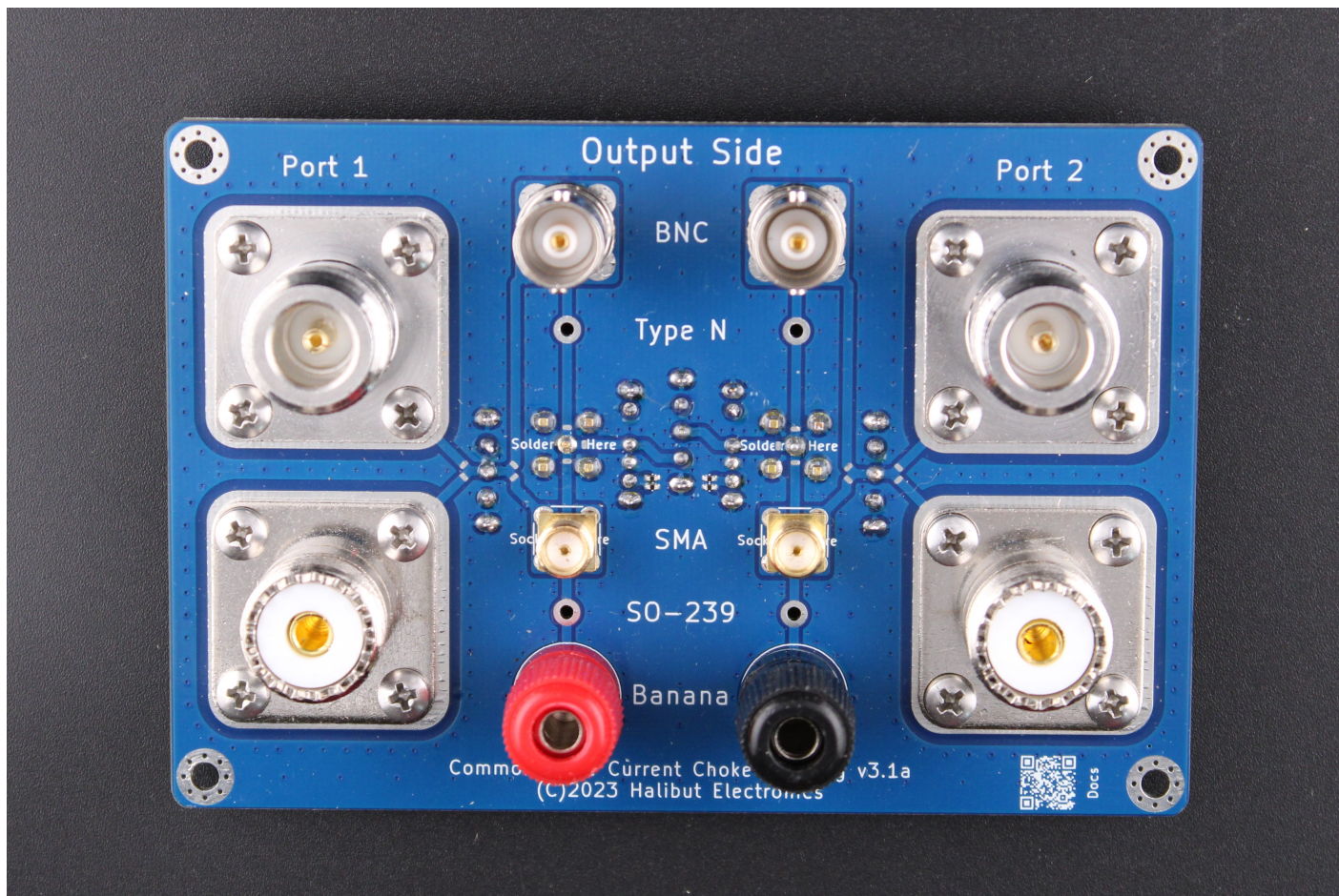


1. Common Mode Current Choke Test Rig, User Guide

Thank you for purchasing the Halibut Electronics Common Mode Current Choke Test Rig! That's quite a mouthful, so I'm just going to call it the CMCC Test Rig, or just CMCC, or Rig, etc. ...we're pretty close, on a first name basis. I like to name-drop it a lot. Gives me street cred. ...Anyway...



CMCC is a kit, some assembly required. And by "some" I mean "all." Please see the [Assembly Instructions](#) for how to build the thing, then come back here for how to use the thing.

This version of the documentation covers both v3.0 and v3.1 of the CMCC Test Rig. v3.1 has on-board calibration standards that were not on v3.0, three additional switches. Otherwise, the boards are identical.

1.1. Change Log

Date	Description
2022-08-18	First public revision. Assembly of v3.0c boards.
2022-11-30	Updating for v3.0d boards. Electrically identical, new silkscreen to clarify assembly.
2024-01-12	Updating for v3.1a boards. Added on-board calibration standards. Updated images.

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3. tl;dr: Quick Start Guide

If you already understand what's going on and just need the specifics of this product, hopefully this will get you started quickly. If you read this and still have some questions, then keep reading.

1. Connect the Test Rig to your VNA through the SMA ports on in the Input side of the board, using whatever SMA jumper cables you have.
2. Calibrate the VNA, **CMCC Test Rig v3.0**:
 - Set the frequency range on the VNA before calibrating.
 - Slide the switches on the Test Rig to the "Thru" position.
 - Ideally, use Open/Short/Load (OSL) calibration standards for whatever connectors you're going to use to measure your CMCC. If you don't have OSL calibration standards for those connectors, that's fine. Use whatever OSL calibration standards you have and calibrate your VNA with the CMCC Test Rig in the system. That is, if you have SMA OSL standards, then connect them to the "SMA" ports on the output side of the board when calibrating.
 - Calibrating the VNA is beyond the scope of this document, BUT!
 - Perform the Open, Short, and Load calibrations with the Test/Thru switches in "Thru."
 - Perform the Isolation, and Through calibrations with the Test/Thru switches in "Test." If you're using jumper cables to connect to a CMCC, include those in the Through tests.
3. Calibration the VNA, **CMCC Test Rig v3.1**:
 - Set the frequency range on the VNA before calibrating.
 - Slide the Test/Thru switches to the "Test" position. They will remain here for all steps of calibration.
 - Do NOT use the normal calibration slugs that came with your VNA. This process uses the on-board calibration standards.
 - Perform the VNA calibration with the Open/Short/Load (both switches set the same every time) and Isol/Thru switches in the following positions:
 - Open: Open, Isol
 - Short: Short, Isol
 - Load: Load, Isol
 - Isolation: Load, Isol (conveniently, the same as Load)
 - Through: Open, Thru (note that all three switches are changing)
4. For taking measurements, slide *all* the switches on the Test Rig all the way up: Test, Open, Isol.
5. Connect the Device Under Test (DUT), your common mode current choke, to whatever connectors it uses. If you are using jumper cables between the DUT and the Test Rig, make them as short and straight as possible. We are measuring the OUTSIDE of the cable, so any coils, or proximity to near by metallic things, will impact your readings.
6. Use the VNA to measure S21 LOGMAG. This tells you how much rejection your CMCC is providing. You want the S21 LOGMAG to be as large a negative number as possible. A good target is about -25dB or more. -30dB is better.

3.1. Err... What does all that mean? What is this thing doing?

Ok, a quick explanation of what we're doing, how this thing works.

Without going into the details (see the Theory of Operation documentation (WIP) for those details), a VNA normally only measures what's going on INSIDE the coax. Everything that happens OUTSIDE the coax is transparent to the VNA. Normally, this is what we want.

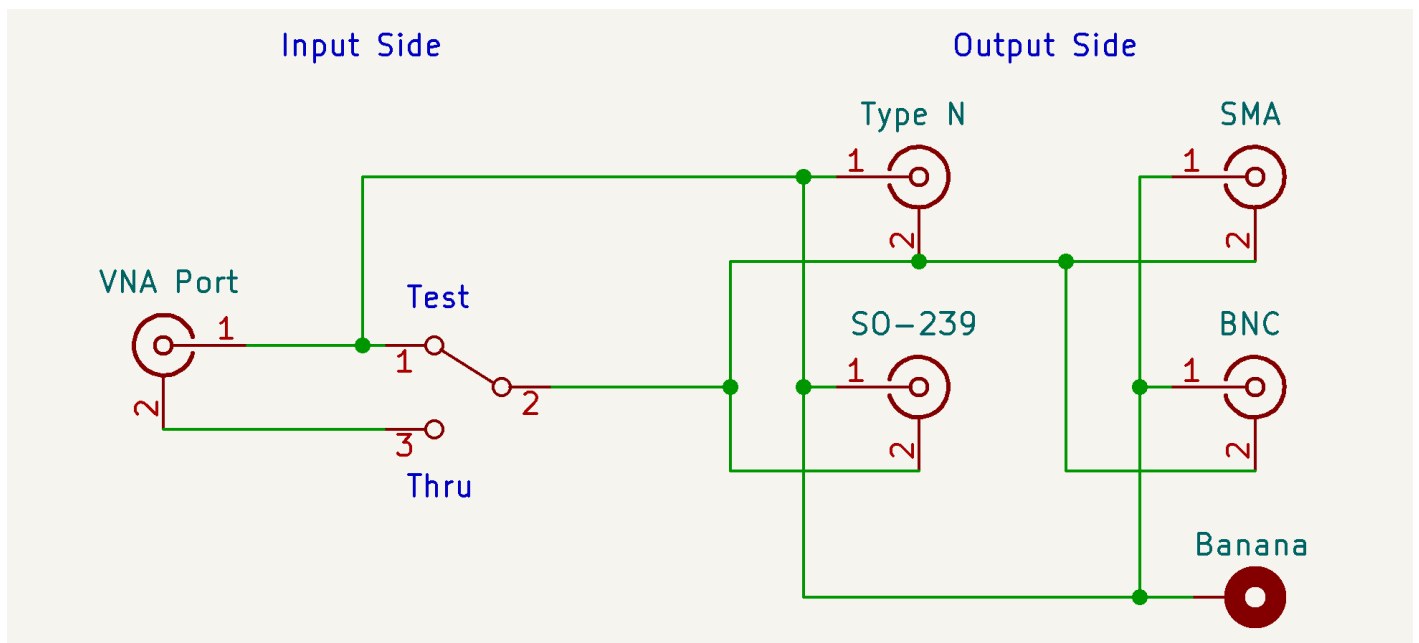
A Common Mode Current Choke is inherently affecting common mode currents (it's right there in the name), and common mode currents only travel on the OUTSIDE of coax. Again, see the Theory of Operation documentation for more details here; for now, we're going to take it as a Given that this is true.

To measure what's happening on the outside of the Coax, we need to route the signal the VNA is generating and measuring from the center conductor of the coax, to the shield of the coax, and back again. Similarly, we have to provide a path for the return currents, a path that is NOT on the coax (otherwise the currents would become differential again, and that's not what we want.) We also need a way to calibrate the VNA, preferably with as much of the test rig in the path as possible.

Those three things are what the CMCC Test Rig is doing:

1. Routes the center conductor from the VNA to the SHIELD of the device under test.
2. Provides a path for the return currents OUTSIDE of the device under test.
3. Can be (v3.0) reconfigured to straight-through for calibration with SMA calibration standards, or (v3.1) calibrated using on-board calibration standards.

Here's the schematic of one half of the CMCC Test Rig:



4. Detailed Operation Instructions

Ok, lets get started.

4.1. Identify Parts On The CMCC Test Rig

This section is redundant from the Assembly Instructions. But someone else may have assembled it, maybe that "someone else" was you from several years ago. Let's not assume you remember.

The CMCC Test Rig board has two sides:

- Input Side: Has the two SMA sockets labeled "VNA Port 1" and "VNA Port 2", as well as several slider switches. v3.0 only has two switches, but v3.1 has a total of five. We'll learn more about these switches later.
- Output Side: Has sockets for Type N, SO-239, BNC, SMA, and Banana.

The board also has two identical halves, Port 1 and Port 2. These are the same "Port 1" and "Port 2" as on your VNA.

Tangent: The NanoVNA decided to number these Port 0 and Port 1. The Programmer in me is all about zero based numbering... But I'm MORE about consistency, and professional VNAs have been numbering their ports 1 and 2 for a lot longer than the NanoVNA has been a thing. This is where "S11" and "S21" come from. "Sxy" is the signal, generated at Port y, as measured at Port x.

I will be using "Port 1" and "Port 2" here to match "Real VNA" convention. If your NanoVNA is numbered "Port 0" and "Port 1", you'll need to keep track of that yourself.

As you can see in the schematic above, all of the output sockets are connected in parallel, they are electrically all the same. The different sockets are provided so you can use whatever connector type your CMCC and/or jumper cables have, without having to use adapters.

Banana plugs are a bit of a special case. They are used for testing non-coax based chokes. For example, if you want to measure the effectiveness of a DC power cable wrapped around a toroid, you can wrap the stripped end of the power cable around the banana terminals to measure it.

4.2. The VNA

This kit was designed assuming most users would be using a NanoVNA, since they've become so ubiquitous lately. But any Vector Network Analyzer will work.

4.2.1. Connecting to the VNA

Connect the two SMA sockets on the Input side of the board labeled "VNA", to the ports on your VNA using SMA jumper cables. Port 1 to Port 1, Port 2 to Port 2.

If your VNA is labeled Port 0 and Port 1, or Channel 0 and Channel 1, then connect Port/Ch 0 on the VNA to Port 1 on the CMCC Test Rig, and Port/Ch 1 on the VNA to Port 2 on the CMCC Test Rig. (See the **Tangent** section above.)

4.2.2. Calibrating the VNA

There are many better documents on how to calibrate a VNA than I can write here. I won't try to reinvent that particular wheel. I'll only give a quick summary of the process, pointing out any CMCC Test Rig specific details where appropriate. If you need more help with calibration, please see any one of the many YouTube videos or written articles on the subject.

This section is the only difference between v3.0 and v3.1 boards.

4.2.2.1. CMCC Test Rig v3.0

The v3.0 boards require you to use the calibration standards that came with your VNA.

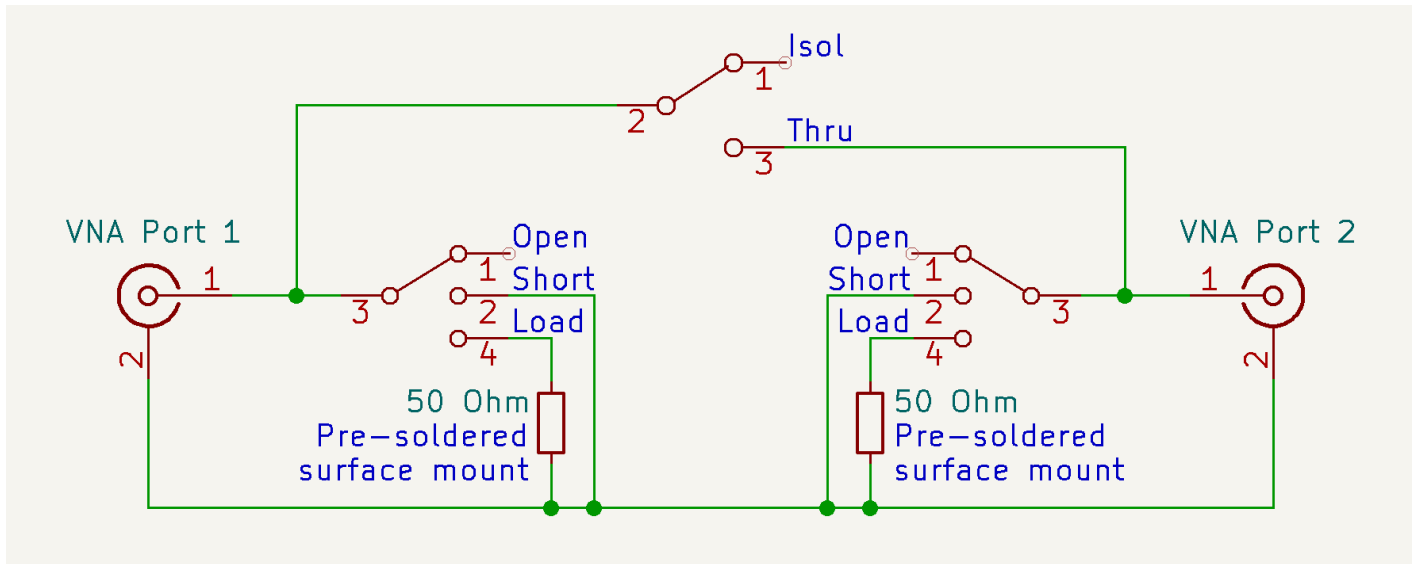
- Make sure you set the frequency range on the VNA before calibrating it. For example, if you're measuring a CMCC for all of the HF band, set it to 1MHz to 30MHz.
- Put the Test/Thru slide switches into the "Thru" position.
 - This makes the Test Rig a "Straight through" cable (albeit a bumpy one.)
- Perform the Open, Short, and Load calibrations, using OSL calibration standards (the little SMA connectors with no cables connected that came with your VNA.)
 - **DO NOT** perform the Isolation and Through calibrations yet! We'll do that in a bit.
 - Ideally, you have OSL standards for whatever connector you're using to measure the CMCC. If not, use whatever OSL standards you DO have on whatever connectors they use. All the output ports are connected in parallel, so it'll still work.
- Put the Test/Thru slide switches into the "Test" position.
 - This routes the signal from the center pin of the input to the shield of the outputs.
- Perform the Isolation and Through calibrations.
 - If you are using jumper cables to connect the CMCC to the Test Rig, include those in the Isolation and Through calibrations if you can. If you can't, that's fine; it just means that whatever impact the jumper cables have on the CMCC will be included in your measurements. Hopefully the CMCC itself will be the dominant effect.

When you're done calibrating, make sure the Test Rig is in the "Test" mode for your measurements.

4.2.2.2. CMCC Test Rig v3.1

NOTE: If you wish to use the calibration standards that came with your VNA instead of the on-board calibration standards, then leave all three switches (both Open/Short/Load, and the Isol/Thru switches) in the fully-up position: Open, and Isol. Then proceed with the section above for v3.0.

The v3.1 boards have on-board calibration standards. This schematic may help you understand the following instructions:



NOTE: When we talk about setting the "Open/Short/Load" switches, always set both switches the same.

- Make sure to set the frequency range on the VNA before calibrating it. For example, if you're measuring a CMCC for all of the HF band, set it to 1MHz to 30MHz.
- Put the Test/Thru slide switches into the Test position. They will remain in the Test position for the whole calibration process.
- Perform the VNA's normal Open/Short/Load/Isolation/Through calibration process, but with the CMCC Test Rig calibration switches in the following positions:
 - **Open Calibration:** Open, Isol (all three switches fully up)
 - **Short Calibration:** Short, Isol (OSL switches in the middle)
 - **Load Calibration:** Load, Isol (OSL switches fully down)
 - **Isolation Calibration:** Load, Isol (conveniently, the same as Load above)
 - **Through Calibration:** Open, Thru (note that all three switches change)
- When done with calibration, for taking measurements, make sure ALL switches (including Test/Thru) are in the fully-up positions.

4.2.3. External Software

This is also beyond the scope of this document, but I encourage you to look into PC software to extend the functionality of your VNA. A very common open source option for the NanoVNA is called [NanoVNA Saver](#). NanoVNA Saver can:

- Measure more than 101 data points over the whole range.
 - If you're measuring 1 to 30MHz, the stock NanoVNA software only measures every ~300kHz. NanoVNA saver can measure that same range in many more steps, to get a more precise measurement.
- Save measurement data into Touchstone files (eg: .s1p and .s2p files) for later retrieval and research.
- Compare two different Touchstone files, setting one as a "Reference" while looking at the second.
- Supports an arbitrary number of Markers, for measuring band edges, centers, etc.
- Displays measurements and graphs in better resolution than on the NanoVNA screen, and can save them to disk as images.

- And a lot more than this. But those are the main features I use it for.

4.3. Measuring a Common Mode Current Choke

Once the Test Rig is connected to the VNA, and the VNA is calibrated, its time to measure some chokes!

- Connect the Common Mode Current Choke to the appropriate output ports on the Test Rig.
- Make sure all switches on the Test Rig are fully up: Test, Open, Isol, Open, Test
- Measure "S21 LOGMAG" with your VNA. We want it to be as large of a negative number as possible, across as much of the frequency range of interest as possible.

That's it!

4.3.1. What the heck is "S21 LOGMAG" and why do we care?

See the Theory Of Operation (WIP) document for a lot more details here. But, in summary:

- The "S21" means: Measuring on Port 2, the signal that was generated on Port 1. That is, what has our device done to the signal as it passes through it?
- The "LOGMAG" means: What's the relative magnitude, measured logarithmically? That is, how many dB has the signal gone up (positive values) or down (negative values)?

The VNA is generating a signal on Port 1 of a known amplitude and phase, and measuring the relative amplitude and phase on Port 2. We use the Test Rig to take the differential mode signal from Port 1, make it common mode by routing the center pin of the input to the shield of the output, send that now-common-mode signal through the Common Mode Current Choke, then route the result back to the center pin of Port 2 of the VNA. So now the signal being measured by the VNA has been attenuated by the CMCC, and will show up as a negative S21 LOGMAG value.

The more negative the S21 LOGMAG value, the more the CMCC is attenuating the common mode currents, the more better.

4.3.2. How do I get my VNA to show me S21 LOGMAG?

That's dependent on the VNA. It's even different among the various flavors of NanoVNA, but its generally in the "Display" section of the menu. I'm sorry, but that's about as specific as I can get. You'll need to read the documentation for your VNA.

Or, better yet, use NanoVNA saver (or similar for your VNA). The Touchstone (.s2p) files contain all the raw data the VNA collected and can be used to extract all possible measurements later (including S21 LOGMAG) whether you were looking at that value while measuring the CMCC or not.

4.4. Designing Chokes

Ok, we've got an "S21 LOGMAG" graph of my Common Mode Current Choke. Now what?

From here, it depends on what your goals are. This gives you the data; its up to you to use that data in your context to improve your situation. But here are a few design guidelines I go by:

4.4.1. What's "Enough Attenuation?"

There's a lot of discussion on this. It's agreed that "more attenuation is better," but where the line between "This juice ain't worth the squeeze" and "That's a good choke" is, has a lot less agreement.

The way I figure it, ANY attenuation is better than none. Do the best you can with what you have, then deploy it. It's not going to HURT the signal, and it might help. Don't give up hope just because some well respected articles say you've got to have a bajillion dB of attenuation and you've only got -50dB (which is *A LOT*, BTW).

My somewhat arbitrary target is about -25dB. This equates to about 890 ohms of impedance in a 50 ohm system.

Worst case: If you had full (US) legal limit of 1500 W being REFLECTED as common mode current(*), with a -25dB CMCC you'd have less than 5W coming back down the shield. This is the power of an HT, so I figure it's a good safety choke.

(*) If you've got 1500W of common mode, you've got much bigger problems on your hands. In reality, the inductor core material will saturate LONG before it's able to choke 1500W. But this is a useful thought exercise to consider what -25dB common mode means at an antenna feed point.

Put at the receiver, -25db is about 4 S-units (6dB per S-unit). Any noise being picked up on the shield and conducted into your receiver because of a sketchy ground, should be quieted by about 4 S-units.

But, if after hacking away at a choke for a while, you can only get about -10dB to -15dB, that's fine! It'll still help! Don't let perfect be the enemy of good enough.

4.4.2. Watch Out For Resonance

Building a choke where the input and outputs can capacitively couple to each other will have a strong effect on the shape of the S21 LOGMAG curve. If your S21 LOGMAG starts looking like a V, a sharp downward point, instead of a flat line, then you've got too much capacitance in your choke.

4.4.2.1. "But, I haven't added any capacitors!"

Its true. But if the cable at the input and output run next to each other for any amount of distance, they will capacitively couple to each other. This parasitic capacitance, and the intentional inductance, form a resonant circuit. This can be great, if that resonance is at the narrow range of frequencies you care about. But it makes all the other frequencies worse. If you're building a wide-band choke (eg: an HF choke meant to cover 3-30MHz), you don't want resonance.

If you're wrapping coax in a coil, make sure it is wrapped in a flat, cylindrical coil around a form where the input and outputs are far away from each other. Ideally, leave about one coax width of space between each wrap of the coax on the form. Try not to just make a loosely wrapped coil like you would coil up an extension cord for storage.

If you're wrapping coax around a toroid, don't just keep wrapping all the way around the toroid where the input and output are on the same end. Instead, wrap half way around the toroid, then go through the center

back to the beginning, and start wrapping up the OTHER side of the toroid, so that the input and outputs are on opposite ends of the toroid when you're done.

4.4.3. Ferrite Material Ain't Cheap

I like to make the most of the ferrite cores I put into my CMCCs. That usually involves wrapping coax around a toroidal core, which is a very effective and efficient CMCC.

But maybe you don't have enough coax length to do that, or it already has connectors on it and can't fit through the center of the toroid, or maybe it's too stiff. So you end up with another design. How can you best deploy your available ferrite material to maximize attenuation? Measuring the result and adjusting your design will help you here.

This is the last of the Design Guidelines because it's just a financial savings. In reality, if I can spend a bit more money on ferrite material to have a much better signal, I will. But there's a knee to this curve somewhere, a point of diminishing returns where more ferrite material isn't helping as much as it used to, and measuring your choke will help you figure out where that knee is.

5. Conclusion

That's it! Feel free to come join us on the Halibut Electronics Groups.io email list:

- <https://halibut-electronics.groups.io/g/general/>

And follow us on the Fediverse/Mastodon:

- <https://mastodon.halibut.com/@electronics>

Thank you, and be good humans. 😊 73 de N6MTS -Mark