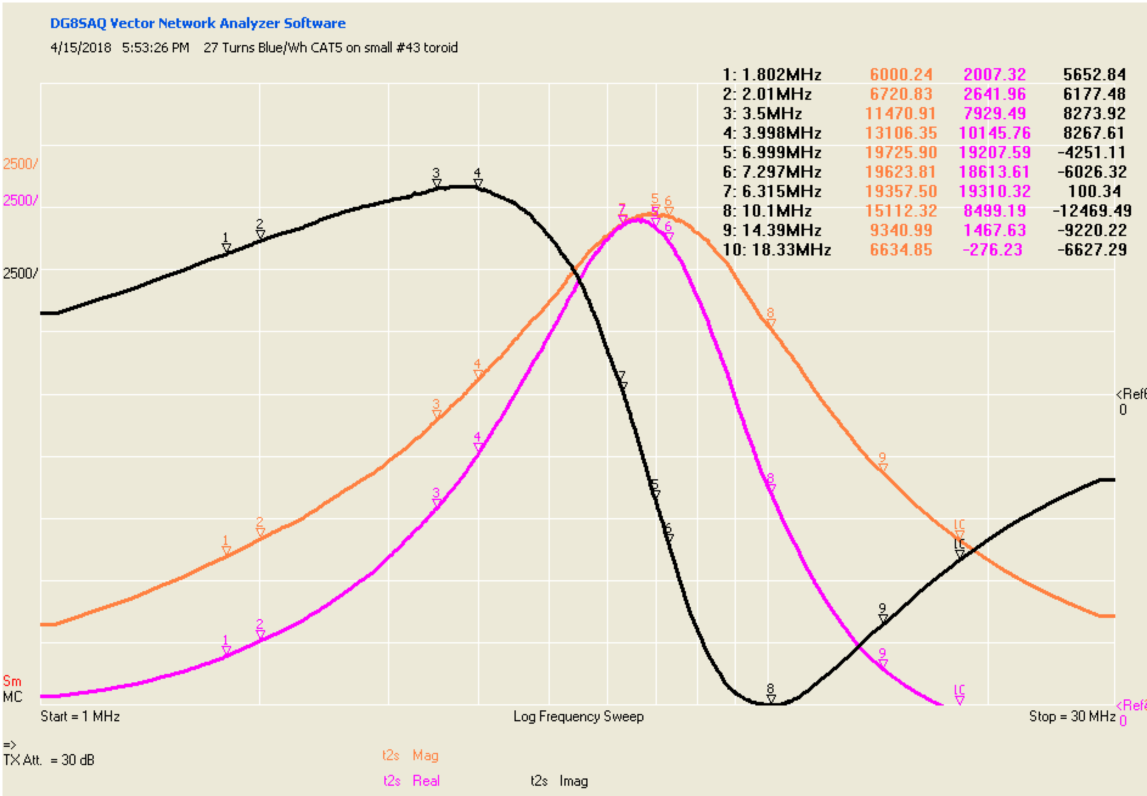


Measured Impedance of Representative Chokes

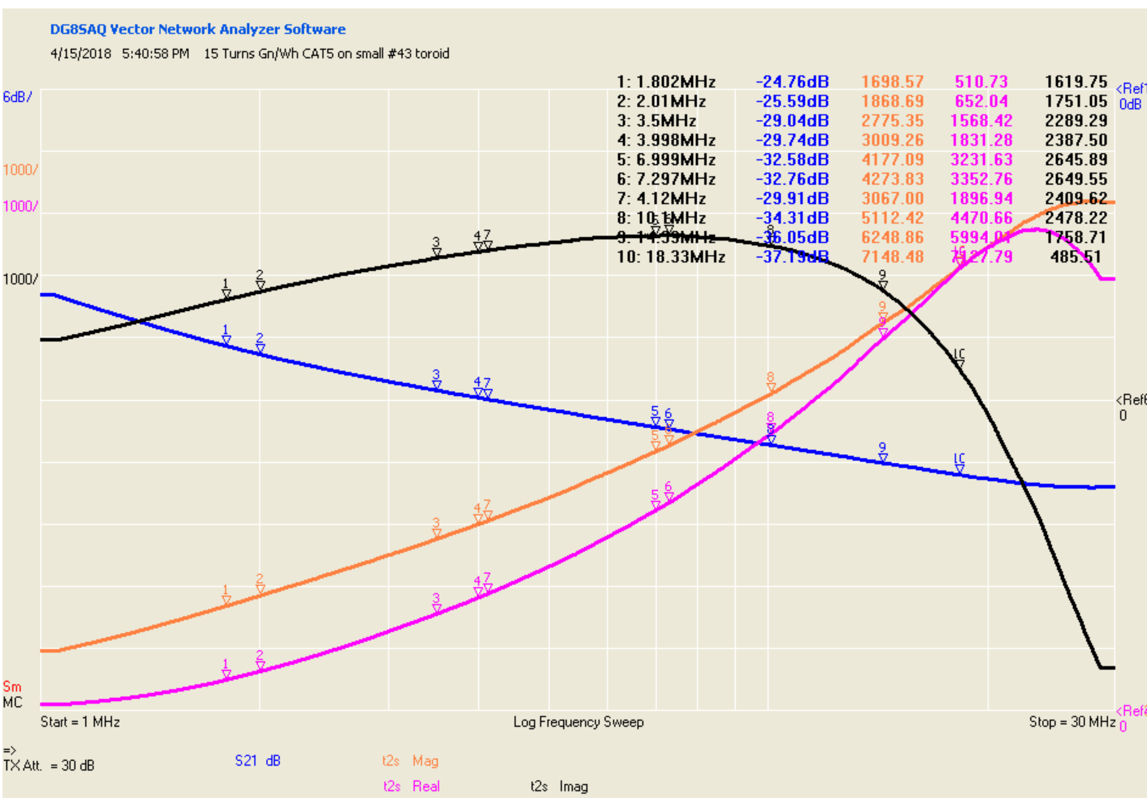
About these data: These data were measured using a VNWA 3e Vector Network analyzer. A network analyzer consists of a calibrated 50 ohm source and calibrated receiver with a 50 ohm input impedance. The choke was placed in series between generator and receiver, making it the series element of a voltage divider, the load element of which is the receiver's 50 ohm input impedance. The analyzer measures S21, which is the voltage gain of the circuit being measured. Zmag, Rs, and Xs are derived from S21 by solving the voltage divider equation backwards. The Orange curve is Zmag, the magnitude of the choking impedance, Magenta is Rs, the series equivalent choking impedance, and Black is Xs, the reactive component of the choking impedance. The blue curve is S21, with zero at the top of the plot. Axis calibration for each curve is along the left axis in dB/div; the frequency axis is logarithmic. Zero for Rs and Zmag is the bottom of the plot. Zero for Xs is the center of the plot.



18 turns of one pair from a CAT5 cable on two small #75 (Fair-Rite p/n 5975001401)



27 turns of one pair from a CAT5 cable on a small #43 toroid (Fair-Rite p/n 5943001601)



15 turns of one pair from a CAT5 cable on the same small #43 toroid