Binocular Transformers

by Dick van der Knaap

(editor's introduction: some years ago, John Bryant and others wrote several thorough articles about impedance matching transformers and RF splitters, using ferrite toroidal cores. Examples of these, such as A-155 and A-168, can be viewed in the IRCA reprints (ircaonline.org "free reprints"). Recently, Dick van de Knaap wrote a similar article concentrating on the use of ferrite binocular cores which appeared in Medium Wave News, and is reproduced here)

Radio frequency transformers are an essential component in any radio experimenter's toolbox. For receiving applications, they are used mainly to transform impedances between different parts of circuits. Particularly in weak signal situations they help transfer the maximum amount of energy from antennas to receivers. Transformers are also really useful when "common-mode" isolation is needed and they are a crucial part of signal combiners and splitters.

Recently I started measuring and optimizing my matching transformers, and discovered some things which I thought might be interesting to write about. This article describes the use of various types of transformers using binocular transformers, some technical background information, and practical information about how to construct them yourself.

So, why use Binocular cores in our transformers instead of regular round cores? Well, they are easier to wind, as there are no difficulties in fixing windings or winding ends. However, because the windings are close to each other, there will be more capacitive coupling between them, which is to be avoided, as I will explain later.

Core material

Most designs found on the internet and in books use either #43 or #73 material. #43 should be better for wide band use, and for use on higher (shortwave) frequencies. For lower frequencies, like mediumwave, #73 is recommended. Example cores (**Figure 1**) are:

- #43 material: Amidon BN43-202 which is similar to Fair-Rite 2843000202
- #73 material: Amidon BN73-202 which is similar to Fair-Rite 2873000202
- #73 material: Fair-Rite 2873006802 is a core twice as long as the 2873000202 type

Prices vary, and some research showed that Mouser sells the Fair-Rite cores for a very good price, much cheaper than its Amidon BNxx-xxx brother.

After several tests it turned out that both smaller cores (BN73- 202 and Fair-Rite 2873000202) are clearly made from #77 material, despite being sold as #73 cores. As a result they perform a little better on lower frequencies and show a bit more loss in the upper shortwave spectrum.

Figure 1

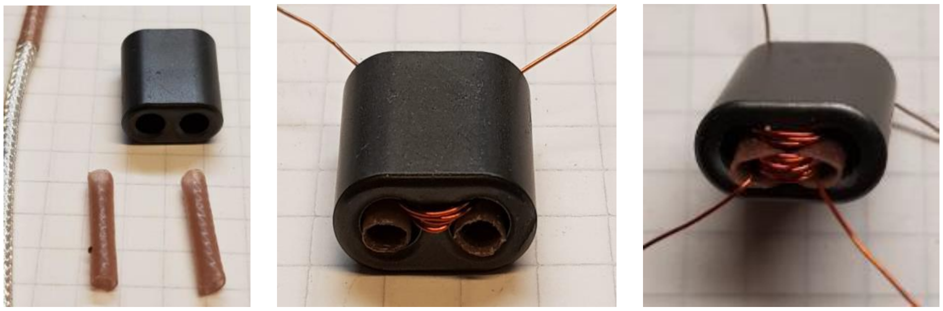
I. Making your own transformers

Wire: usually enameled or speaker copper wire around 0.22mm (AWG31) or 0.25mm (AWG30) is fine for a total amount of up to 20 turns or so. With fewer turns, even 0.32mm (AWG28) up to 0.40mm (AWG26) can be used.

However, the standard enameled or speaker copper wire has quite some capacitance between the windings. This can lead to reduced isolation between the separate coils.

More turns means more capacitance and therefore more 'leakage', from common mode currents for example, "jumping across the transformer". *Therefore it can be worthwhile to use a 'tube' through each hole in the core to add extra insulation between the windings.*

Here is an example how to isolate windings by using 'tubes' made from the outer insulation from a piece of coaxial cable, fitted inside the holes in the binocular core. The use of PTFE (Teflon) tubes will give you lowest capacitance. The best way is to insert the tubes first and start by winding the lower number of turns outside the tubes. Next step is to wind the higher number of turns through the tubes.



PTFE "tubes" | 4 turns for the 75Ohm part | 14 turns 919Ohm part inside tubes

Figure 2

Figure 2 shows the 3 stages of construction of a 75 Ohm to 919 Ohm transformer (4:14 turns ratio) which is normally used to connect a flag or delta shaped antenna to 75ohm coaxial cable. A schematic is at **Figure 3**.

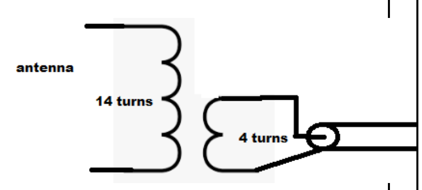
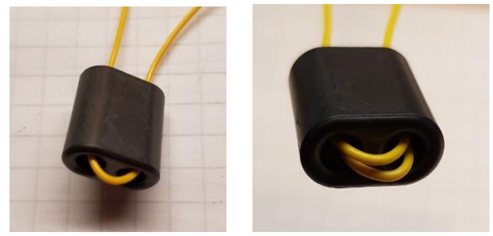


Figure 3



1 turn 2 turns

Figure 4

With binocular windings it is important to know how to count the number of turns. When talking about 1 turn, we mean feeding the wire through 2 holes (“2 passes”), as in **Figure 4**.

TIP: if you are using the same type of wire for each winding, use a marker pen or dot of paint to mark the low or high impedance winding on your transformer. Better still, use wire with different color insulation so you cannot confuse the different windings.

TIP: For smaller cores or for a large number of turns, you may need to use enameled wire. This avoids the thickness of insulation, but is a bit harder to work with.

TIP: Carefully use sandpaper to remove the insulation from the enameled wire, so that you can make electrical connections (**Figure 5**).

TIP: It is also a good idea to mark the ferrite cores so you know which material you are using. Do this as soon as you receive cores to avoid confusion later. (example in **Figure 6**).

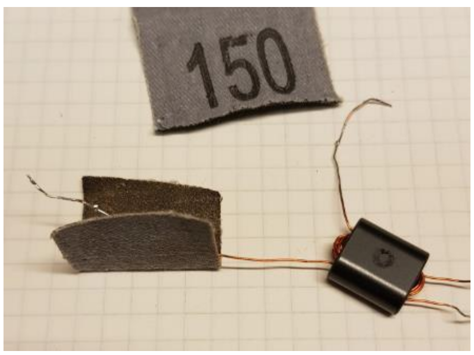
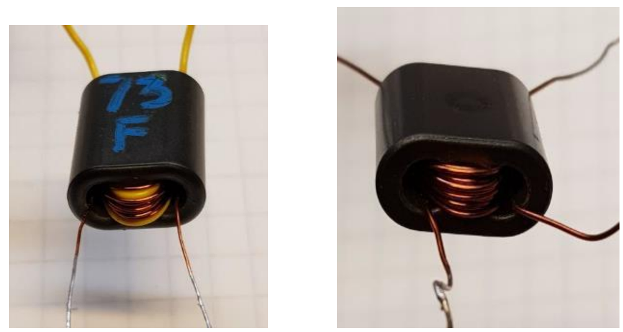


Figure 5 – Cleaning enameled copper wire with sandpaper



using 4 turns insulated wire using all enameled wire

Figure 6 – winding transformers without using insulating tubes

Performance testing

Test 1: I tried comparing transformers using 4 turns of normal insulated wire in a 4:14 turn transformer instead of the ‘tube’ solution using enameled copper wire for both windings (**Figure 6**). Measurements however did not show any big improvement using 4 turns of insulated wire against an ‘all enameled copper’ wired transformer (see **Table 1**).

Test 2: I also tested the longer type of core, and compared it against a pair of stacked cores (**Figure 7**) but measurements show that their performance is almost equal to a single core type of transformer.

Table 1 summarizes the performances of each transformer over the frequency range of 0.5-30MHz.

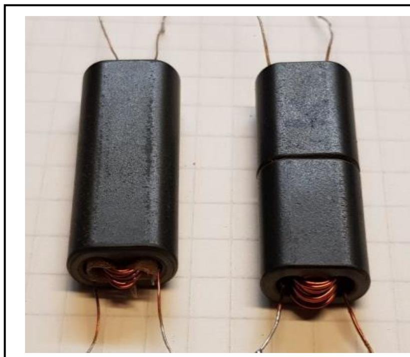


Figure 7

Frequency MHz ->		0.5			1			2			4			10			20			30	
type	loss	isol.	RL out	loss	isol.	RL out	loss	isol.	RL out	loss	isol.	RL out	loss	isol.	RL out	loss	isol.	RL out	loss	isol	RL out
4:14 Amidon #73	0.06	46	25	0.1	40	34	0.12	35	42	0.12	29	30	0.16	21	20	0.27	16	15	0.47	12	12
4:14 Amidon#73 14t isol.	**0.1**	**50**	**27**	**0.13**	**50**	**34**	**0.16**	**44**	**37**	**0.21**	**39**	**37**	**0.42**	**31**	**27**	**0.67**	**25**	**16**	**0.75**	**22**	**9**
4:14 FR #73	0.1	44	27	0.13	39	35	0.16	34	39	0.2	28	34	0.29	21	25	0.5	16	20	0.8	13	16
4:14 FR#73 4t isol PE wire	0.12	45	26	0.2	42	33	0.25	35	26	0.31	30	28	0.41	23	22	0.64	17	16	1	14	11
4:14 FR #73 14t isol.	**0.09**	**53**	**26**	**0.13**	**49**	**31**	**0.17**	**45**	**35**	**0.22**	**39**	**35**	**0.41**	**32**	**28**	**0.74**	**26**	**17**	**0.75**	**21**	**11**
4:14 Amidon #43	0.33	48	10	0.13	43	17	0.13	37	24	0.17	32	34	0.17	24	31	0.19	18	24	0.27	14	18
4:14 long core FR#73	0.04	40	40	0.06	34	42	0.08	28	42	0.1	23	40	0.16	16	32	0.58	11	13	2.1	9	19
4:14 long core FR#73 14t isol	0.05	48	27	0.08	46	29	0.13	40	33	0.21	35	32	0.42	27	21	0.56	22	9	4.1	19	4
2:7 long core FR#73 7t isol	0.12	53	16	0.15	48	23	0.19	43	31	0.2	39	38	0.27	31	25	0.41	26	19	0.56	22	13

“14t isol” = 14 turns fed through the insulation tube, with 4 turns outside the tube.

“4t isol PE-wire” = 4 turn winding made from PE insulated wire, but not using tubes “FR”= Fair-Rite core

Table 1 – Performance testing various 75ohm to 919ohm transformers

Loss: This is the insertion loss of the transformer itself in dB. As you can see, we are talking about low figures less than 1dB. On lower frequencies, there is not much difference between the various types of cores.

Isol: This is the isolation in dB between the low impedance and high impedance parts of the transformer. Isolation was measured by shorting the two connections of each coil as in **Figure 8**, so that the input coil and output coils act like a capacitor of a few picoFarads. The lower the capacitance, the better the isolation, indicated here by higher attenuation. Poor isolation means that currents on the outer conductor of your coaxial cable might be fed into the antenna or the antenna pattern might get disturbed by coupling to the coaxial cable.

RLout Return Loss ("SWR") is measured in dB at the low impedance (75 Ohm) part of the transformer, while the high impedance part is connected to a 919 Ohm resistor.

An antenna analyzer is connected to the low impedance part of the transformer and transmits a signal on a certain frequency. When the transformer is ideal, all energy from the analyzer is transformed to the resistor. When there is a mismatch, a part of the energy is reflected back into the analyzer, which means we are losing energy somewhere. 0dB is full reflection of power, or as bad as it can be, and 50dB or more means that virtually no energy is reflected. Practically, a return loss of around 20-25dB or more is good enough.

We see that although a #43 material core has only around 0.2dB more loss on 500kHz, the mismatch is much higher and will reduce performance.

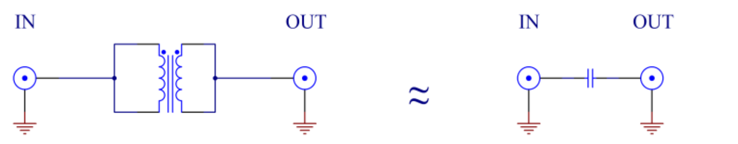


Figure 8

Summarized from Table 1:

- A single core BN73-202 or Fair-Rite 2873000202 with 4 turns enameled copper wire for the 75 Ohm side and 14 turns for the high impedance side (919Ohm) will be a good choice.
- You can gain an extra 10dB of isolation by feeding the 14 turns part through isolation tubes.
- A longer core or a stack of 2-cores will give you marginally less loss on lower frequencies, but will show less isolation and more losses on higher shortwave frequencies.

But, I use 50 ohm coax cable

The above section was all about transformers designed to match to 75 ohm coax cable. For a 50 ohm situation, you might try 4 turns for the low impedance winding and 17 turns for the high impedance, which will give 50:903 ohm match.

Calculating other impedance ratios?

Use the following formula:

$$\left(\frac{N_P}{N_S}\right)^2 = \frac{Z_P}{Z_S}$$

Np = number turns on primary
Ns = number of turns on secondary winding
Zp = impedance at primary
Zs = impedance at secondary

For example, use of 4 turns for primary and 14 turns for secondary gives an impedance ratio of 3.5x3.5=12.25. So, 75ohm coax cable connected to the 4 turn winding is transformed to look like 919 ohms at the connections of the 14 turns.

Using a 17:4 turns winding ratio gives an impedance ratio of 18.1 which transforms 50ohm coax to look like 903ohms.

TIP: Try to stay around 3 to 5 turns for the low impedance part when using #73 material.

II. Isolation Transformer (common mode filter)

Unwanted signals picked-up by your coaxial cable (on the outside of the screen) might get into your antenna or might get into your receiver. In either case you want to stop that happening. To avoid this, these currents on the outside of your coax cable screen have to be blocked.

This can be done by sliding ferrite beads over the cable, or winding the coaxial cable several times through a suitable ferrite core. Sometimes this is called a "braid breaker". (editor's note: see IRCA Reprint A-200 from an earlier Technical Column for further details)

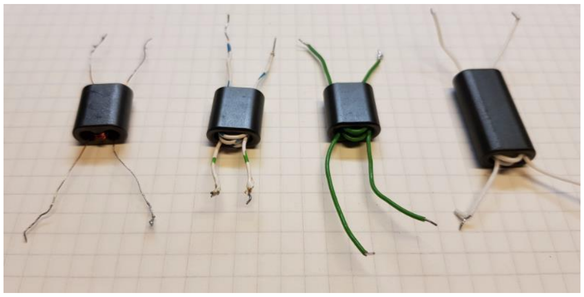


Figure 9

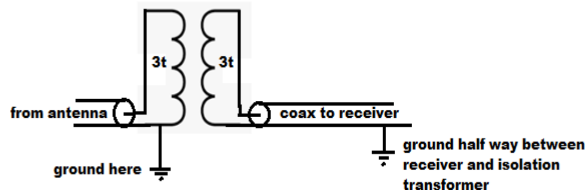


Figure 10

For this purpose, either a large number of ferrite beads or a large ferrite core could be used, which might be rather impractical. Alternatively a simple 1:1 transformer on a binocular core will do the same job. I created several different versions of isolation transformers (**Figure 9**), and tested them.

Frequency MHz ->		0.5			1			2			4			10			20			30	
type	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol	RL
1:1 FR 2x3T copper	0.09	31	27	0.18	26	33	0.29	22	35	0.48	19	33	0.75	16	24	1.31	14	16	2.06	12	13
1:1 FR 2x4T copper	0.06	31	30	0.1	26	33	0.16	21	31	0.31	18	26	0.62	15	19	1.27	13	13	2.27	11	10
1:1 FR 2x3T PE/PVC isol	0.12	53	24	0.19	49	28	0.21	44	29	0.23	38	27	0.28	30	21	0.42	24	16	0.62	21	12
1:1 FR 2x3T PTFE isol	**0.11**	**54**	**24**	**0.19**	**51**	**29**	**0.21**	**46**	**27**	**0.22**	**40**	**25**	**0.29**	**33**	**18**	**0.51**	**27**	**12**	**0.86**	**23**	**9**
1:1 FR long 2x2T copper	0.05	53	18	0.11	51	24	0.18	45	27	0.2	39	27	0.28	32	22	0.42	26	17	0.65	22	13
1:1 FR long 2x2T PTFE	0.06	53	19	0.14	50	24	0.17	46	26	0.2	40	25	0.27	32	20	0.5	26	14	0.81	23	11

Table 2 – Overview of the isolation transformers measured

Summarized from Table 2:

- The longer type of core seems to perform a bit differently here, as there is not much difference between the uninsulated or isolated variant.
- 2 times 3 turns insulated wire through a single core BN73-202 or Fair-Rite 2873000202 will do the job for us.
- More turns will give lower loss, but might be impractical to achieve with standard insulated wire.
- Standard insulated electrical wire will be sufficient.
- The use of Teflon (PTFE) insulated wire will not make much difference.
- The use of insulation tubes, as was used in the antenna transformer, will not bring much advantage.
- Transformer will work also in 50 Ohm coax.

III. Impedance matching transformer 75 Ohm to 50 Ohm

Most receivers have a 50 Ohm input, so when using 75 Ohm TV or satellite coaxial cable as a feed line, there will be some kind of 'mismatch'. Although in practice the losses due to this are low, we might want to achieve a good match. We can use an isolation type transformer with separated windings, which will act as an isolation transformer and as a matching transformer in one, or we can use a 'step-up' autotransformer which has lower loss, but no isolation at all.

Isolation type: constructed the same way as the antenna transformer, 5 turns for the 50 Ohm side and 6 turns on the 75 Ohm side.
For best isolation, feed the 6 turns through an insulation tube.

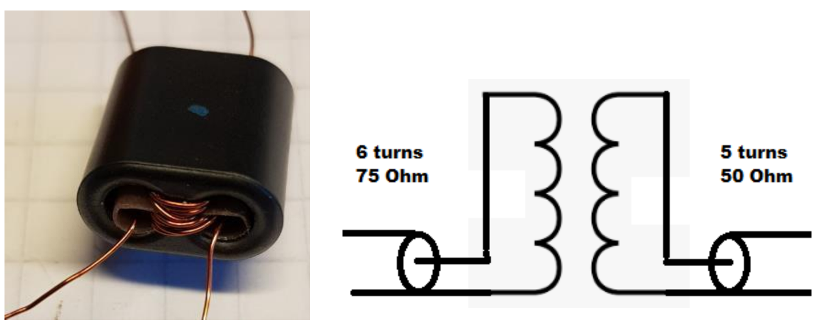


Figure 11

Autotransformer Construction

We need 11 turns with a "tap" at 9 turns (**Figure 12**). Just start winding and when you reach 9 turns twist the wire as shown and continue winding 2 more turns (**Figure 13**). *Don't forget to mark on the core, or in another way, which wire is the ground and which is the high impedance wire…*

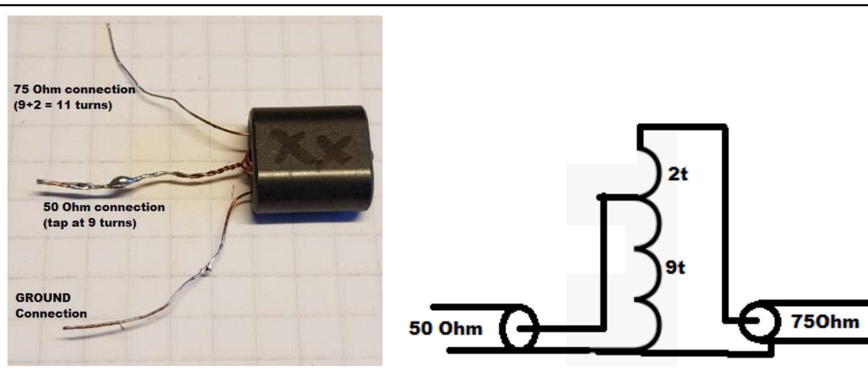


Figure 12

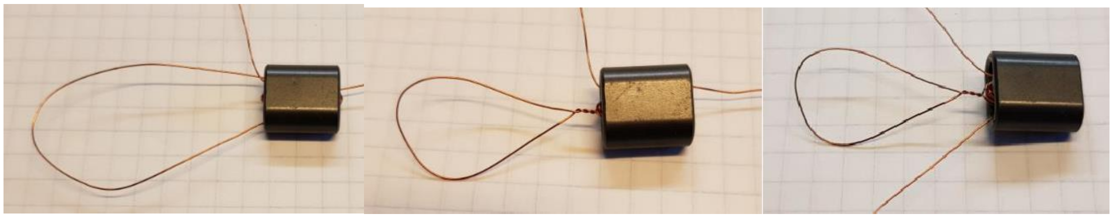


Figure 13

Frequency MHz ->		0.5			1			2			4			10			20			30	
type	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol	RL
5t:6t FR73 copper	0.19	19	33/29	0.23	17	35/30	0.28	15	33/29	0.37	13	28/27	0.6	10	20/20	1.07	9	13/14	1.66	8	10/10
5t:6t FR73 6t isol	**0.13**	**53**	**29/27**	**0.19**	**50**	**28/27**	**0.25**	**45**	**24/24**	**0.39**	**40**	**19/19**	**1.08**	**33**	**12/12**	**2.6**	**27**	**7/6**	**3.8**	**24**	**5/4**
5t:6t Amidon #43 6t isol	0.15	55	16/17	0.12	52	20/21	0.19	50	20/21	0.31	46	17/17	0.88	38	10/11	2.11	33	5/6	3.2	29	3/4
5t:6t FR73 long copper	0.04	33	30/30	0.08	28	29/30	0.12	24	26/27	0.19	20	22/23	0.48	16	15/16	1.2	13	9/10	2.05	11	6/7
5t:6t FR73 long 6t isol	0.04	52	25/26	0.1	48	23/24	0.19	44	19/20	0.45	39	14/15	1.6	32	7/8	3.44	26	3/4	4.7	23	2/2
11t 9t tap FR73	0.35	0	46/43	0.38	0	29/34	0.45	0	28/30	0.6	0	25/27	0.93	0	21/24	1.33	0	18/24	1.62	0	16/20
11t 9t tap Amidon #73	0.08	0	40/44	0.1	0	46/56	0.15	0	46/62	0.23	0	41/56	0.41	0	32/41	0.61	0	26/27	0.77	0	22/20
11t 9t tap Amidon #43	**0**	**0**	**27/27**	**0.02**	**0**	**32/33**	**0.03**	**0**	**36/38**	**0.05**	**0**	**36/40**	**0.05**	**0**	**31/35**	**0.05**	**0**	**27/26**	**0.07**	**0**	**24/22**
11t 9t tap FR73 long	0.04	0	46/43	0.05	0	56/48	0.06	0	55/49	0.1	0	46/55	0.2	0	36/38	0.37	0	29/25	0.53	0	25/19

"RL": first figure is measured from 50 Ohm side; second figure is measured from 75 Ohm side

Table 3 – Overview of 50 Ohm to 75 Ohm transformers measured

Summarized from Table 3:

With the isolation type transformers, the losses and return loss on shortwave and up will let us down.

- BN73-202 or Fair-Rite 2873000202 will be fine for use on MW and lower part of shortwave.
- When isolation is not important, it is better to use an autotransformer. Here, a #43 material core (BN43-202 or 2843000202) will give lowest losses and good return loss over a wide frequency range.
- #73 material gives better return loss, especially on lower frequencies, but has more losses on higher shortwave frequencies.

IV. 2-way splitters

If you want to share a signal from one antenna to two receivers without losing much signal strength or experiencing interaction between the two receivers, a proper signal splitter is recommended.

These splitters consist of two transformers. The first one connects the two outputs together with an input impedance that is half of a single port. That is, with 50 ohm output ports, this transformer has a 25 Ohm input. The second transformer will transform this 25 Ohm back to 50 ohm for the input.

We can also choose to transform to 75 ohm, so in that case, we can transform our 75 ohm feedline into two 50 Ohm outputs for our receivers... therefore, no additional impedance transformer is required!

Construction is a bit more complicated, so let's go...

The output transformer has 4 turns of twisted wire. A mini-drill with screw hook can be helpful to twist the wires. (**Figure 14**) The pictures in **Figure 15** show how the wiring is done, illustrated with colored insulation to show the connections.

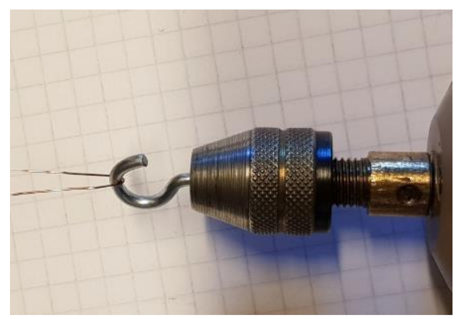


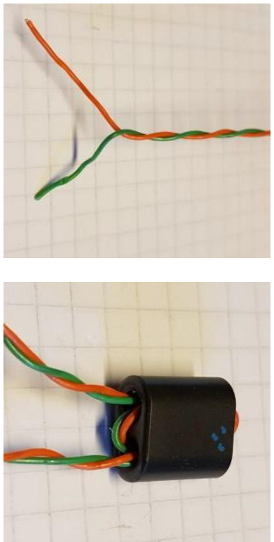
Figure 14

But, for practical transformers, we need to use enameled copper wire so that we can make enough turns through the binocular core.

You can mark one of the wires before twisting them, or measure it with a resistance meter afterwards to find out the correct wire ends.
Next step is winding the step-up transformer, in the same way as the previous 50 Ohm to 75 Ohm "autotransformer".

- 50 Ohm input: 7 turns with a tap at 5 turns, which will be our 25 Ohm input.
- 75 Ohm input: 7 turns with a tap at 4 turns, which will be our 25 Ohm input.

Finally, we have to solder the two transformers with their low impedance parts together. Solder a 100 Ohm resistor between the outputs and optionally, solder an 82pF compensation capacitor between the common low impedance point and ground. (**Figure 16**)



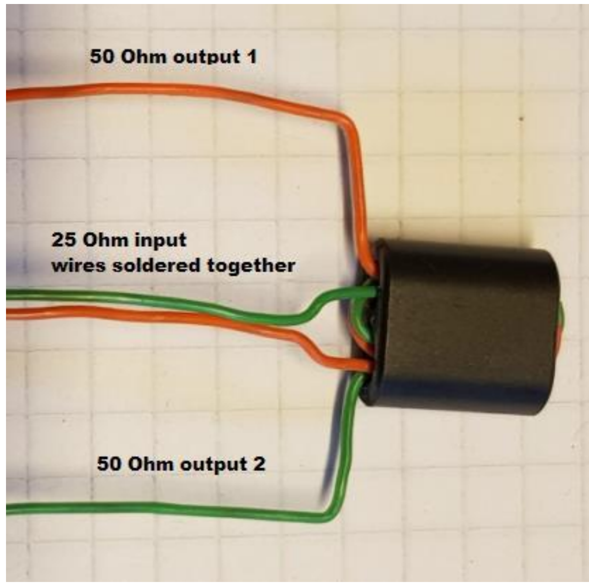


Figure 15

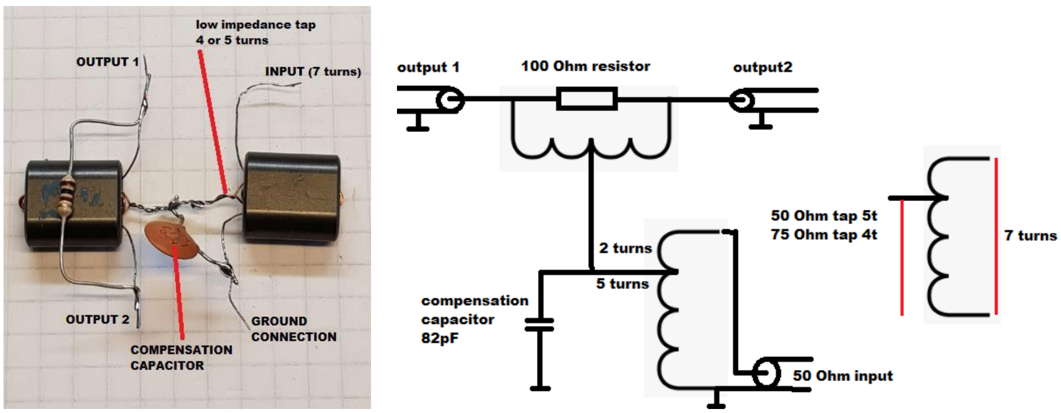


Figure 16

Frequency MHz ->		0.5			1			2			4			10			20			30	
type	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol.	RL	loss	isol	RL
FR #73	3.08	35	33/35	3.,11	33	33/35	3.15	32	32/34	3.19	29	29/32	3.3	24	23/28	3.5	29	17/23	3.7	17	14/20
FR #73 + 82pF capacitor	3.14	33	33/35	3.2	33	33/34	3.21	31	32/31	3.22	29	30/29	3.24	26	27/25	3.16	24	24/22	3.68	23	21/21
FR #73 long	3.01	38	35/37	3.03	38	35/41	3.05	36	32/39	3.08	32	28/35	3.17	25	21/28	3.36	20	15/23	3.58	17	13/20
FR #73 long + 82pF cap.	3.01	38	36/39	3.03	38	38/44	3.05	38	38/46	3.06	36	38/48	3.12	32	34/48	3.21	29	31/42	3.29	27	29/32
Amidon #43	3.01	32	22/21	3.03	37	27/26	3.05	37	29/30	3.09	34	27/30	3.13	28	21/26	3.29	22	16/21	3.46	19	13/18
Amidon #43 + 82pF cap.	3.03	32	23/21	3.04	36	28/27	3.08	38	32/32	3.09	37	33/35	3.12	35	31/34	3.16	32	27/34	3.23	30	24/39

Table 4 – Some of the splitter variants measured

Loss: attenuation between the input and output 1 or 2. In an ideal world, this should be 3dB; in practice, it is a bit more due to unwanted losses. This is measured with the unused output port terminated with a 50 Ohm resistor.

Isolation: measured between the two outputs, while the input is terminated with a 50 Ohm resistor.

RL return loss: the first figure is input, while the second figure is output 1 or 2. Unused splitter port is terminated with 50 Ohm.

Summarized from Table 4:

- For those looking for optimum response on longwave/low part mediumwave, a #73 core is a good choice; otherwise a #43 core will be fine.
- Especially on higher frequencies, the addition of an 82pF compensation capacitor can dramatically improve port isolation and return loss.

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