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Chokes and Isolation Transformers for Receiving Antennas

Why We Need Them

A feed line 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 feed line is coaxial cable, this current flows on the outer surface of the shield; on two-wire feed 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 feed line; and (2) directly to the inside of the coax by a mechanism often quantified as its *transfer impedance*.

Noise Coupling and Transfer Impedance

The transfer impedance of a shielded cable 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 all of 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 (SNR). When that RF current is a signal off-axis of the receive antenna's desired direction, it reduces its directivity. i.e., 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 cable-television distribution (CATV) systems, it's dirt cheap — often less than $100 for a 1,000-foot spool. The downside is that the shield is aluminum foil and aluminum braid; this is generally just fine for the CATV systems, but its high shield resistance makes it vulnerable to coupling via its transfer impedance.

The important point here is that common-mode current on feed lines 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 feed line 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 feed line length needed to wind it. Table 1 summarizes my work to find the right size core of the right core material for 630 through 40 meters. (These resonances can be clearly seen in plots of measured data for a few representative chokes in the Appendix material, which will be posted on the NCJ website, **http://ncjweb.com**.)

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 R_S are better; values are in bold for recommended chokes and bold italicized 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

Table 1
Receiving Choke Cookbook (Fair-Rite Mix / Part #)

Description		Choking Impedance R_S (Ω) at Frequency (MHz)					
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

kHz to 10 MHz (including the AM broadcast band).

The cores for both chokes and transformers are small toroids, typically about 1 inch outside diameter (OD) by about 0.3125 inch 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.

Transformers

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 that are used to carry high power, i.e., for transmitting antennas, usually have bifilar windings, with the primary and secondary wound in close proximity 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 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, such as Beverages and large loops, and those with relatively low output, such as 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 decibels loss in the feed line 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, SNR 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 by 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, SNR 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) 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 feed line, the preamp should be at the antenna.

An excellent tutorial presentation by OH6LI that addresses these concepts is at **http://wwrof.org/webinar-archive/receiving-antenna-metrics-with-examples/**

If that preamp is at the antenna, feed-line loss doesn't matter; 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 feet at 2 MHz and 0.5 dB/100 feet at 3.6 MHz. Loss deviates from the square root of the frequency at low frequencies, because the center conductor is copper clad steel. Plots of the measured loss, VF, and Z_O for this cable are in the Appendix on the *NCJ* website.

Table 2
Loss data for 1:1 receive transformers on small Fair-Rite cores

Mix / Part #		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 summarizes loss data for transformers wound on opposite sides of small cores for three different ferrite mixes. 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.

Resonance in Ferrite Inductors

Figures 1 and 2 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 (Figure 2). These are Vector Network Analyzer (VNA) sweeps with the transformer connected between output and input. The VNA input and output impedances are 50 Ω; the unit can simultaneously measure both gain (loss) and the impedance seen by the generator. The upper curve is the gain (loss) through the transformer, 6 dB/division, with zero at the top; the lower curve is the impedance seen by the VNWA, 500 Ω/division, 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 (Figure 1).

When a turns ratio other than 1:1 is used (usually to match a high-impedance receive antenna to a coax feed line), 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 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 40 meters.

Placement

A choke (or transformer) should always be placed at the antenna feed point. One or more additional chokes along the line break up the line into non-resonant lengths, so 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 feed lines to high dipoles, so that they do not act as parasitic elements to my 160-meter vertical. We also break up feed lines 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 0.01 dB.

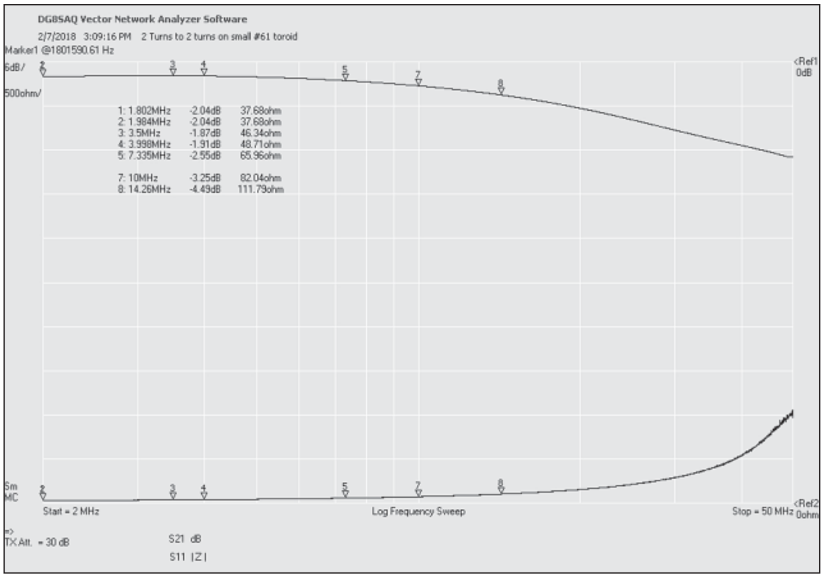
When and When *Not* to Use a Transformer

Do not use a transformer on low-output antennas (small loops), where feed-line loss is a concern, or for any antenna where dc is carried on the coax to power a preamp or control a relay. High-output antennas (Beverages, large loops) with no dc on the coax for a preamp or relay can use either a choke or a transformer.

Building Them

Chokes and transformers should be mounted in *non-conductive* enclosures 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). Weather-proof boxes should be used outdoors. Figure 3 shows a 4 × 4 × 2-inch 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. This one is Carlon part number E989NNJL. I paid about $7 at the local big box store.

Figure 3 — Weather-proof box for outdoor use with a cover that is protected with gaskets



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1: 1.802MHz    -2.04dB    37.68ohm
2: 1.984MHz    -2.04dB    37.68ohm
3: 3.5MHz      -1.87dB    46.34ohm
4: 3.998MHz    -1.91dB    48.71ohm
5: 7.335MHz    -2.55dB    65.96ohm

7: 10MHz       -3.25dB    82.04ohm
8: 14.26MHz    -4.49dB    111.79ohm
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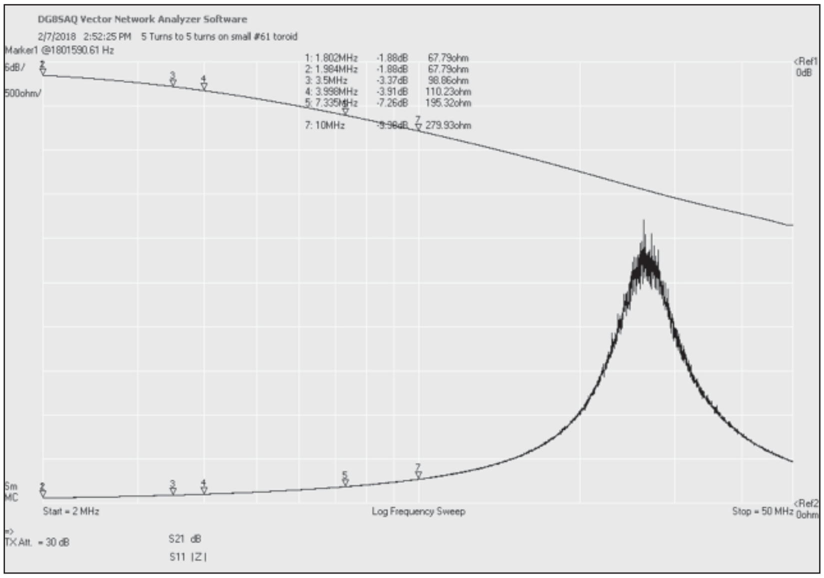
Figure 1 — 2½ turns #61



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1: 1.802MHz    -1.88dB    67.79ohm
2: 1.984MHz    -1.88dB    67.79ohm
3: 3.5MHz      -3.37dB    98.86ohm
4: 3.998MHz    -3.91dB    110.23ohm
5: 7.335MHz    -7.26dB    195.32ohm

7: 10MHz       -9.98dB    279.93ohm
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Figure 2 — 5½ turns #61

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 (see Figure 4). The two conductors in Figure 4 were shorted together for measurement. In use, they are connected as a transmission line. These cables have a nominal Z_0 of 100 Ω, which is close enough to 75 Ω that the short electrical length of the winding 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. Figure 5 shows one of the 3:3-turn transformers being measured. The windings are #24 solid copper.

Series and Parallel Equivalent Circuits

A ferrite choke works by forming a *parallel* resonant circuit, where L_p and R_p are the inductance and resistance coupled from the core and C_p is the stray (parasitic) capacitance between turns and between the windings through the core (the core is a dielectric). L_p, C_p, and R_p can be derived from the measured data using classic circuit analysis. For any given choke, L_p, C_p, and R_p 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.

This measured data provides values for the choke's *series* equivalent circuit, R_s + j X_s, and Z_{mag}, where Z_{mag} is the square root of the sum of the squares of R_s and X_s. For any given choke, these values are different for every frequency. Knowing R_s, however, is quite convenient for our

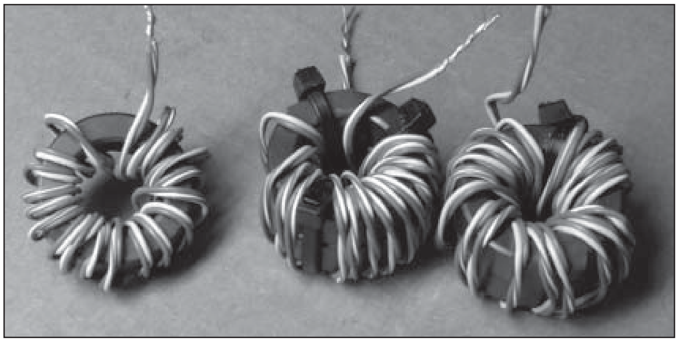

Figure 4 — FairRite 75 Receiving Chokes

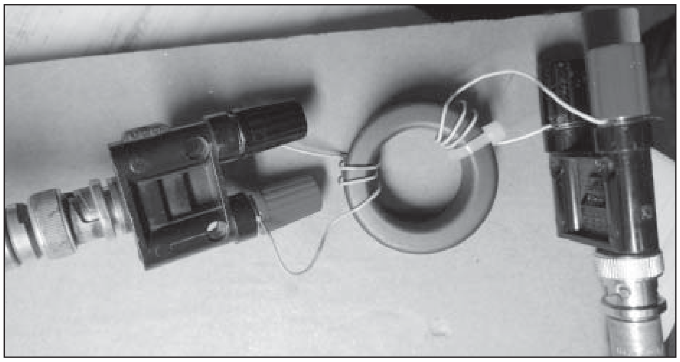

Figure 5 — Receiving Transformer

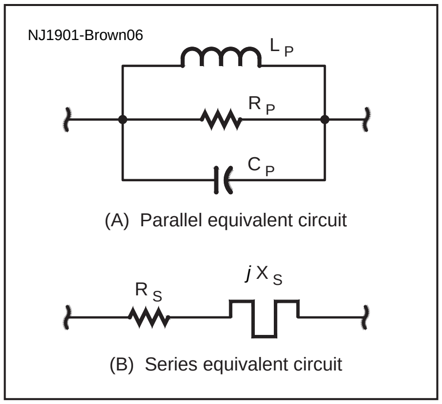

Figure 6 — (A) Parallel Equivalent Circuit. (B) Series Equivalent Circuit

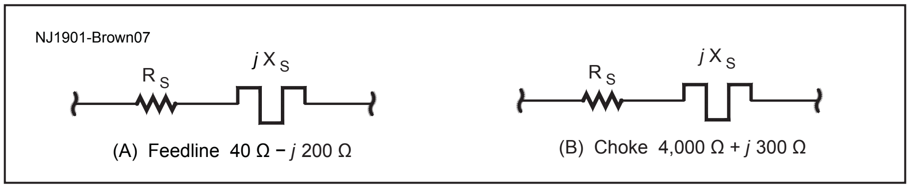

Figure 7 — Choke examples

analysis of their usefulness, because it is R_S that always reduces common-mode current.

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 velocity factor (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, ($R_S + jX_S$), by virtue of its electrical length, which is different at every frequency. At some frequencies, X_S will be positive (inductive); at others it will be negative (capacitive).

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

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

A line that is electrically short at a given frequency — less than 0.25 λ — looks inductive; X_S of a choke that looks inductive at those frequencies will reduce current. As the line becomes longer between 0.25 and 0.5 λ, 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 R_S "swamps" the effects of reactance, so that the reactance values don't matter, or can only decrease current. A choke with a high R_S value is effective for any length of coax.

Note that the coax shield does not 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).

Table 3
The cores

Part #	OD (in)	ID (in)	Thick (in)
5943001601	1.225	0.75	0.312
5975001401	1	0.61	0.32
2675821502	1.22	0.748	0.59

Acknowledgements:

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