BNC Connector Power

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I'm a hobbyist who uses coax cables with BNC connectors on them for convenient connections when I'm making electrical measurements. I virtually always use them with a female BNC to dual banana plug adapter to connect to DC power supplies to supply power to something. I wondered what the maximum DC current should be when using these cables.

Manufacturers don't specify things for you (e.g., for the Pomona 2249 cable). Thus, we have to measure things ourselves.

Executive Summary

Question: what is the DC power-handling specification for a BNC connector?

Context: I like to use BNC connectors for input and output on things. This is because I use coax cables with BNC connectors on them for connecting to DC power supplies, function generators, etc. I was curious as to how much DC and low frequency (say, line frequency to audio frequency levels) current I should allow through these BNC connectors.

Answer: A pragmatic answer is that the power handling capability is more determined by the cable you use than the connector itself. The actual power-handling capabilities of the BNC connector are not clearly specified anywhere I have seen; various numbers floating around the web are 100 to 300 watts. These numbers almost certainly aren't for the dissipation allowed in the BNC connector itself, as that much power in such a small volume would likely damage the insulating dielectric (i.e., melt it) -- people probably mean the power being transmitted through the connector to a load.

I made measurements on two representative coaxial cables I have and estimated the maximum power I'd want to dissipate in the cable by measuring the temperature rises in the cable and BNC connector. For a cable that I wanted to use for a long time (e.g., decades), I'd limit the power dissipation to about 3 W/m; for occasional use, I wouldn't mind twice that. This applies to the typical RG-58 type coaxial cable used for RF cables used with measuring instruments. For the two 1 meter long cables I tested, this translates into 5 A of current for long-term use, 7.5 A of current for occasional use.

It would take substantially more work and resources than I have or am willing to commit to determine the real power dissipation allowed by a BNC connector itself.

From my measurements, I wouldn't hesitate to put 10 A through a BNC connector mounted on a bulkhead if I needed to, as long as the connector was connected with a low thermal resistance to e.g. a metal panel. This number comes from my engineering judgment and the measurements I made below, not any fancy evaluation of actual connectors.

In this document, I'll also get a bit chatty about a few things. In particular, I'll talk about making connections to things for measurements. While I've used Pomona Electronics products for many decades, there are other vendors who sell such stuff and I've found I've been happy with the things I've purchased in the last few years from Cal Test Electronics. While the hobbyist who's new to electrical stuff may be a bit take aback by the cost of some of these electrical accessories ("15 bucks for a simple adapter???"), you'll find that buying good stuff pays off, as you can use it with care for decades. There are few things more frustrating than to find you've wasted time with an inferior tool. Oh, if you look carefully at those adapters, you'll find out that they're not quite as simple as you may think they are -- some can take some fairly sophisticated and costly equipment to make, not to mention some human labor for assembly.

Web search

I have not been able to find a spec on the power-handling capabilities of a BNC connector on the web. There appears to be quite a bit of hearsay and speculation on various people's parts, but I haven't found a manufacturer's spec. Some people comment that they haven't found a rating spec in excess of 300 W.

The "Application Guide to RF Coaxial Connectors and Cables" by Michael J. Hannon and Pat Malloy at http://www.ar-worldwide.com states that the BNC cable is capable of 80-100 W, but do not typically carry a power rating, although their voltage limit is about 500 V. On page 4 of that document, they give a power vs. frequency chart that implies the theoretical maximum of the BNC is around 450 W at 100 MHz (this assumed a matched impedance, VSWR < 1.35:1, meaning about 97.7% of power is transmitted to the load).

Some hams who appear knowledgeable comment that the rating is going to be more what the coax cable's rating is rather than the connector's. This makes sense and is consistent with the measurements I made (see below in the **Experiment on coaxial cables** section).

The internal diameter of a BNC's center conductor is the same as a type N connector's center conductor; I measured one at 1.33 mm; this is about 16 AWG. For 16 gauge copper wire, the current allowed per extrapolated NEC specs (based on current density; see the `resistor.zip` file at http://code.google.com/p/hobbyutil/) would be about 9 A, so the pick I make below of 5 A is conservative.

Here are some N connector specs from Amphenol http://www.amphenolrf.com/products/typen.asp?N=0&sid=4D8BDB0037C6617F& (corrugated N): center contact resistance 1 mΩ, average power 600 W.

I submitted a request for information on this power-handling spec to Amphenol's site. They responded promptly and politely with a justifiable "it depends". In truth, the ways people put such things to use vary widely and before a definitive answer could be given, the boundary conditions and assumptions would have to be defined. Amphenol indicated they could give answers, but it would require modeling and they'd want to be paid for their work. Fair enough -- let's get the answer by some experimentation.

Cables and equipment

In this experiment, I used two BNC coax cables:

1 m HP model 10503A coax cable[1]: actual length = 1265 mm, estimated cable length = 1225 mm (gotten by subtracting 20 mm from each end, which is an estimate of the connector length).

1 m Cal Test Electronics coax cable, model CT2942-100: actual length = 1027 mm, estimated cable length = 987 mm (gotten by subtracting 20 mm from each end, which is an estimate of the connector length). This cable was purchased new in April 2009.

I also used the following test equipment:

HP 3456A digital voltmeter (I bought it used around 2005)

HP 3435A digital multimeter (I bought this new in March of 1978)

HP 6038A system power supply (provides 200 W maximum with up to 60 V and 10 A; I bought it used about 2006)

None of these instruments are in calibration, but I have checked the multimeters for consistency with my Fluke 83 DMM and my old Fluke 893A differential voltmeter. In particular, the Fluke 893A and the HP 3456A agree typically to 4 or 5 significant figures -- not bad for old equipment.

1 This cable is one I got from HP labstock in the early 1980's (it was OK for employees to take such stuff home for "G-jobs" back then).

I also used two home-made current sources to make Kelvin 4-wire resistance measurements. Current source 1 is a small, battery-operated 1 A current source. It uses a voltage reference and an op amp to control the current from a 1.5 volt C cell through an IRF540 MOSFET. Its constant current, measured with the 3435A in ammeter mode was 999 mA. It uses a stable 0.2 ohm shunt made from some quite stable HP 0.4 ohm wire-wound resistors (I picked these resistors because they didn't change resistance when a 1 A current flowed through them). Current source 2 is a line-powered one using a 12 V 2 A wall wart for power and is made from an LM317 regulator with a 1.2 ohm resistor (this simple circuit is given in the LM317's datasheet). Its output current is 1002 mA.

My current measurements with the 3435 are probably stable over time to 3 parts or so in 1000. (Some day I will get a precise and calibrated low resistance so I can make accurate current measurements.)

I used the Cen-Tech IR thermometer (purchased at a Harbor Freight store for $10; it's part number 93983) shown in Figure 1 to measure temperatures. It resolves to the nearest 0.1 deg F. The temperature measurements below are primarily differential measurements, so issues with emissivity cancel out. By the way, I consider this little instrument one of the handiest tools I have ever purchased. I use it for all kinds of things, especially differential measurements of temperature (i.e., temperature rises). It's great for finding a component that is overheating.

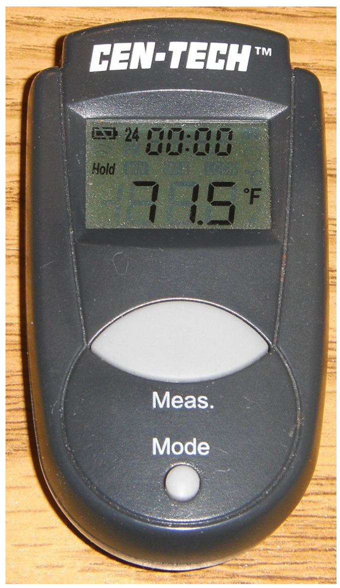


Figure 1

The IR temperature measurement tool measured 67.2 °F on the metal of the BNC connector of the HP cable, while the same measurement a few inches away on the outside of the coax cable read 67.8 °F. This shows that the emissivity difference between the cable's insulating jacket and the BNC connector's metal is insignificant[2]. For the Cal Test cable, the metal was 67.2 and the outside of the cable read 66.2. Again, I don't consider this difference significant, although it does show a measurable difference between the jackets of the two cables. The HP cable is the typical HP putty-gray color and the Cal Test cable is black.

Experiment on coaxial cables

Since I realized that the cable is likely the limiting factor in use of these RF cables for general-purpose connections on the bench, I decided I would characterize the temperature rise of the cables as a function of dissipated power per unit length.

I connected the HP cable to the 6038A power supply and measured the temperature of the ending

2 Metals (especially when polished) typically have low emissivities; plastics, minerals, insulators, and paint often have emissivities in the 0.8 to 0.95 range.

BNC male connector and a spot on the coax cable with my Cen-Tech IR thermometer. I'd wait 5 to 10 minutes or more between each reading -- then see if it appeared that the temperature stabilized. For the currents 5 A and above, I'd wait 15 to 20 minutes or more, hoping to catch things in thermal equilibrium. I didn't bother trying to figure out the emissivity of things; these measurements are purely seat-of-the-pants and differential.

The temperature measurement method was to put the sensor end of the IR thermometer in contact with the item of interest, then move it back and forth with the reading button held down to find the maximum displayed temperature.

Both the current and voltage were the readings displayed on the power supply's front panel. I used two 40 inch-long 12 gauge copper wires to connect the power supply to a Pomona 1296 dual banana jack to male BNC adapter, then a BNC female splice, then the BNC male connector of the cable under test. The other end was treated the same except a shorting plug made from a General Radio 274-MB adapter was used (this adapter was shorted with a 12 gauge piece of copper wire).

The data were collected in a spreadsheet; the spreadsheet columns are:

> Current, A: the output current as set on the power supply (reading from digital meter on front panel of power supply).
>
> PS output voltage, V: the output voltage as set on the power supply (reading from digital meter on front panel of power supply).
>
> Power dissipated in cable, W: product of the previous two numbers. Note I don't bother correcting for the 10 mΩ resistance of the two 12 gauge copper wires from the back of the power supply. The effect of these 12 gauge conductors will be around 10% in measured power, so the readings I give are about 10% over the true power in the coax cables.
>
> Conn. temp., deg F: IR measurement of the metal of the BNC male connector on the cable.
>
> Cable temp., deg F: IR measurement of the jacket temperature of the cable about 150 mm from the end of the cable.
>
> Conn. ΔT, deg F: (Conn. temp., deg F) - 71
>
> Cable ΔT, deg F: (Cable temp., deg F) - 71
>
> Res., Ω: cable's resistance from dividing the voltage by the current. Note this includes the two 12 gauge solid copper wires. Since 12 gauge copper wire has 1.59 mΩ/ft, this would add (80/12)1.59 = 10.6 mΩ or about 10% to the overall resistance. Based on using the 3456A as a voltage standard and the 3435A as a current standard, I characterized the 6038's voltage reading as within 0.5% and the current reading within 3% of the standards' readings.

Note: if I did the experiment over again, I'd use the power supply's sense terminals to eliminate offsets caused by the 12 gauge connection wires.

The dashed entries are those cases where there was no sensible temperature rise.

HP Cable

Current, A	PS output voltage, V	Power dissipated in cable, W	Conn. temp., deg F	Cable temp, deg F	Conn. ΔT, deg F	Cable ΔT, deg F	Res., Ω
0	0.000	0.000	71.6	--	--	--	
1	0.120	0.120	70.8	--	0	--	0.120
2	0.225	0.450	70.8	--	0	--	0.113
5	0.585	2.925	72.4	73.8	1	3	0.117
7.5	0.825	6.188	74.9	82.3	4	11	0.110
10	1.110	11.100	79.3	93.6	8	23	0.111

10 A was as high as my power supply could go.

I ran the same test with the Cal Test cable. The BNC splices and adapters were still warm from the previous test, so I allowed them to cool down for 15 minutes or so while running the current at 5 A.

Cal Test Cable

Current, A	PS output voltage, V	Power dissipated in cable, W	Conn. temp, deg F	Cable temp, deg F	Conn. ΔT, deg F	Cable ΔT, deg F	Res., Ω
5	0.615	3.075	72.3	77.1	1	6	0.123
7.5	0.930	6.975	75.4	86.3	4	15	0.124
10	1.200	12.000	77.2	100.8	6	30	0.120

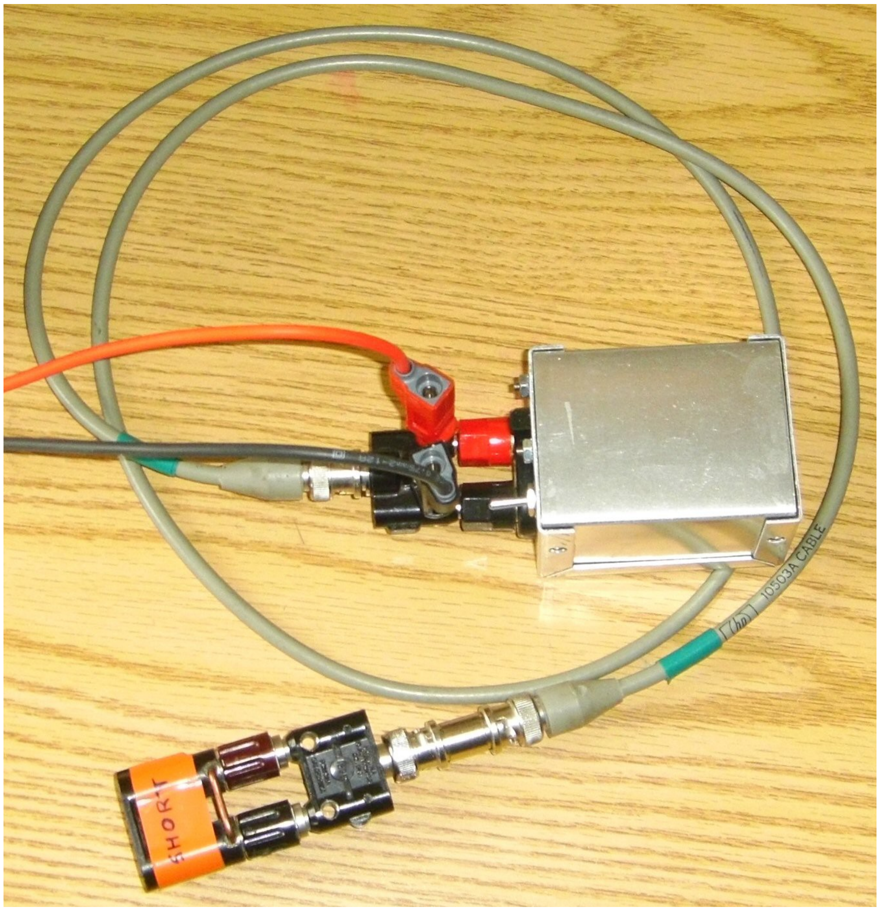
I forgot to get the zero current measurements from the Cal Test cable. A day later, I measured the two cables (both at a lower room temperature than when I made the measurements and the temperature of the two cables differed by half a degree F, which I consider insignificant.

Cable resistance

I also measured the DC resistances of the cables. Here's the basic measuring procedure:

The picture shows current source 1 being used to measure the 4-wire resistance of my shorting plug; the black and red cables run to the 3456A voltmeter. I use these current sources to supply current to an unknown resistance and measure the voltage drop across the resistance with an HP 3456A voltmeter (this is commonly known as the "4-wire" or "Kelvin" measurement of low resistances and is used to greatly reduce problems of contact resistance and lead resistances). The short's resistance was 198 μΩ. with current source 1. It was 199 μΩ with current source 2.

Here's how the HP cable resistance was measured using current source 1:



Again, the red and black cables go to the 3456A voltmeter.

This configuration gave a resistance of 80.0 mΩ for the HP cable. The same measurement with the Cal Test cable gave 134 mΩ. These were the first measurements I made and I noticed somewhat strange behavior, as the DC resistance dropped slowly (1 part in 1000) every few seconds on some measurements (although the Cal Test cable's measurements below show a rise). Since this doesn't happen with e.g. measuring the resistance of copper wire, I surmise it is some effect caused by the cable's dielectric. While it arouses my curiosity, I don't feel it's germane to the purpose of this experiment, so I chose to ignore it.

These measurements are taken quickly, as the resistance will change a bit versus time. Here's the effect for the Cal Test cable:

Time, s	**mΩ**
0	135.7
10	135.4
15	136.5
20	136.6
30	136.4

Here's the HP cable:

Time, s	**mΩ**
0	78.6
10	78.4
15	78.3
20	78.3
30	78.25

These measurements are without disconnecting the cable. If I disconnected the HP cable at the BNC connection at the current source, here are the measurements in mΩ after reconnecting (i.e., there was a disconnect/reconnect cycle after each reading):

78.3, 78.3, 78.1, 77.9, 77.7, 77.8, 78.0, 79.3, 77.6, 77.8

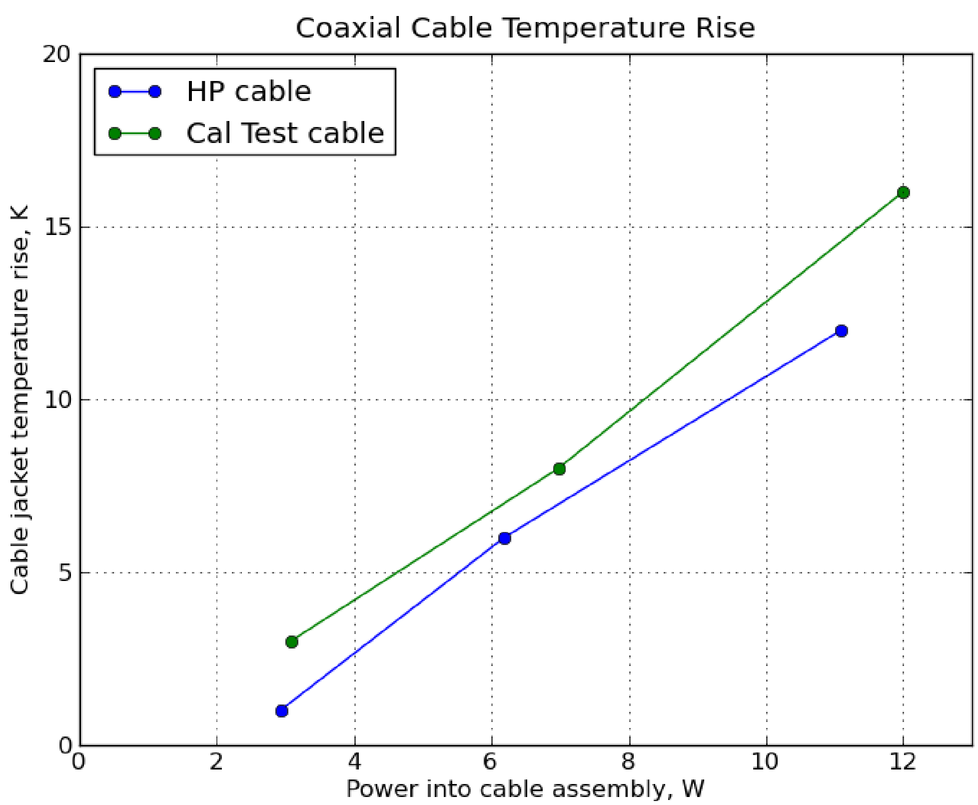
Mean = 78.08 mΩ, standard deviation = 0.49 mΩ. Note this is 2 mΩ less than the first measurement of 80 mΩ. Because of this (unexplained variation; perhaps contact resistance), I figure that I can only measure the resistance repeatedly to around 1%.

If I used the 3456A's 4-wire ohm measurement, it measured the HP cable at 77 mΩ; it could measure one more digit, but that digit was bobbling around as it corresponds to 100 nV. This measurement used some Kelvin clips connected to the banana plugs of the BNC to male banana adapter. This number is consistent with the numbers gotten with the current sources.

Are these resistance numbers consistent with the voltages and currents measured in the previous section? Not terribly. Subtracting off the 10 mΩ for the 12 gauge wires on the power supply, the HP cable was around 100 mΩ from the power supply numbers and the Cal Test cable was around 110 mΩ from the power supply numbers. Thus, the numbers don't check terribly well. I trust the measurements made with the current sources.

Data summary

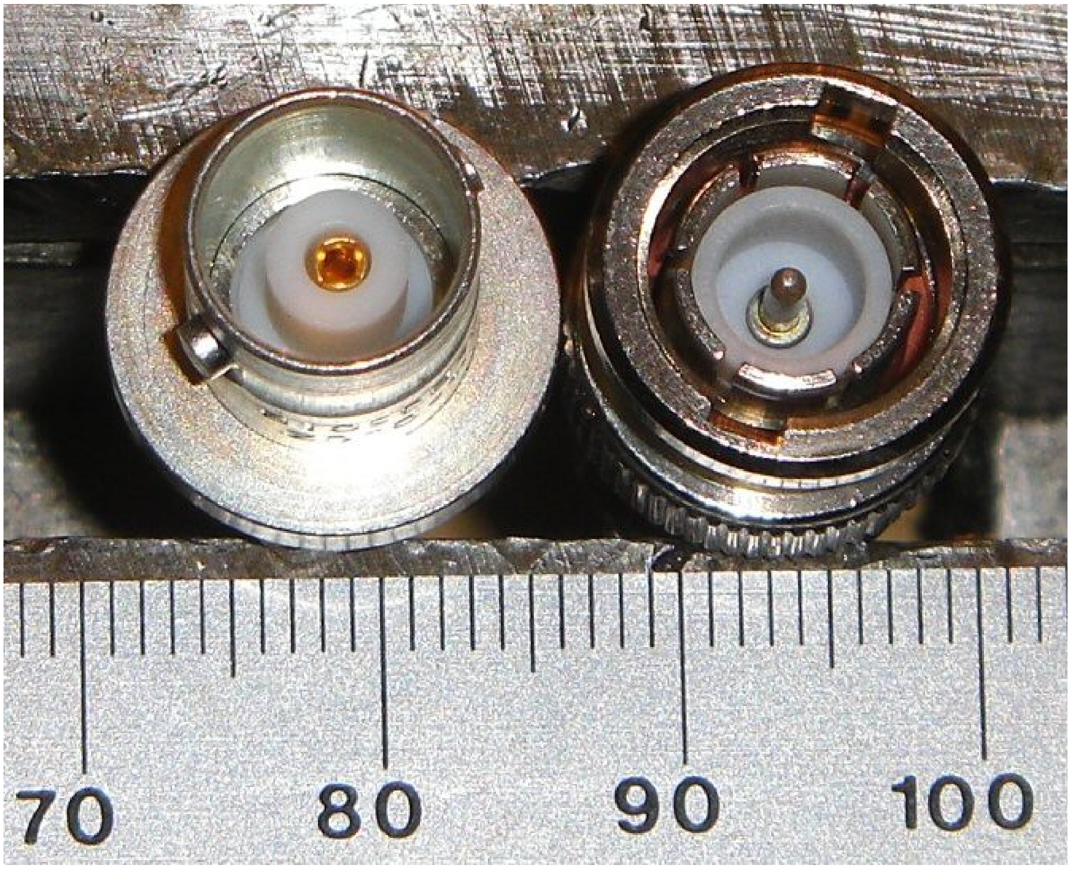
Here's a plot of the temperature rises versus power into the cable (i.e., the power dissipated by the cable):



Measuring BNC connector resistances

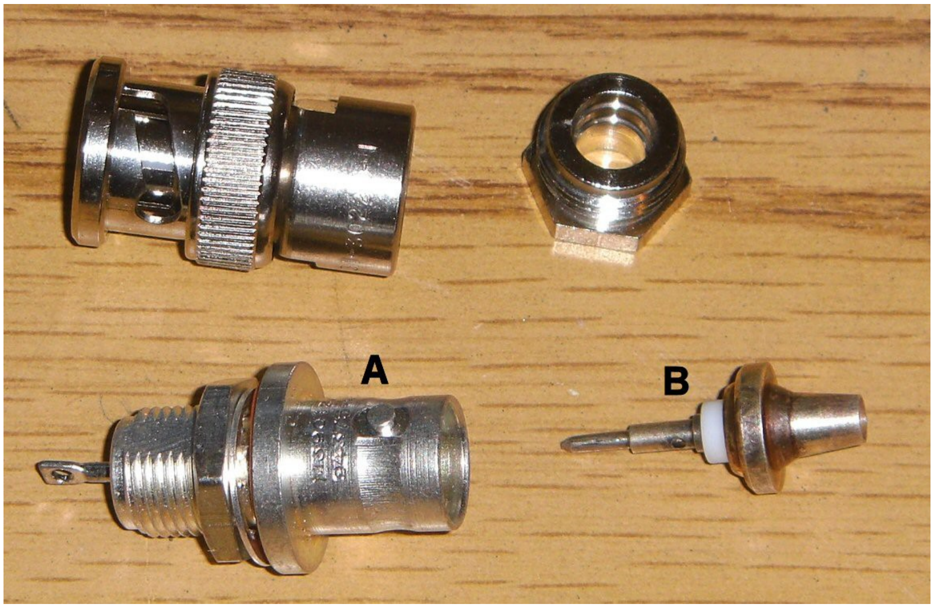
So what is the typical resistance of BNC connector and BNC connections? These are simple questions to ask, but they're not easy to answer with the typical equipment available to a hobbyist. If I still worked in industry, I'd be able to get the help of machinists and technicians to make some special tooling. But that stuff's not easy to do at home.

Here's the problem. You want to measure a low resistance (resistances will be on the order of 1 to 10 mΩ), so a Kelvin connection is required. Here's what you need to make your connections to:



The rule's graduations are in mm. How do you make a good Kelvin connection to those center conductors? In industry, I'd ask an experienced tech or machinist to spot weld two wires to those center conductors. I worked at places where the techs were so experienced and talented that they could make their own tooling to do such things. I certainly can't do it in my home shop, not to mention that my over-40 eyes couldn't see such things without a stereo microscope.

Thus, I have to settle for other methods. The method I chose was to use the center pin of an unused male connector to let me connect to the female center pin. The subsequent measurements will of course include the contact resistance of the connection. Here are the parts

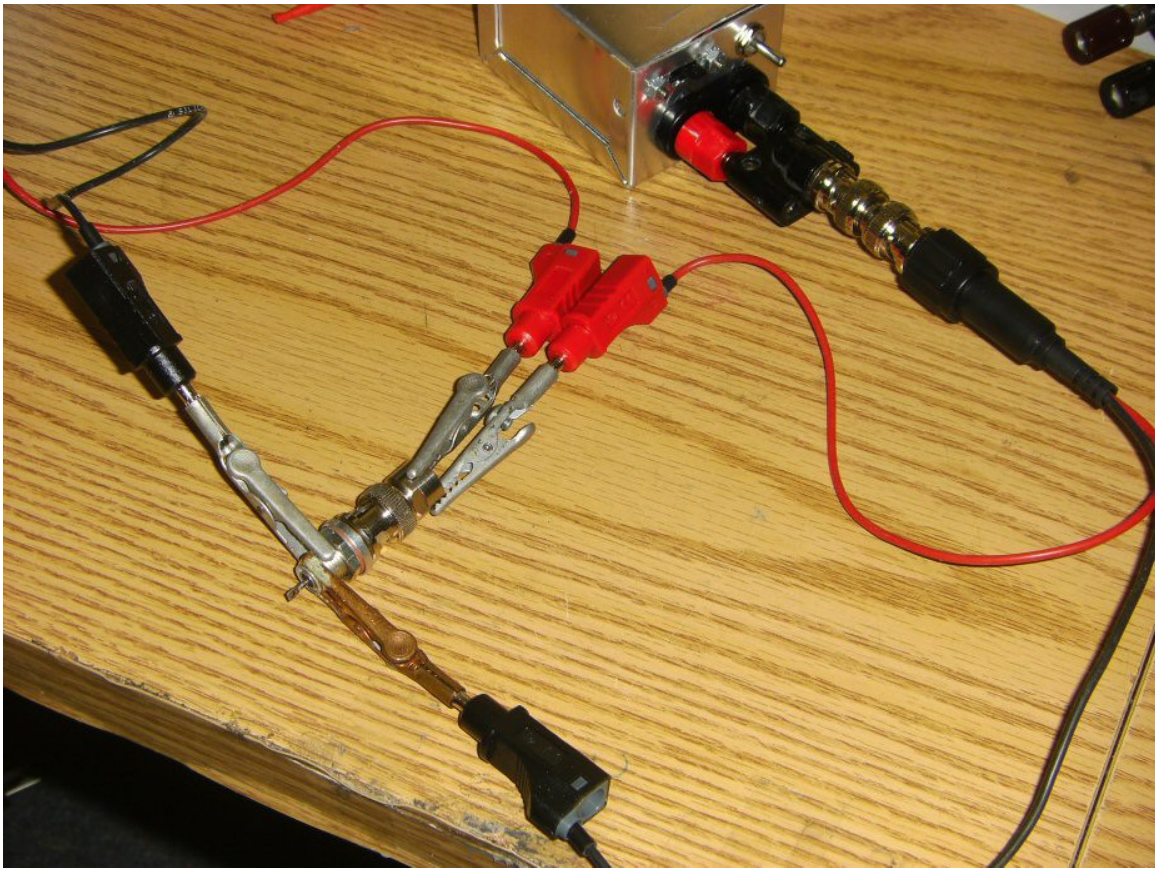


Part A is the female bulkhead jack whose resistance I want to measure and B contains the center pin from the assembly above that I'll use to make a 4-wire connection to the center conductor of A. The center pin pulled out from the white insulator so that you could solder it to the center conductor of a cable.

Using the pin pulled out from B, I measured the resistance of the center conductor of A as 3.0 to 3.1 mΩ (the resistance varied a bit as I clipped the leads to different locations on the pin from B or rotated the pin in the socket. If we assume that about half of this resistance is contact resistance, then it's reasonable to assume that the center pin's resistance is about 1 mΩ, consistent with the spec I found on the web that the N connector's center pin is around 1 mΩ.

Because the pin would be soldered to the center conductor of a coax cable, it's reasonable to suppose that the resistance of the center conductor of two mated BNC connectors will be about 3 mΩ.

Measuring the outside conductor's resistance (including the contact resistance) is a bit easier. I connected part A in the above picture with the shell for the male connector above it. This resulted in a resistance of 0.48 to 0.6 mΩ. Note it's important to jiggle things around a bit, as each resistance measurement will be a little different. The range gives you an idea of the variability. Here's a picture of the measurement setup:



While I suspect some folks like to use copper alligator clips like the one shown at the bottom, I've found I prefer the plated steel connectors like the other three alligator clips. All of those clips are made by Mueller Electric and I've been using some of those steel ones for nearly 50 years. They've given excellent service. The aluminum box at the top is battery-operated current source 1.

Those BNC male to 4 mm banana adapters are made by Cal Test Electronics (model CT3268) and I like them because they use a nice flexible silicone-rubber insulated wire. While they're $15 each (ouch!), they get used quite a bit. I prefer to use stacking banana plugs as shown in the picture over regular banana plugs. A nice thing about those stacking banana plugs is that the gray plastic insert appears to snap into the shell. Thus, if the wire ever got damaged, I suspect I could take the thing apart and repair it, unlike a molded part. Another place these adapters become handy is when you find a piece of test gear where the manufacturer didn't put the banana jacks at the standard 3/4" spacing, as they still allow you to use coax cables for hook ups.

Conclusions from experiment

1. A 1 m coax cable made from RG-58 coax with BNC connectors commonly used for RF measurements has a DC resistance of about 100 mΩ from center pin to outside conductor on the same connector when shorted at one end.
2. A reasonable maximum-allowed DC power dissipation in these cables would be 6 to 7 W/m. This is based on the middle dots of the graph above, which were for currents of 7.5 A.
3. For long-term (decades) use of a cable, I would recommend currents of no more than 5 A, which represents 3 W/m.
4. The maximum I would run one of these cables is around 10 to 12 W being dissipated in the cable, based on my engineering judgment (part of this comes from just feeling the cable and not liking to run cables hotter than it felt at 10 A).

5. These measurements show that the cable itself is the limiting factor in power dissipation, not the connector. The cable temperature rises were around 3 to 5 times higher than the corresponding connector temperature rise.

Further work

It would be appropriate to mount a bulkhead-type female BNC connector to a sheet metal panel that acts as a heat sink and measure the temperature rise of the BNC connector as a function of current through the connector.

The same experiment could be repeated with a thermally-insulating mounting, such as a plastic box. Both measurements could give guidelines on maximum-allowed currents for such mountings. However, one would first have to develop some criterion that could demonstrate the onset of permanent damage to the connector to truly have an upper limit. Instead, it would be simpler to just pick an allowed temperature rise and use that to define the upper limit.