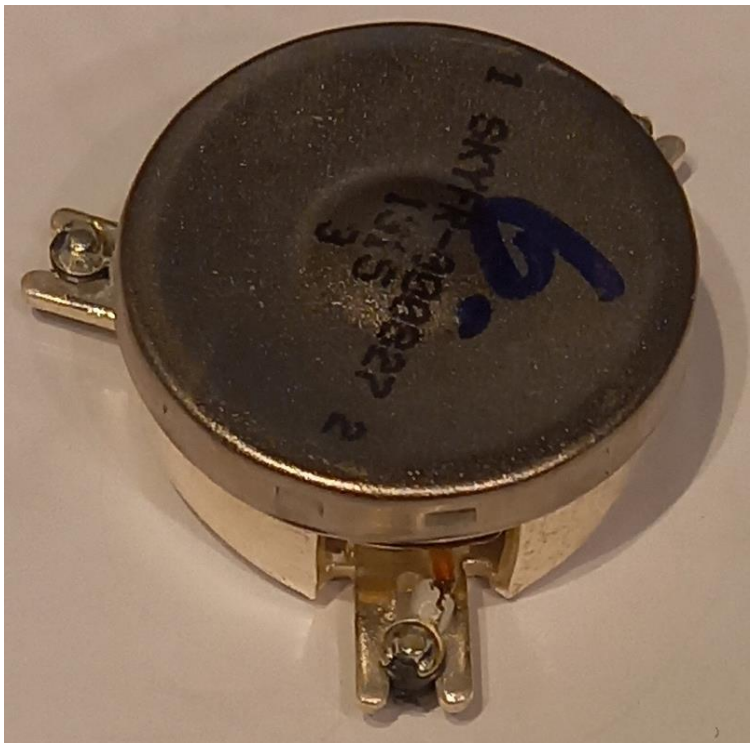
A 2.4GHz 200W Circulator based on Skyworks SKYFR-000827

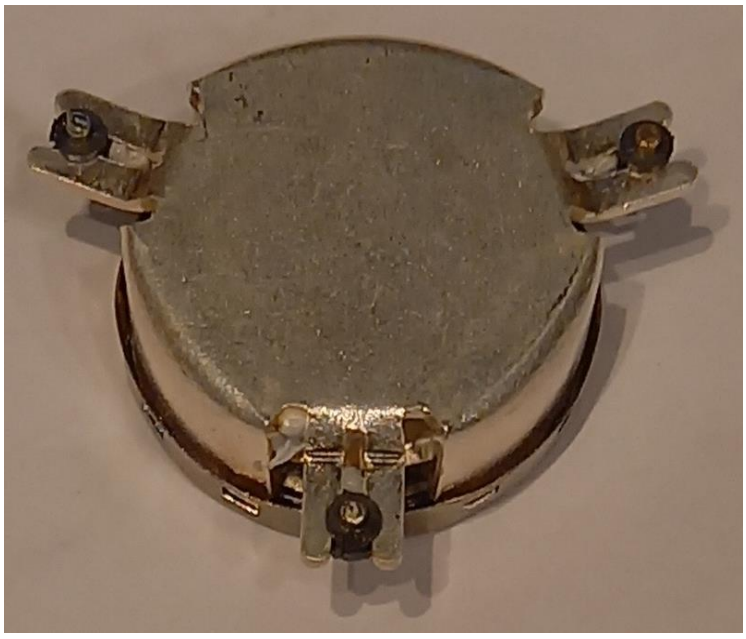
Matthias, DD1US, October 25th 2022, Rev 0.3

Hello,

Some time ago I was able to acquire some circulator devices Skyworks SKYFR-000827. They are SMD type devices and can handle a maximum power of 200W CW / 600W peak. The insertion loss is specified to be 0.15dB max. Isolation is specified to be min 20dB. Input and output return loss is given as 20dB min.

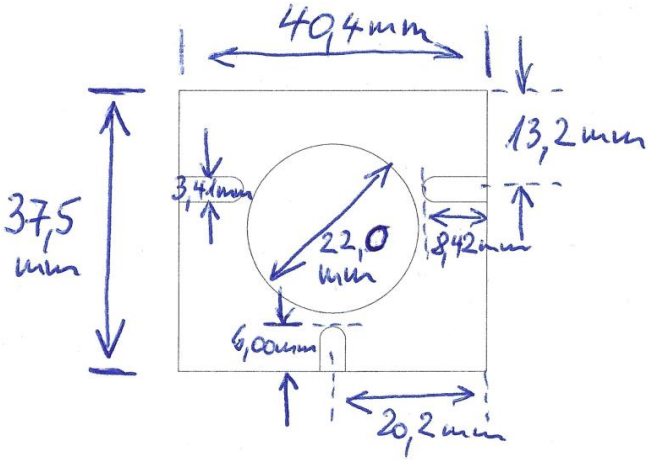
Here are two pictures of one of my units:

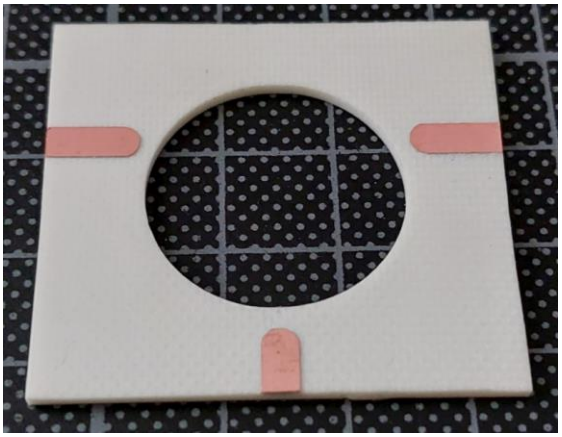




Recently I found time to design a test setup to characterize such a circulator.

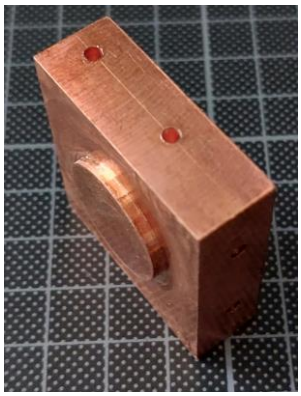
A friend, Markus DH5WM, kindly helped me with his lathe and we fabricated a small PCB made from Rogers RO4003C with a thickness of 1.524mm. We left the lower side of the PCB with a complete ground plane and he milled the upper side with a deepness of 50um. The 50 Ohm striplines have a width of 3.41mm.
Below please find a sketch and a photograph of the upper side of the PCB:

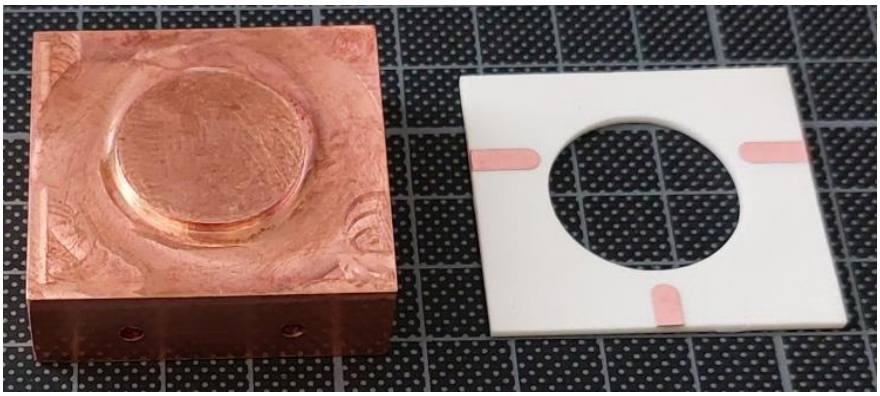


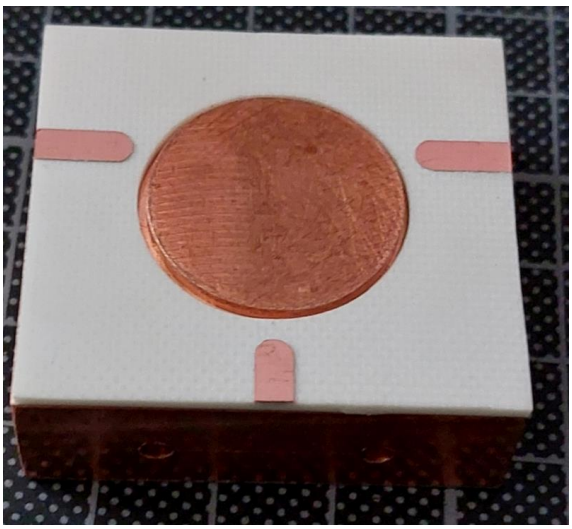


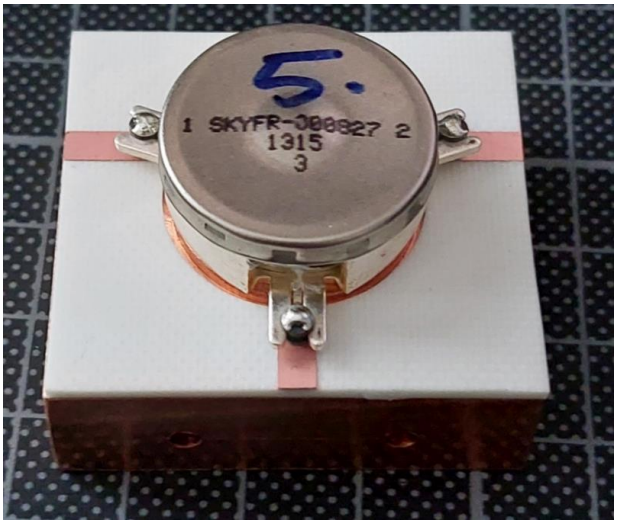
In the center there is a hole with a diameter of 22mm through which the circulator is directly soldered to a copper block in order to provide a perfect RF ground connection and a very low thermal resistance to the heatsink.

Markus also milled a copper block with a 1.6mm high post and a diameter of 21.5mm. The PCB will be soldered to the copper block and finally the circulator device on the top. Here are some pictures:



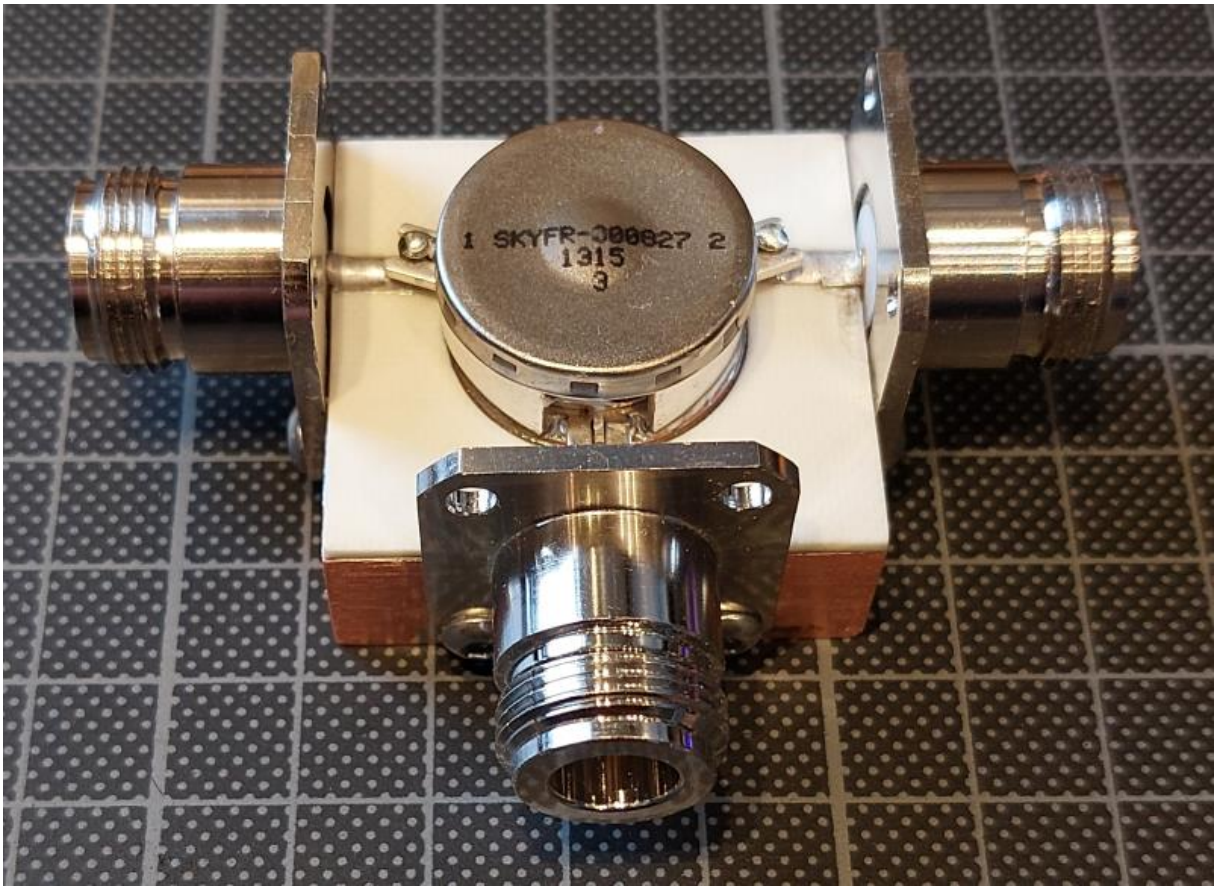


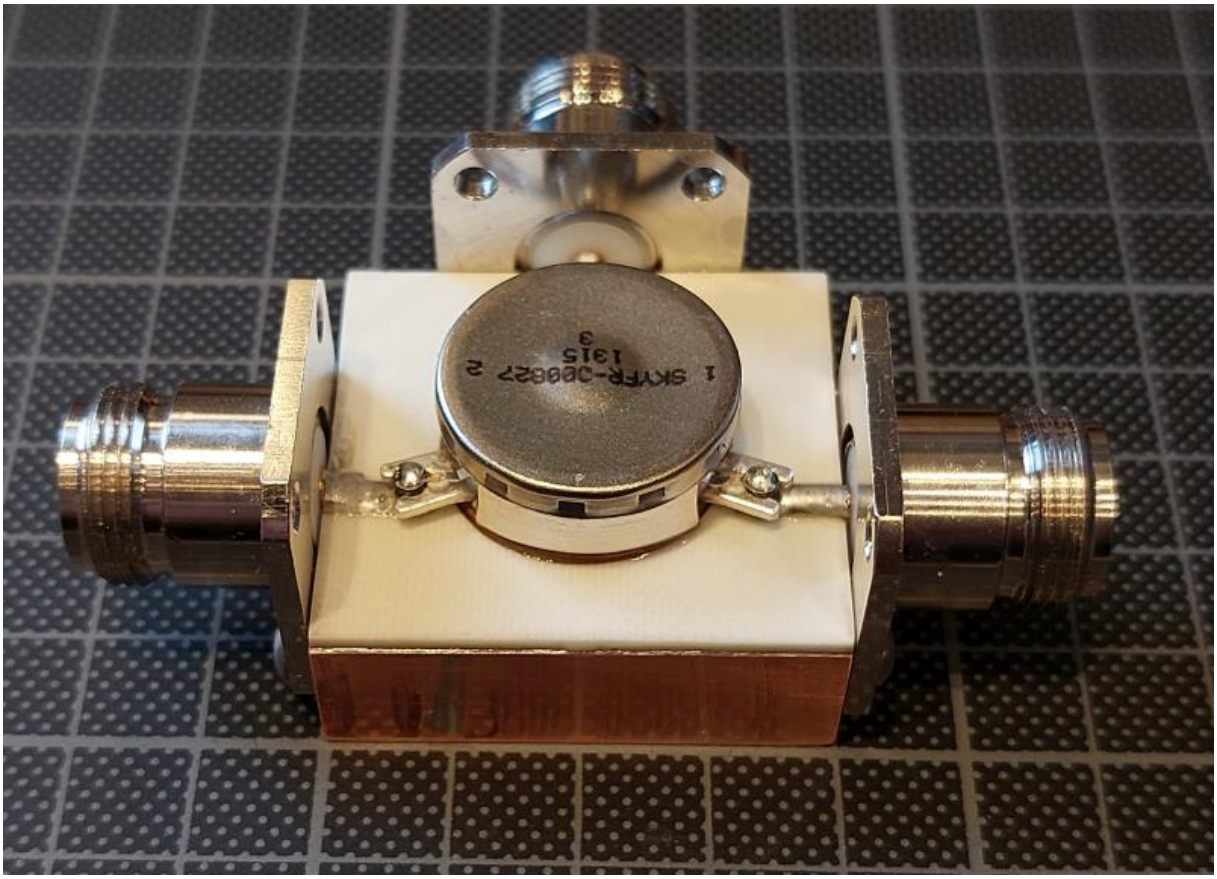


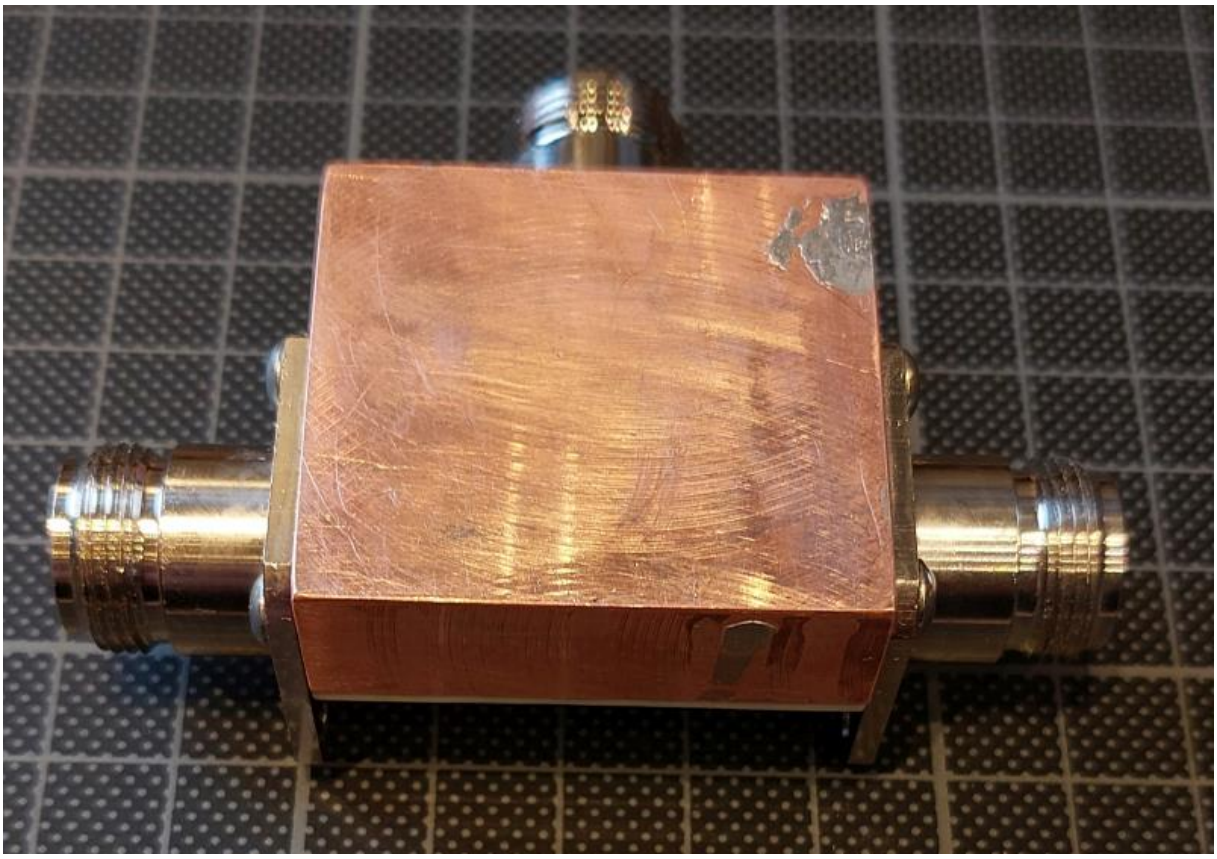


The copper block was polished and the PCB and thereafter the circulator device were soldered at a temperature of 160°C using a solder past with the following alloy: Sn42Bi58

You can see in the pictures above hole with 3mm threads in the copper block. They are used to screw on the N plugs to the copper block.



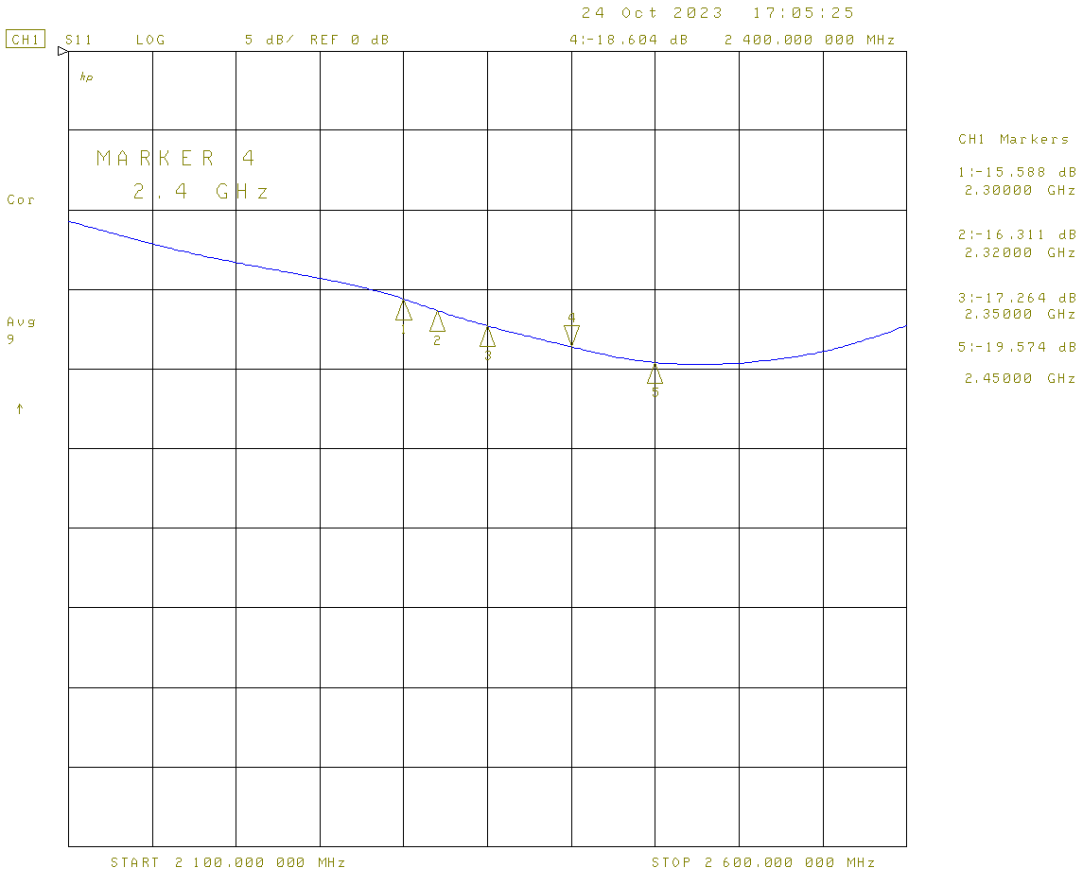


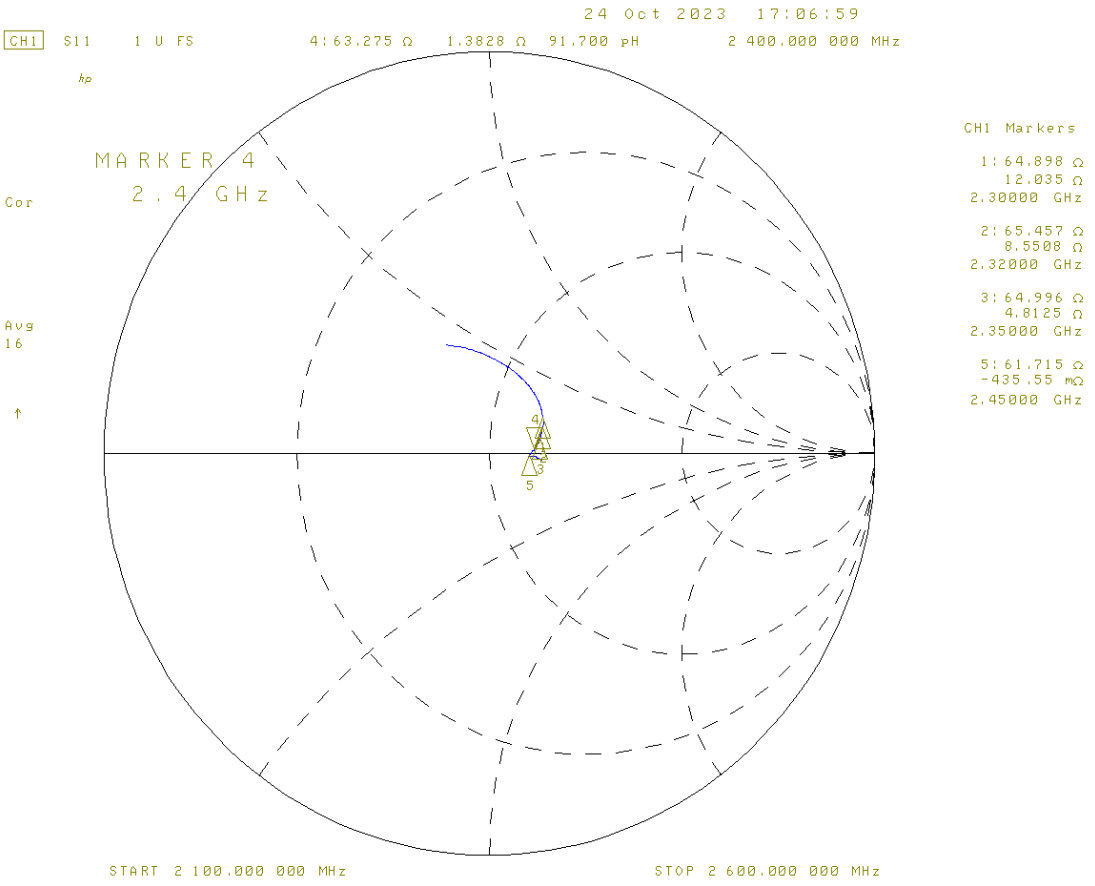


Next the test setup was characterized using an HP8753E network analyzer focusing on the target frequency of 2.4GHz.

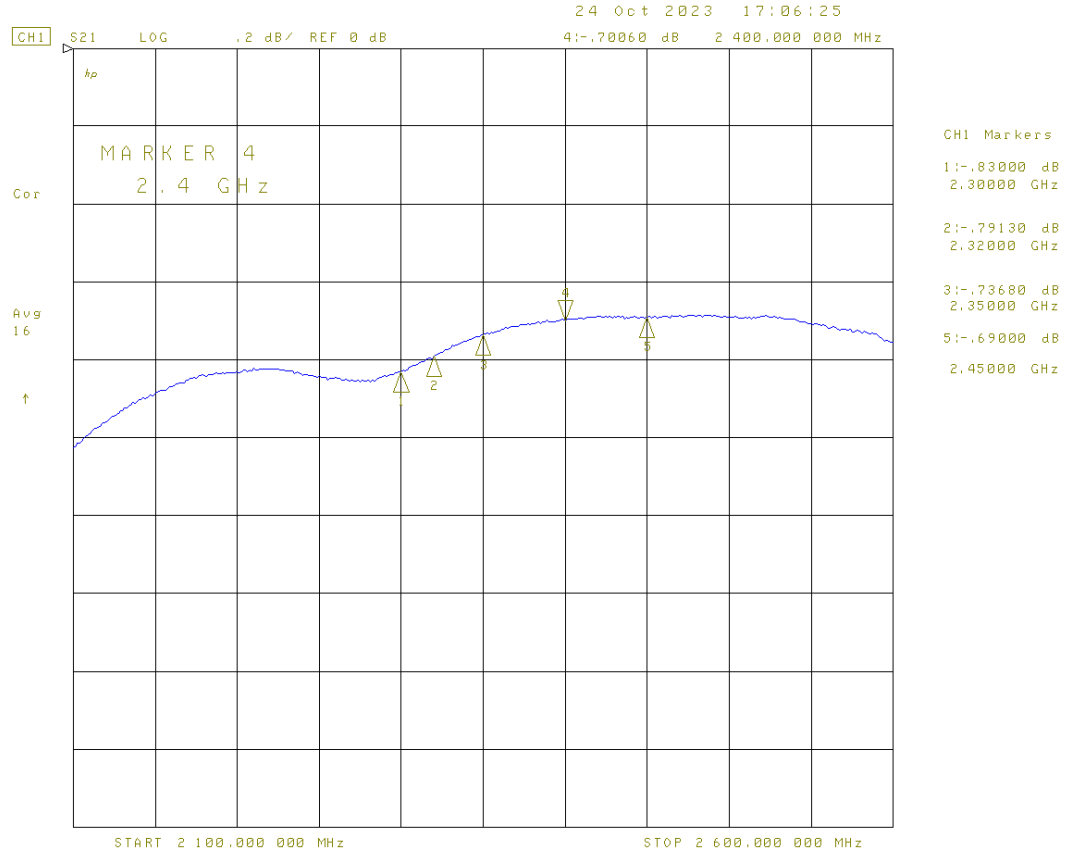
The first series of measurements was using port 1 as input and port 2 as output. Port 3 was terminated with 50Ohm.

S1 -> S2: S11 input return loss 18.6dB @2.4 GHz

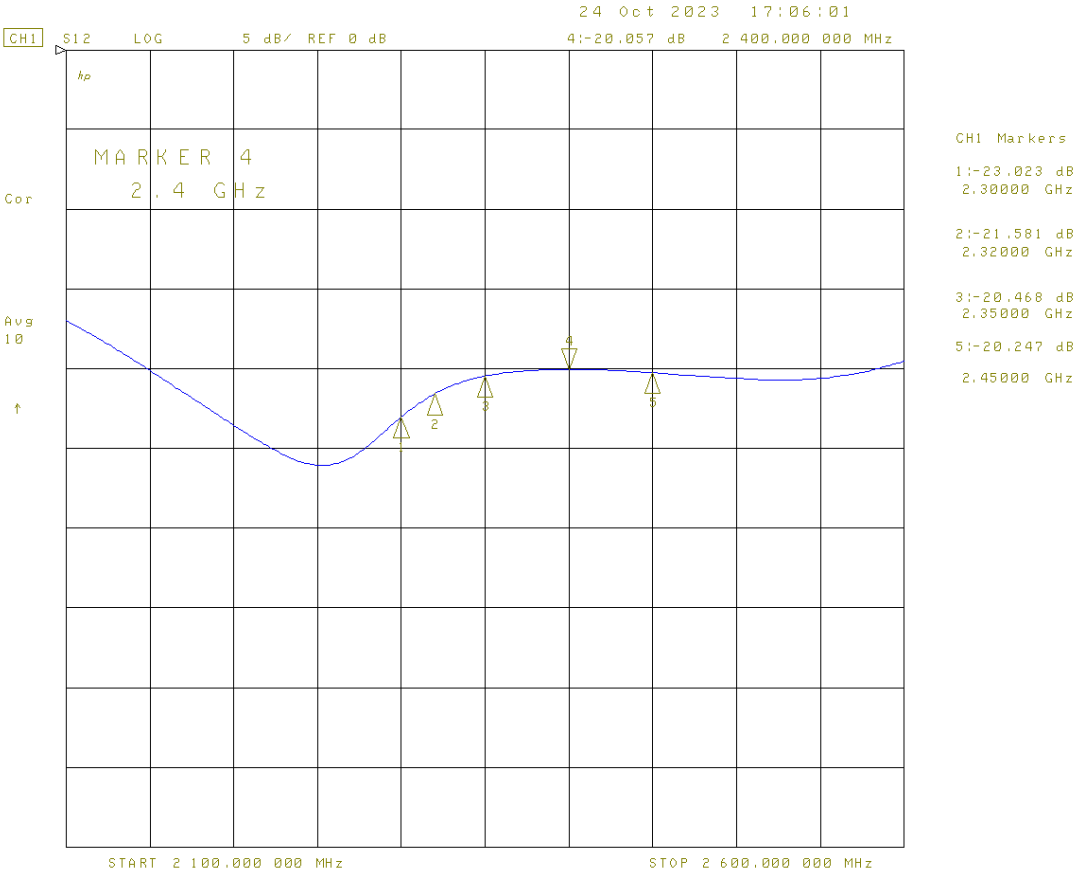




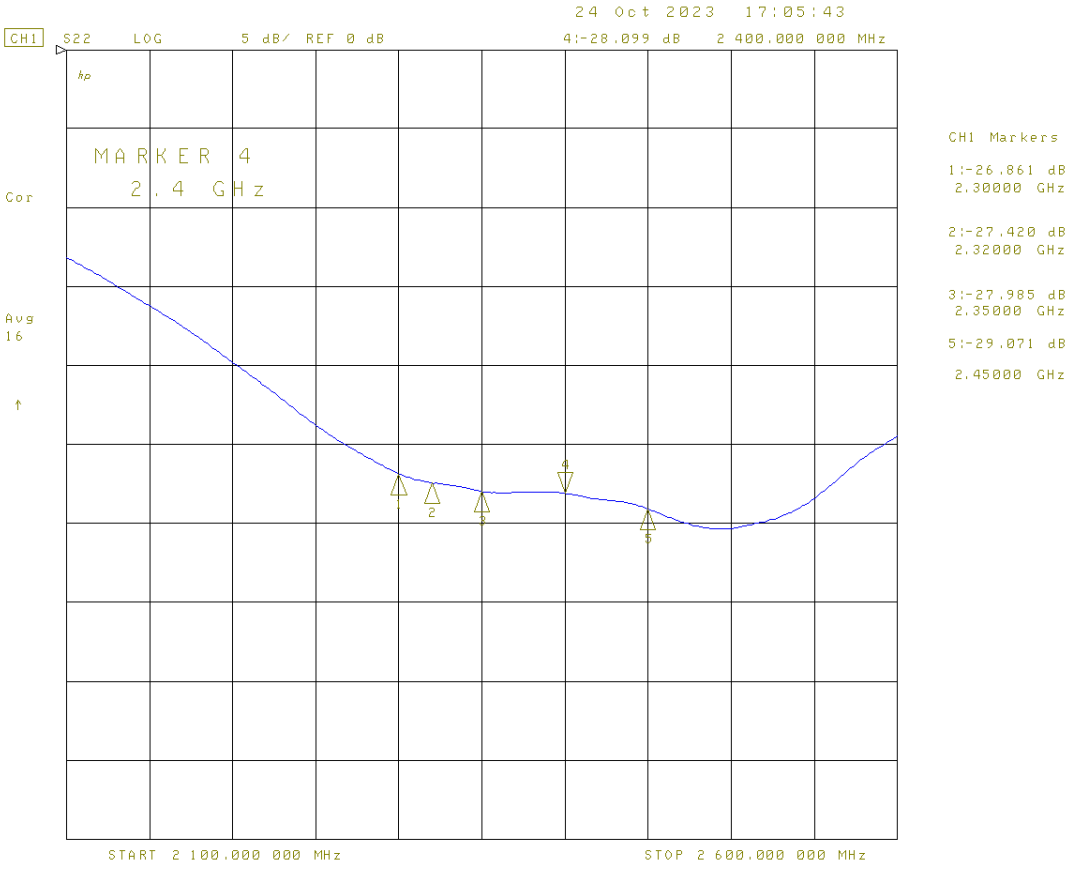
S1 -> S2: S21 insertion loss 0.70dB @2.4 GHz

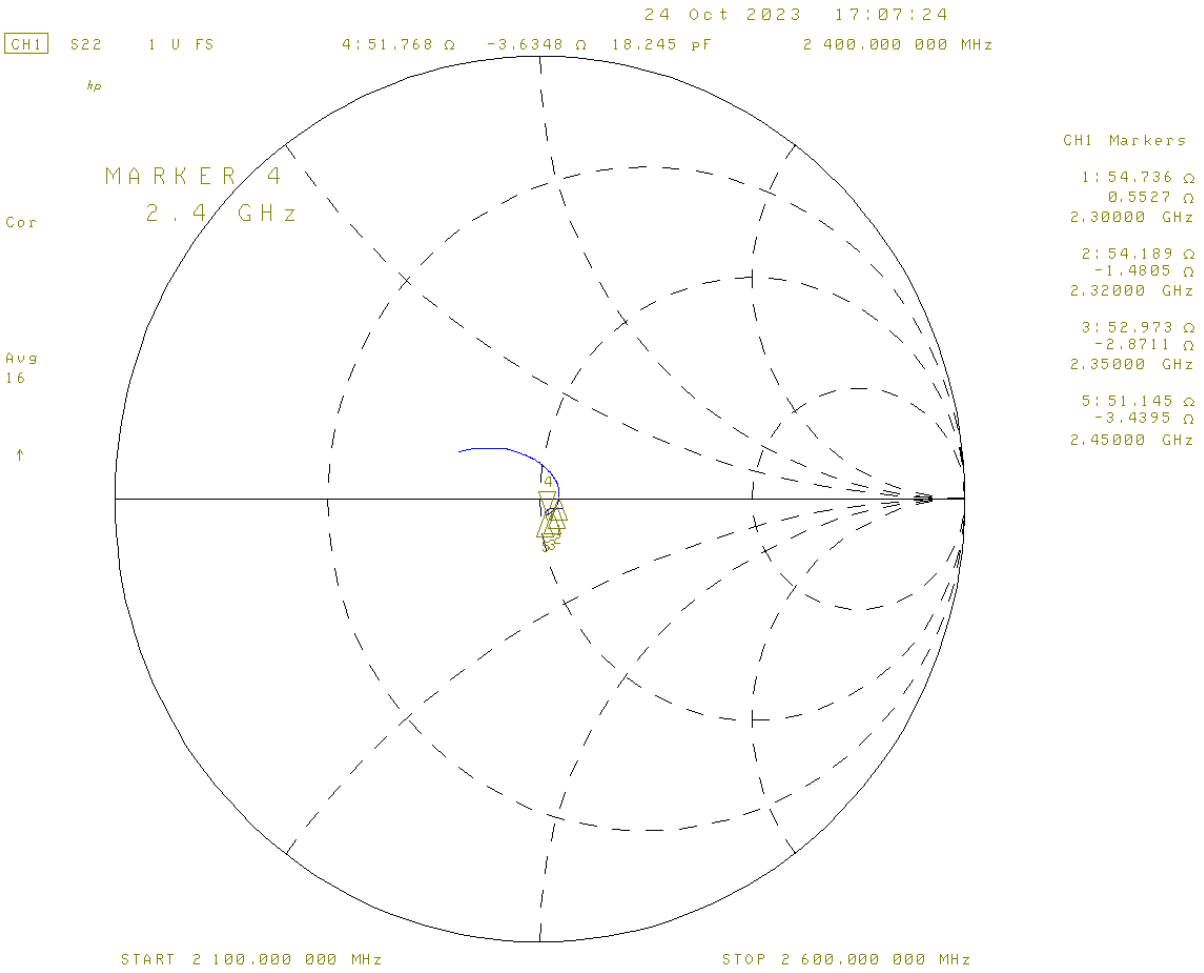


S1 -> S2: S12 isolation 20.1dB @2.4 GHz

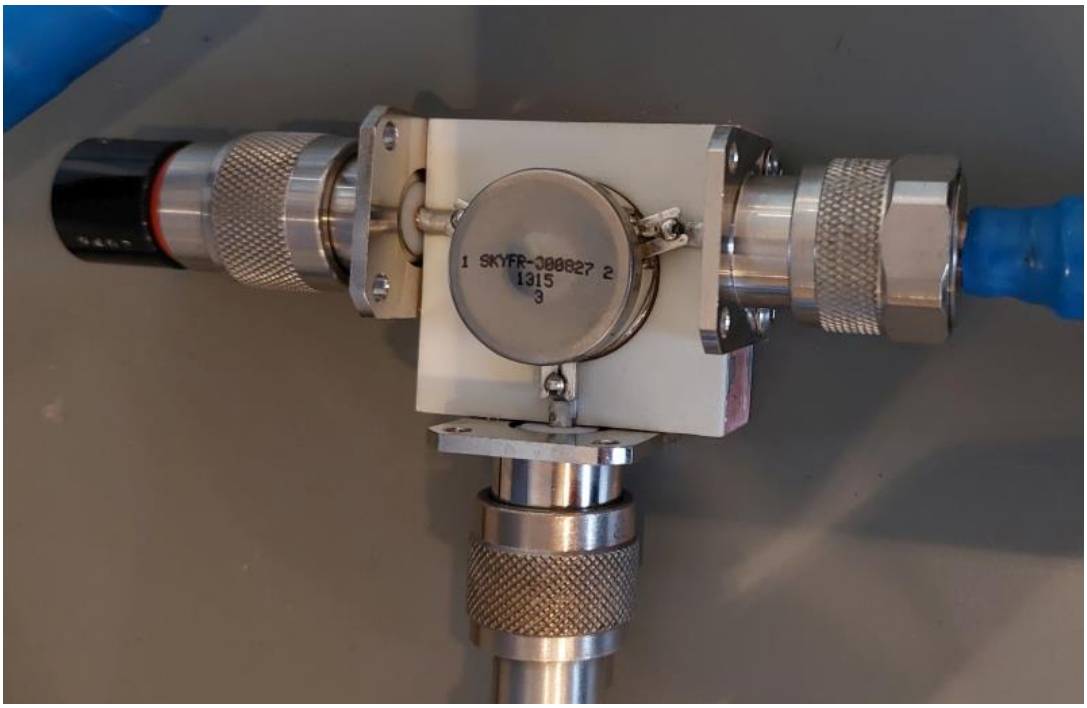


S1 -> S2: S22 output return loss 28.1dB @2.4 GHz

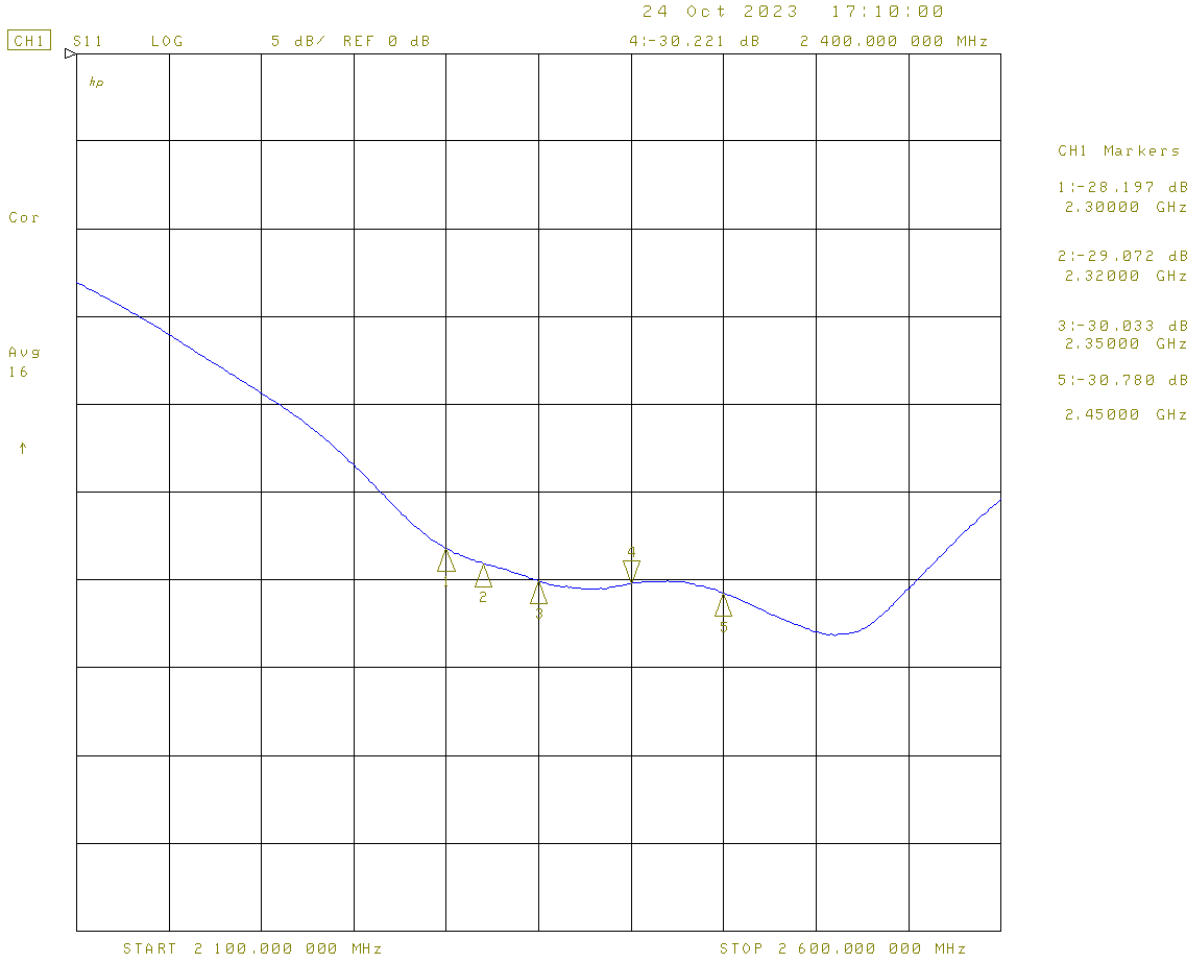


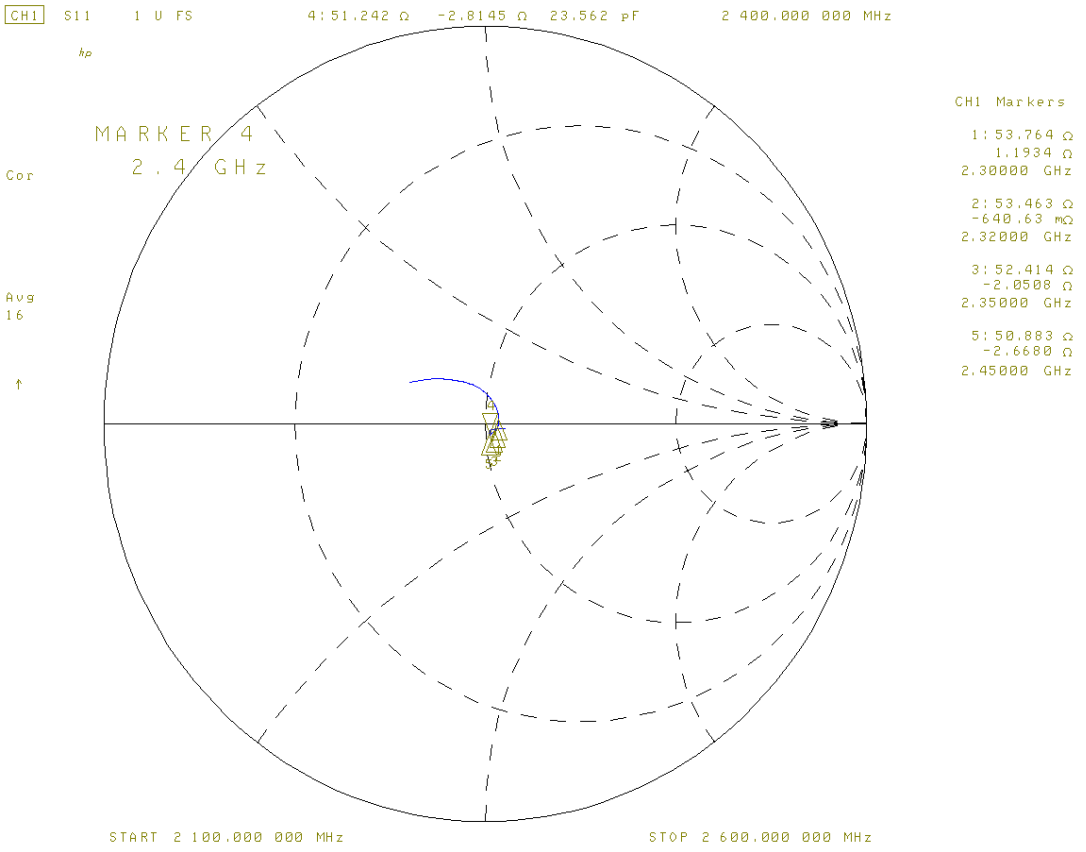


Next, the measurements were repeated port 2 as input and port 3 as output. Port 1 was terminated with 50Ohm.

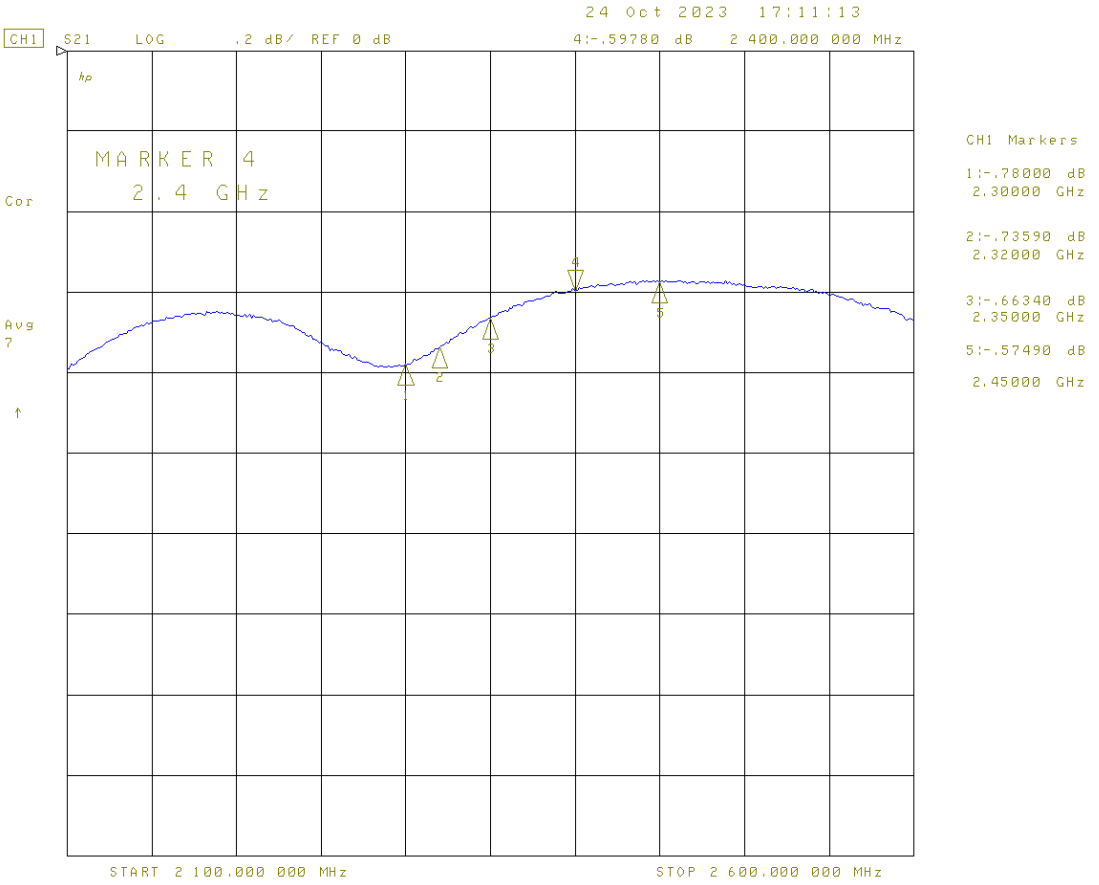


S2 -> S3: S11 input return loss 30.2dB @2.4 GHz

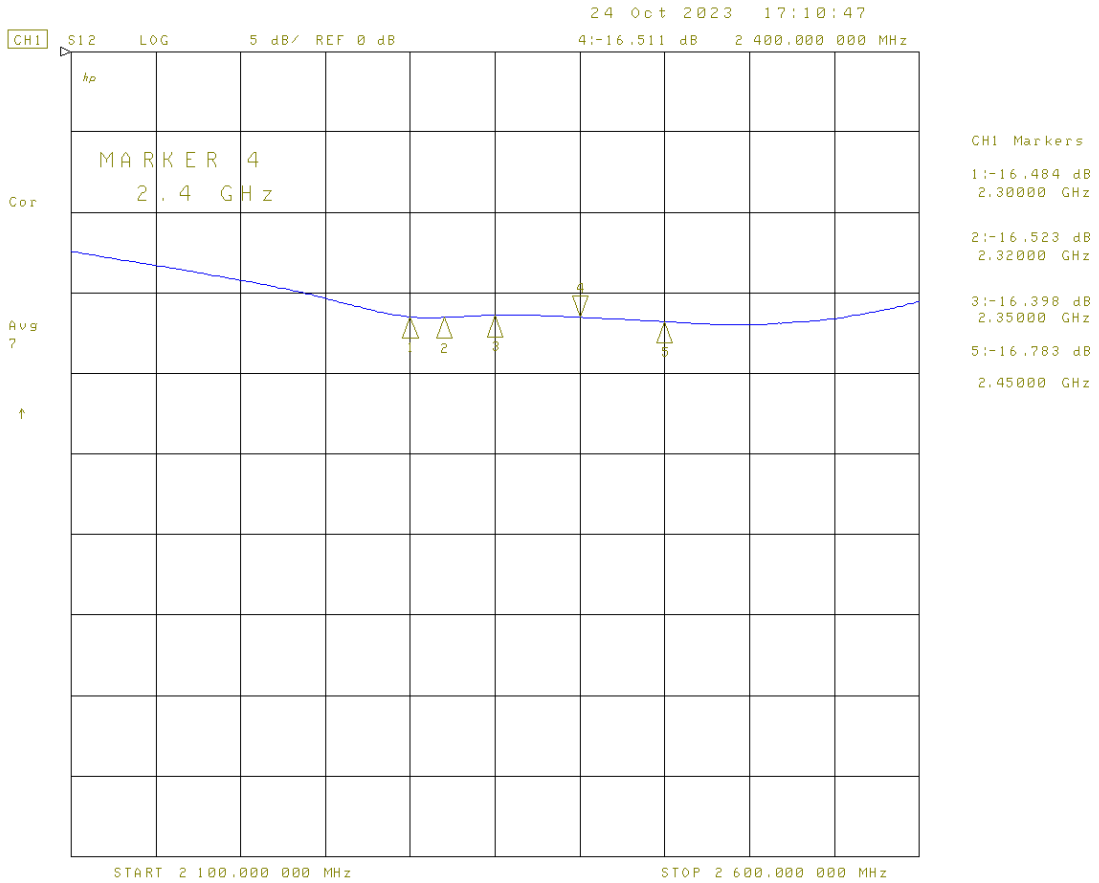




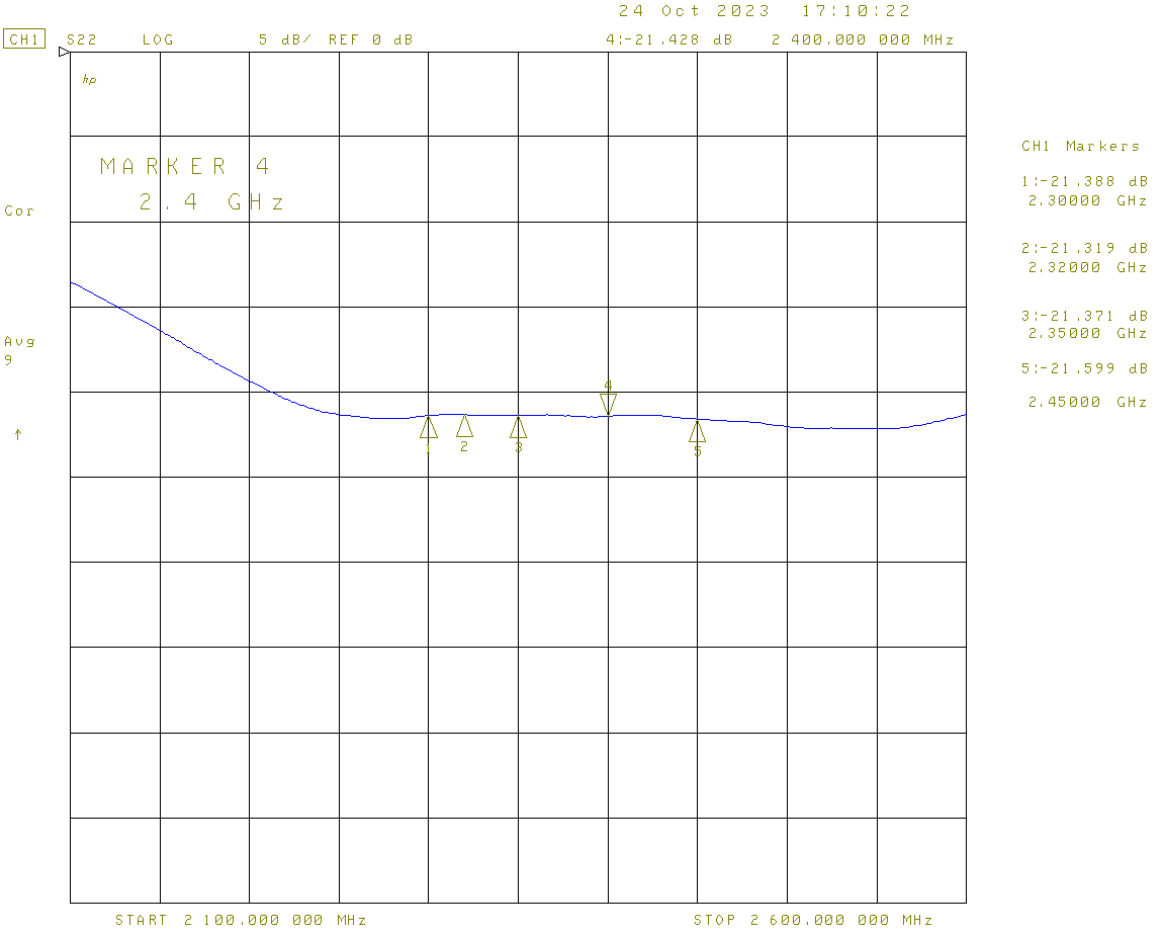
S2 -> S3: S21 insertion loss 0.60dB @2.4 GHz

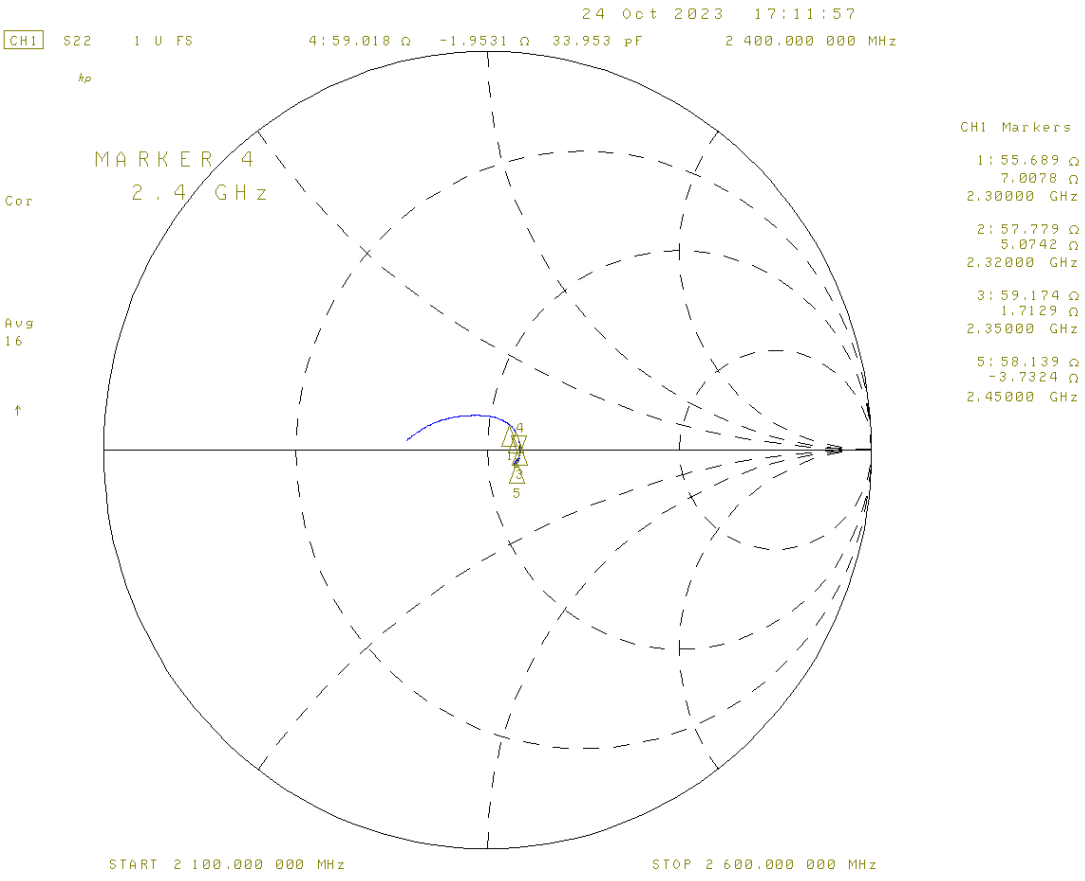


S2 -> S3: S12 isolation 16.5dB @2.4 GHz

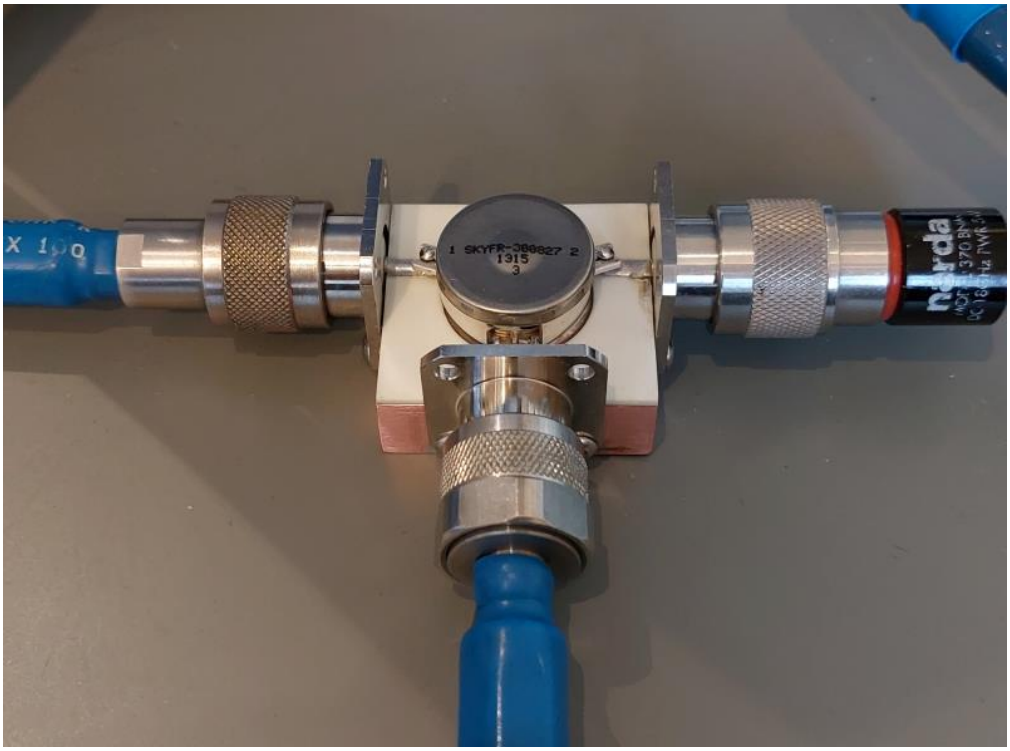


S2 -> S3: S22 output return loss 21.4dB @2.4 GHz

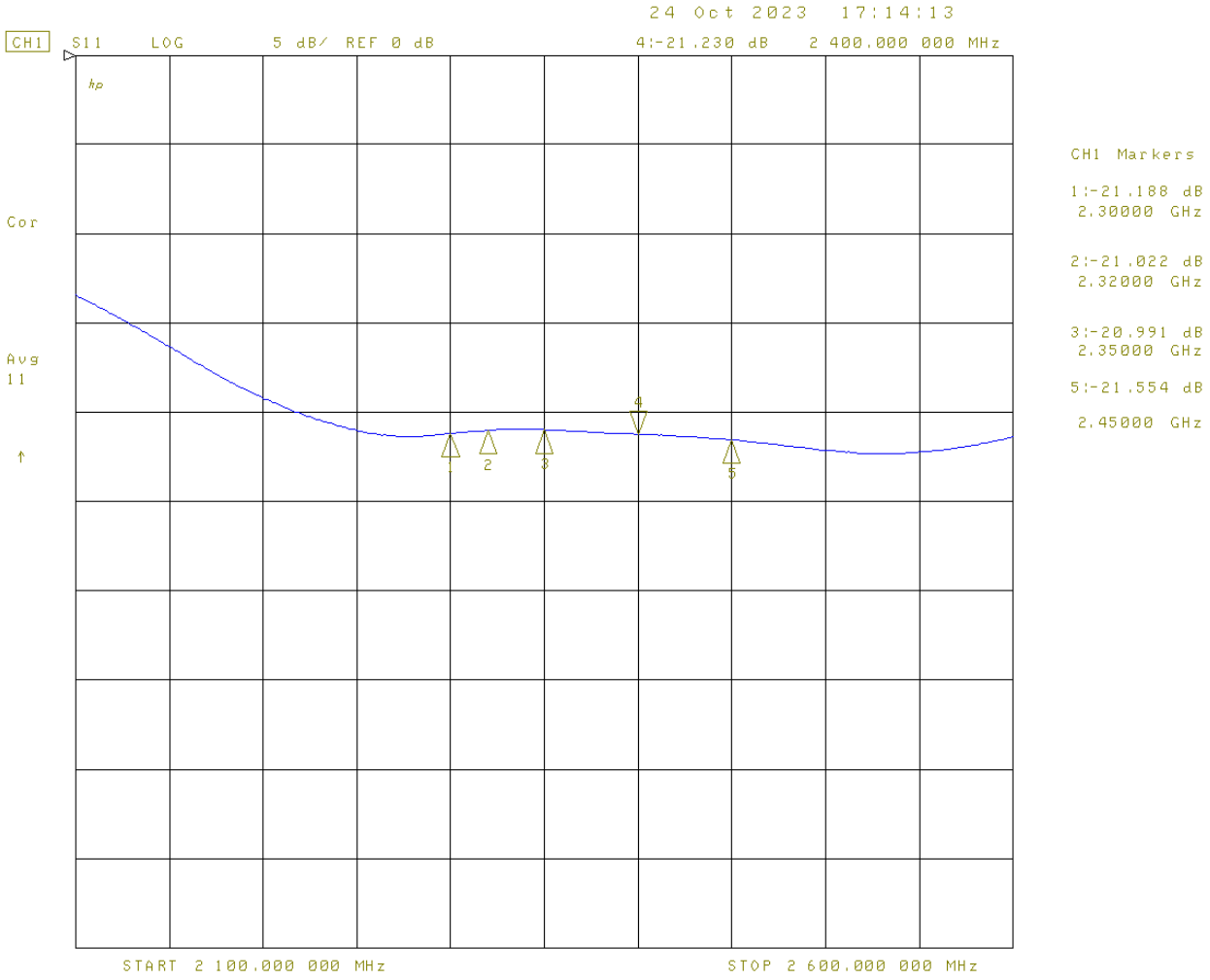


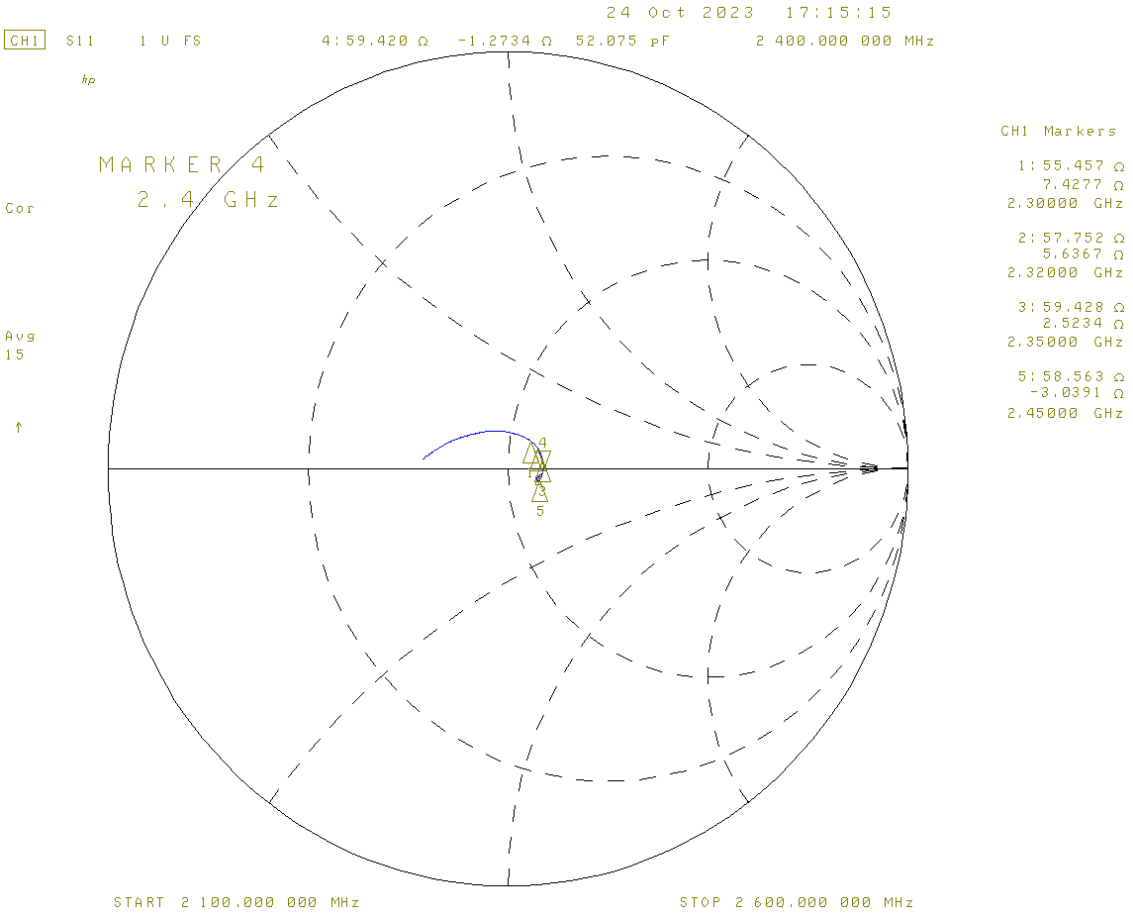


Finally, the measurements were repeated port 3 as input and port 1 as output. Port 2 was terminated with 50Ohm.

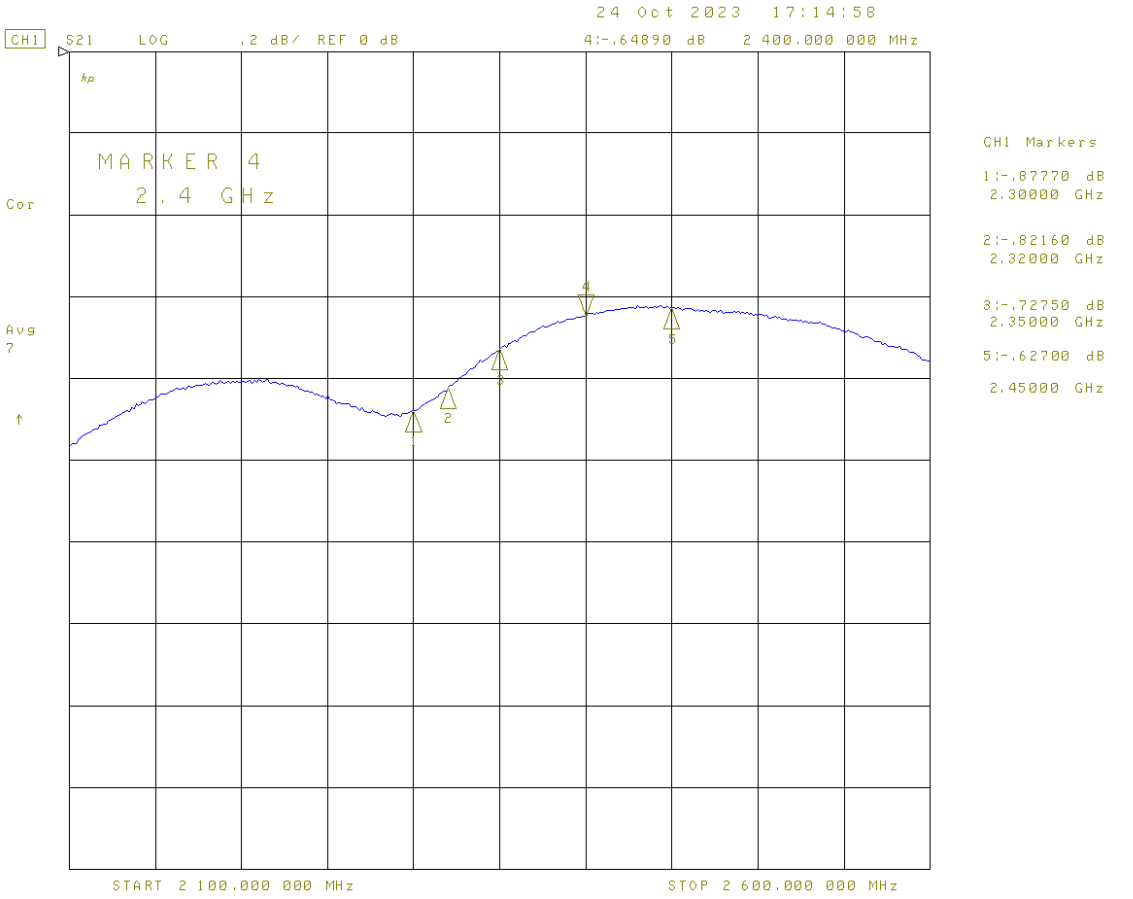


S3 -> S1: S11 input return loss 21.2dB @2.4 GHz

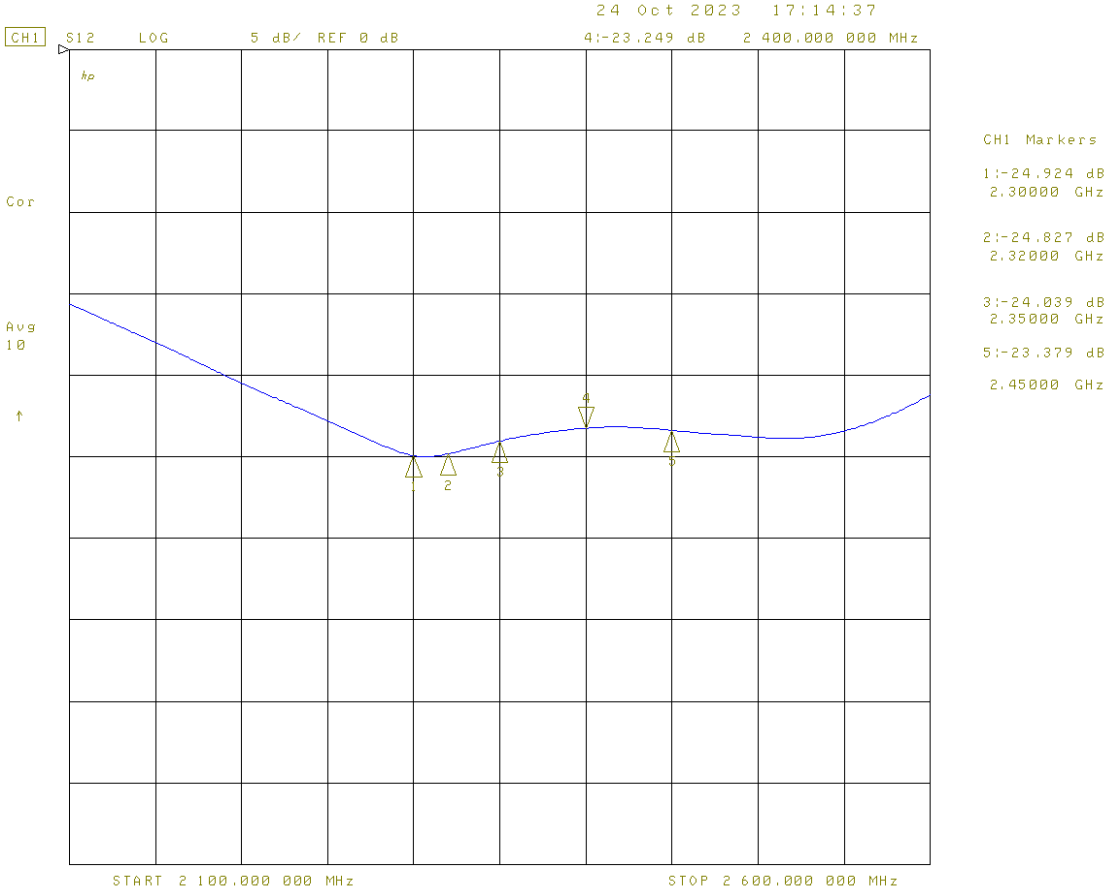




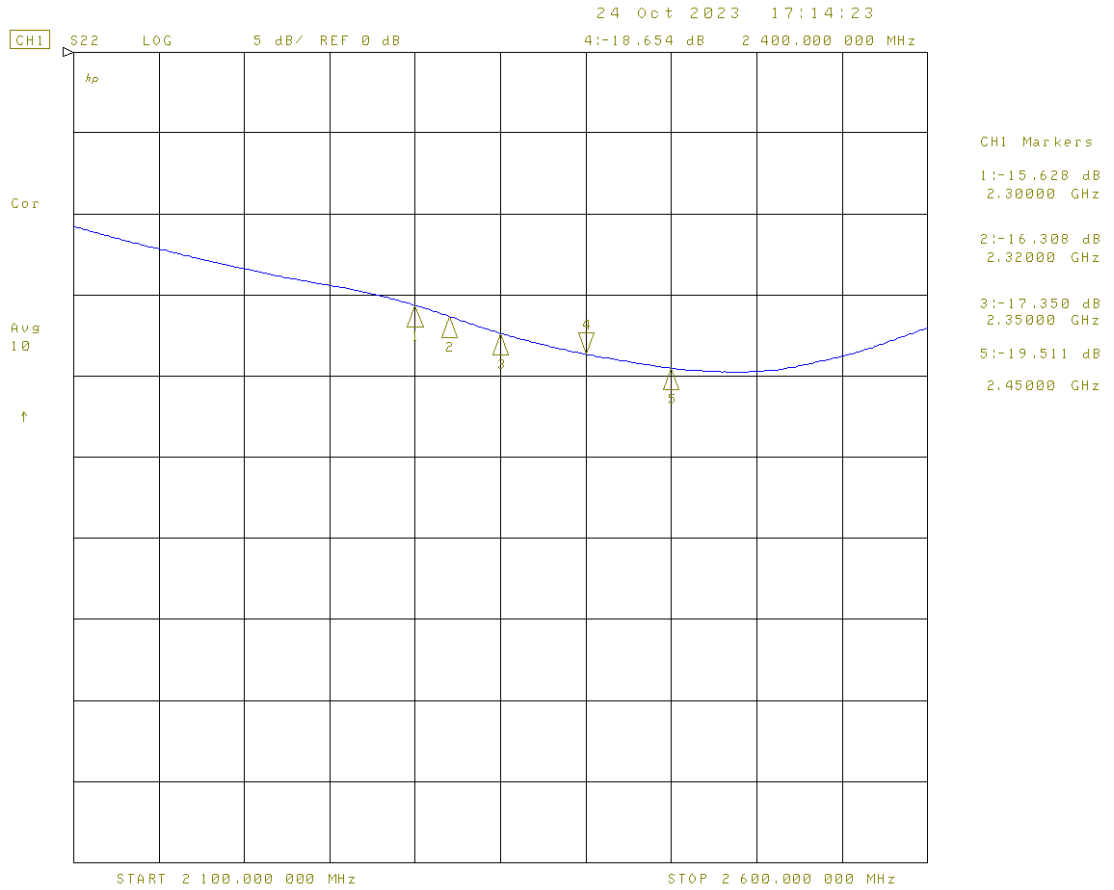
S3 -> S1: S21 insertion loss 0.65dB @2.4 GHz

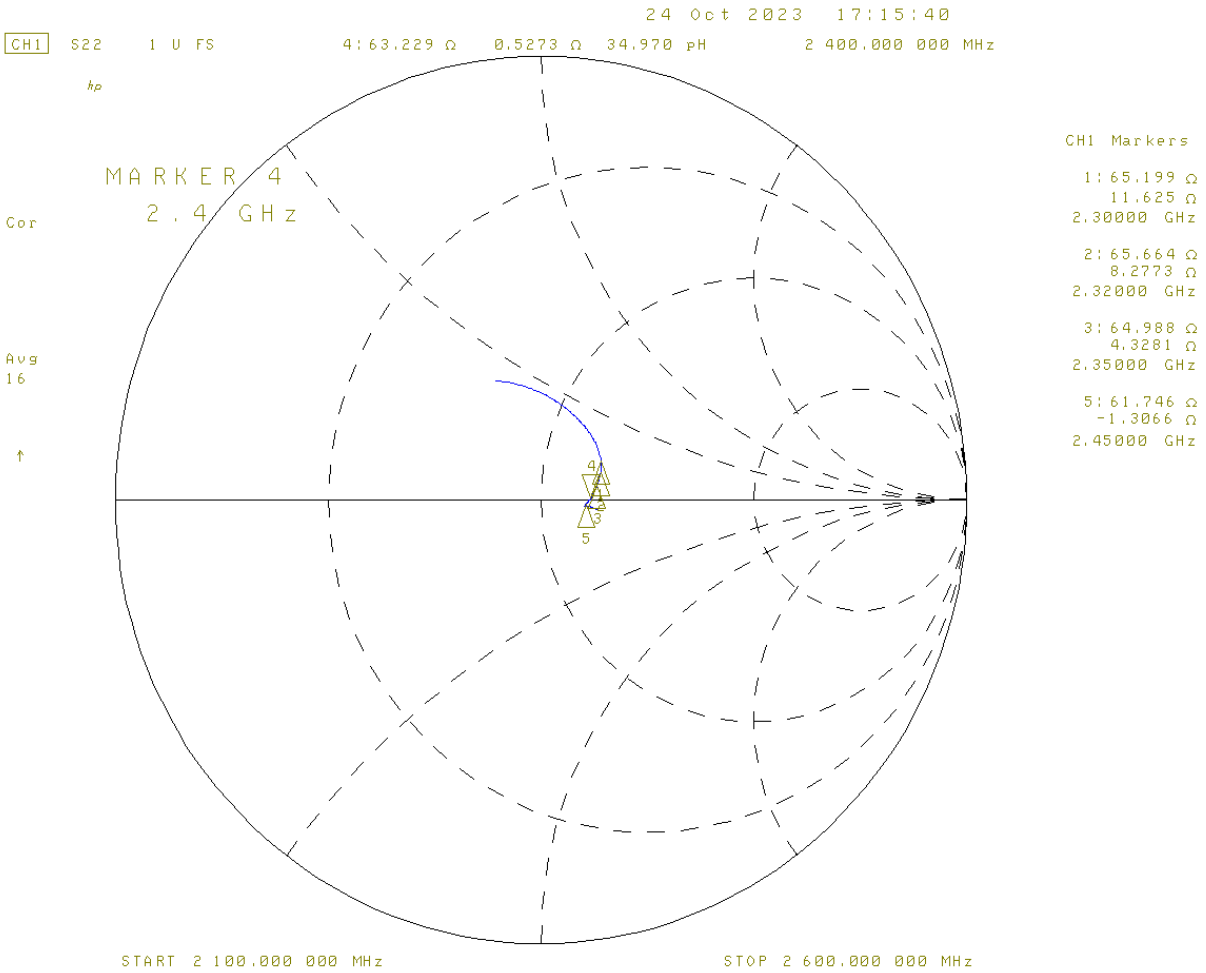


S3 -> S1: S12 isolation 23.2dB @2.4 GHz



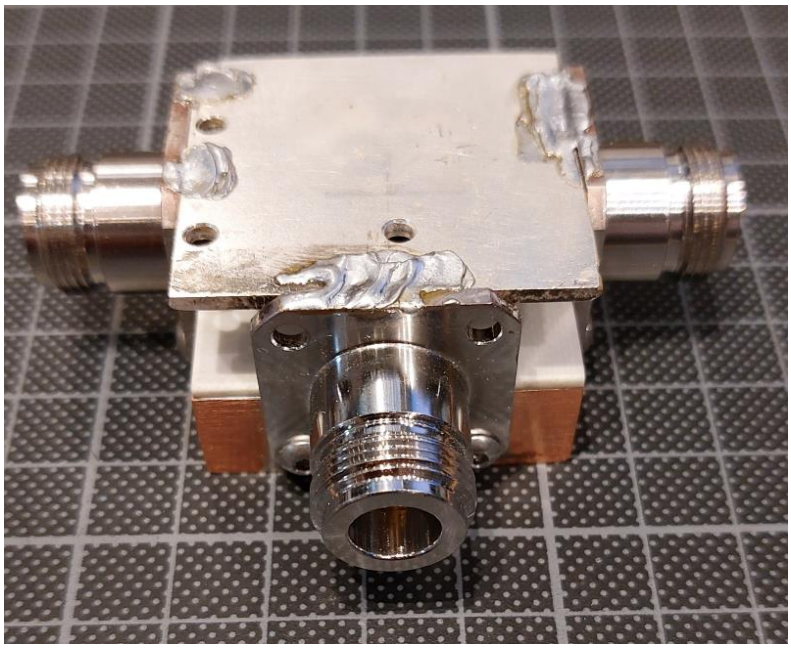
S3 -> S1: S22 output return loss 18.7dB @2.4 GHz



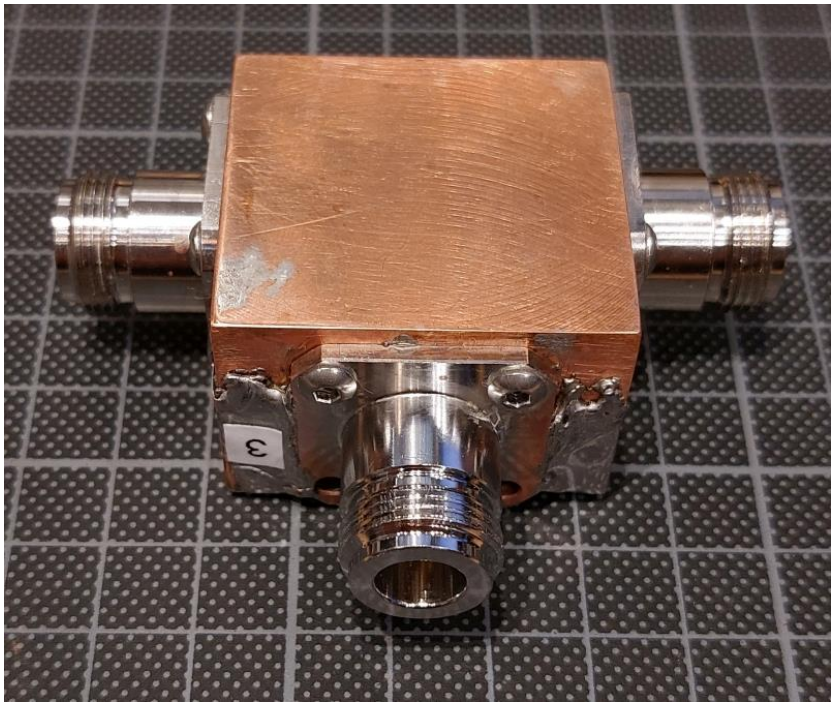


In total I was not happy with the rather high insertion loss of 0.6 to 0.7dB. Some investigations showed that I could improve input return loss and isolation by adding small pieces of copper foil acting as small capacitors at the ports. However, insertion loss was not really improving.

I then found that adding a brass plate on top of the setup showed some effect, possible because of the additional ground connection between the ports.

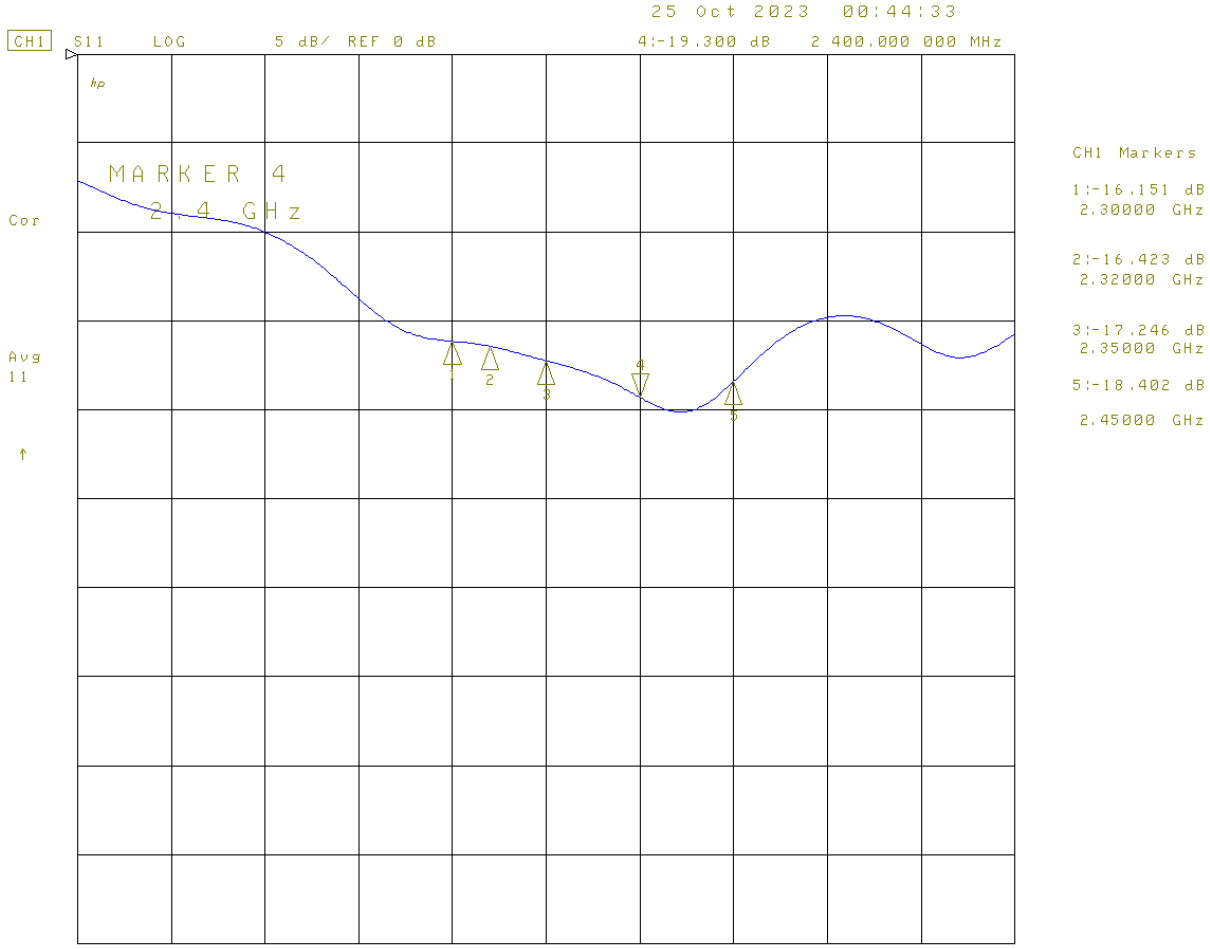


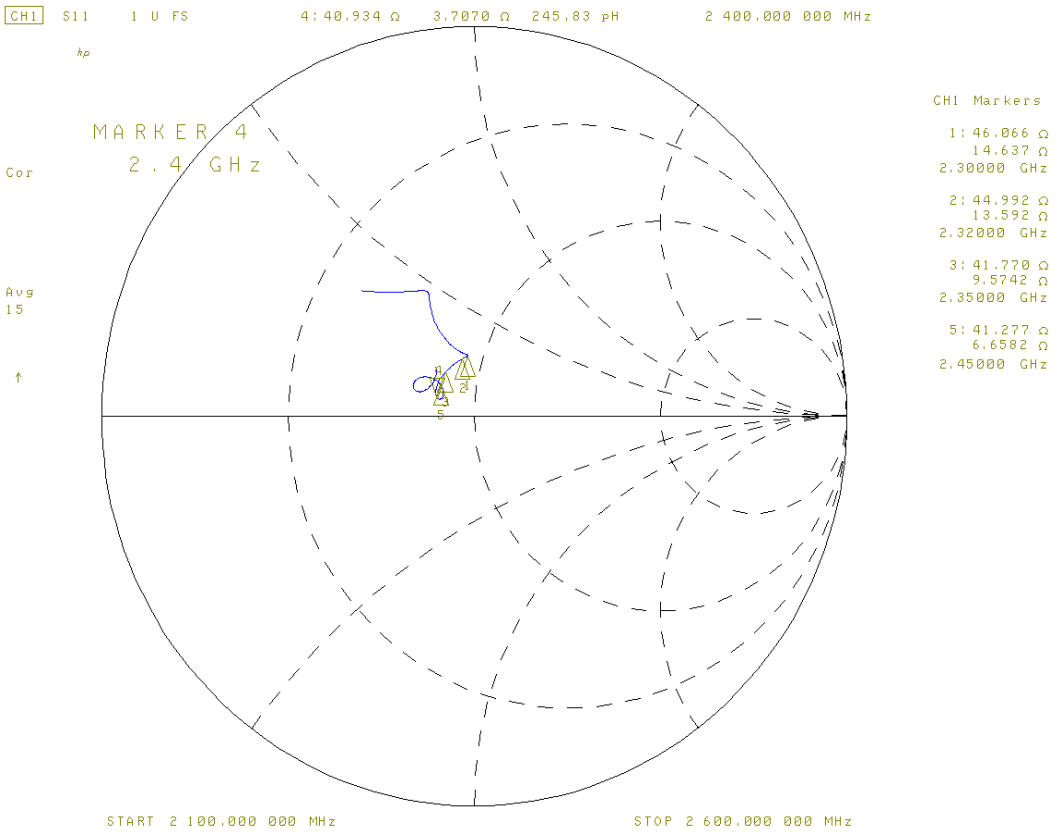
By this brass plate, which is not touching the lid of the circulator device, I could get the insertion loss down to 0.4dB. I focused on a minimum insertion loss at 2.4GHz and compromised other parameters like input return loss and isolation. Thus, I completed the shielding of the setup using copper foil.



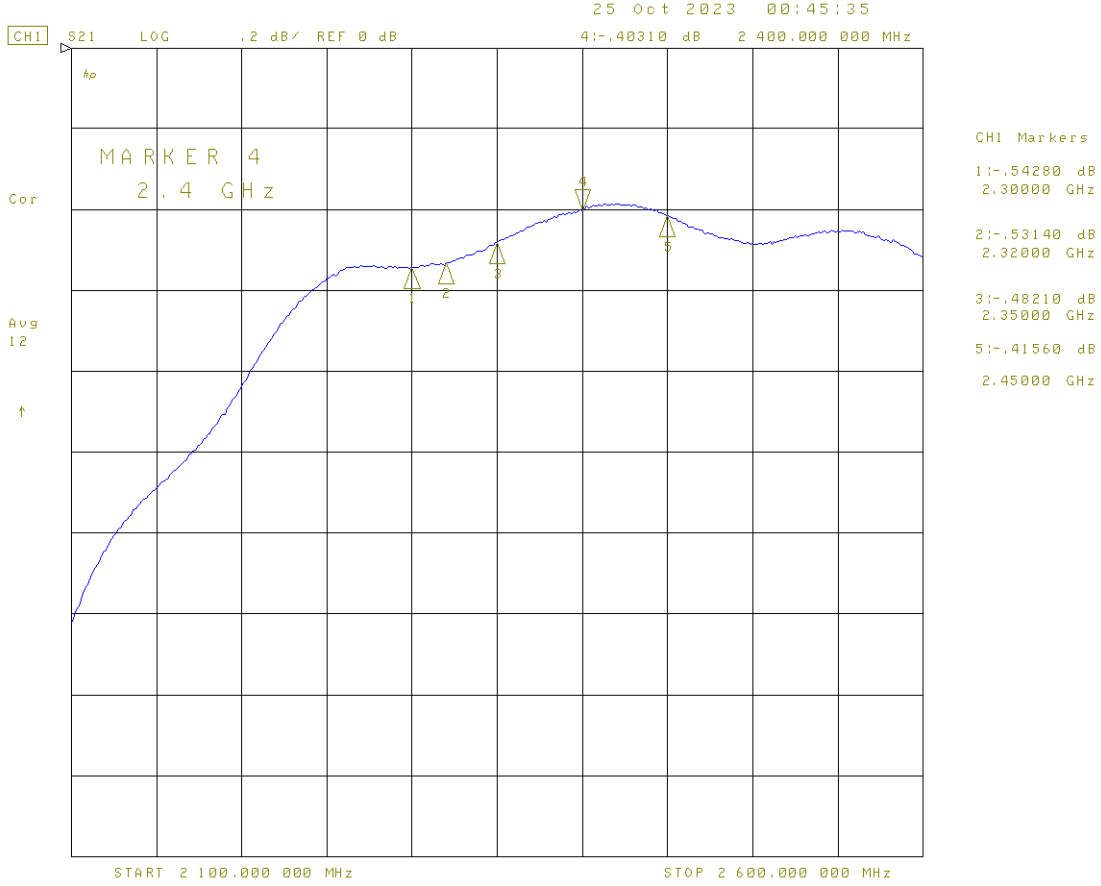
Finally, I repeated the measurements using port 1 as the input and port 2 as the output. The other port combinations gave very similar results.

S1 -> S2: S11 input return loss 19.3dB @2.4 GHz

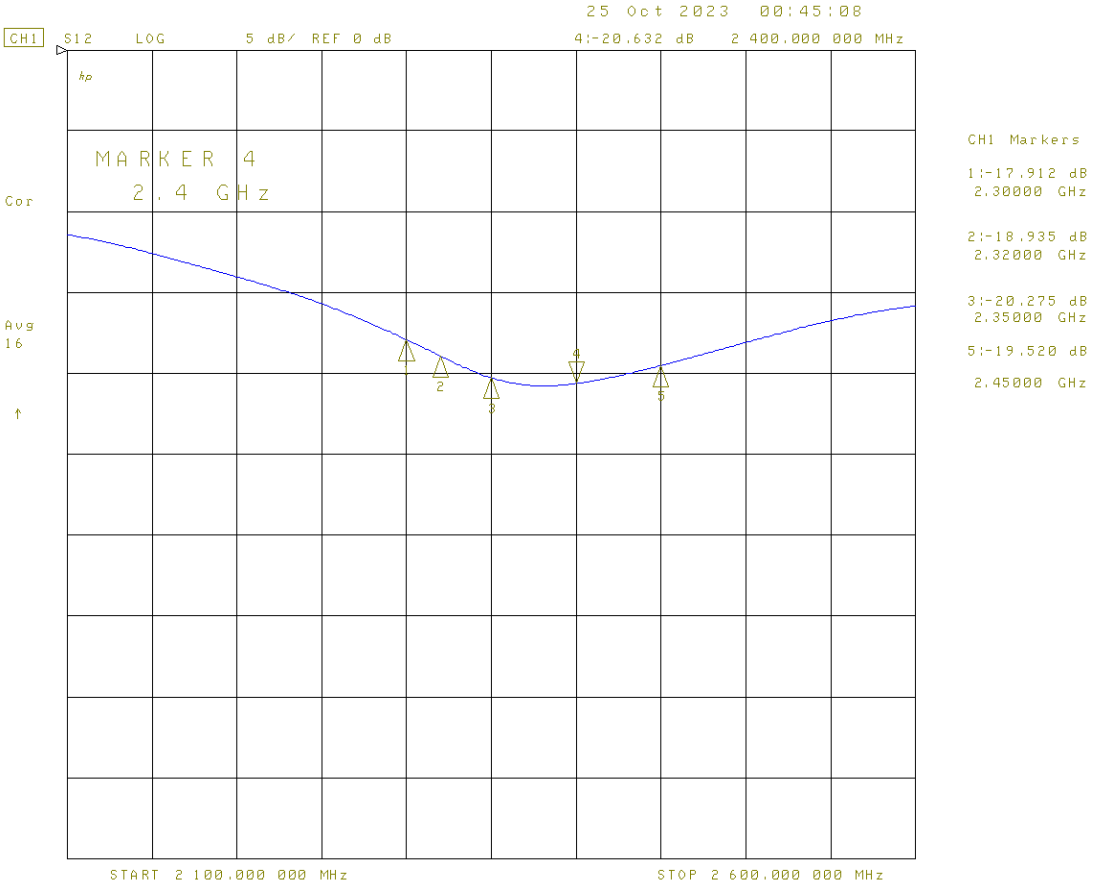




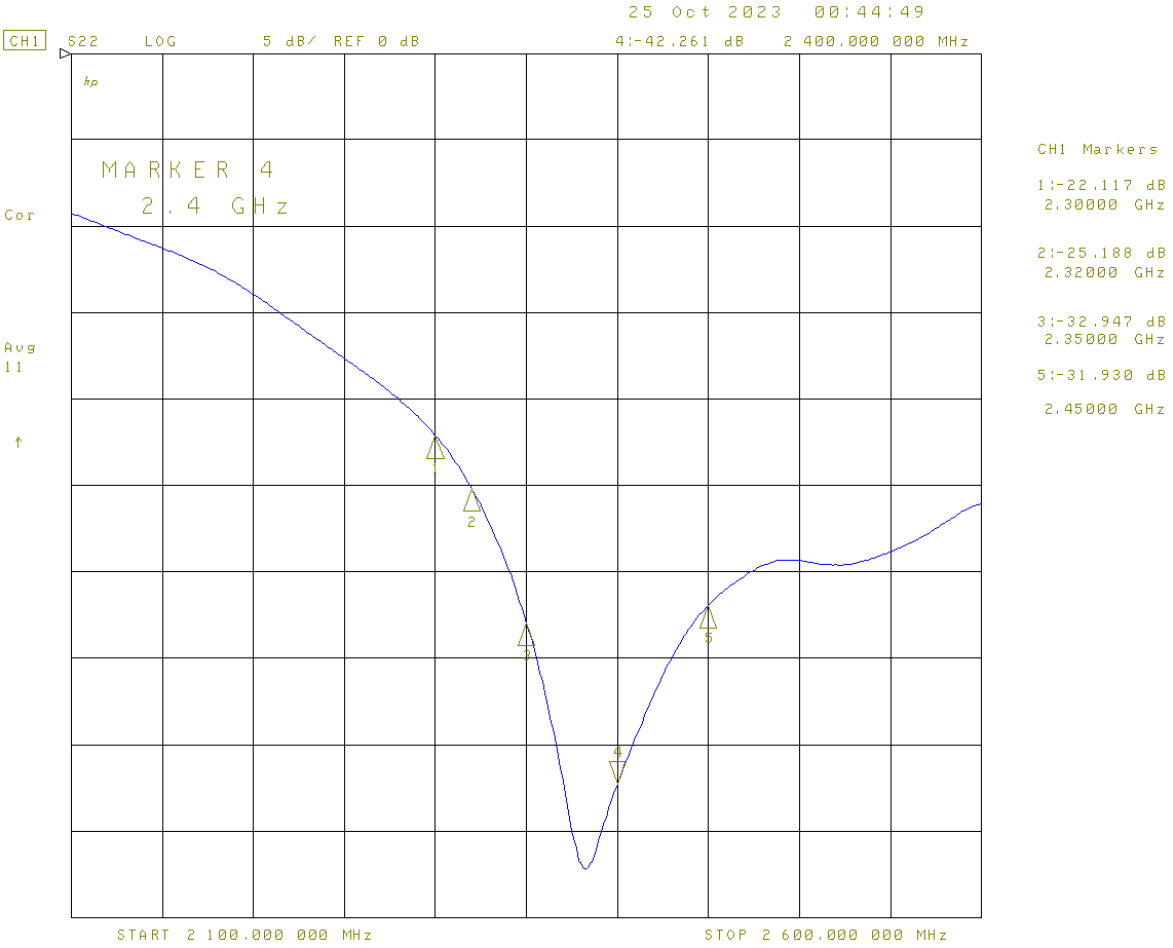
S1 -> S2: S21 insertion loss 0.40dB @2.4 GHz

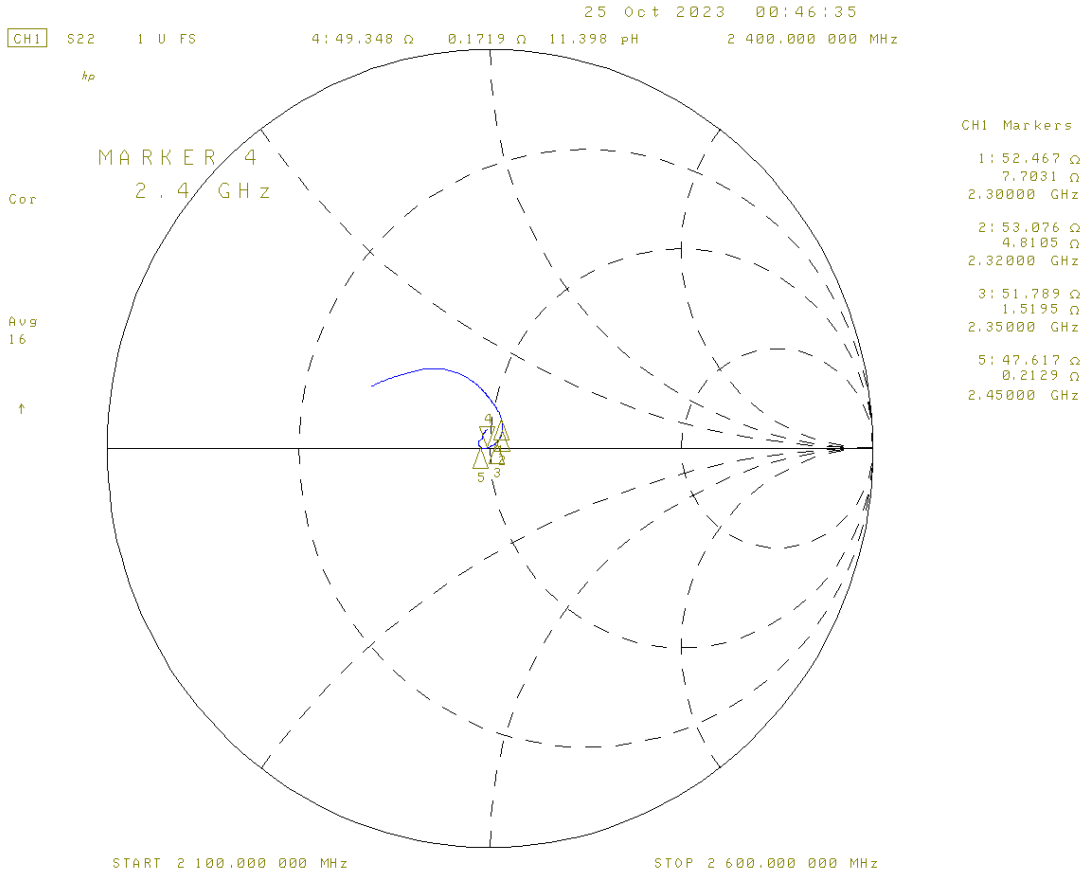


S1 -> S2: S12 isolation 20.6dB @2.4 GHz



S1 -> S2: S22 output return loss 42.3dB @2.4 GHz





Even though I did not achieve the insertion loss of <0.15dB as claimed in the datasheet I am now quite happy with this device. In summary I achieved the following results measuring from port 1 to port 2 with port 3 terminated with 50Ohm:

S11 -19.3dB
S21 -0.4dB
S12 -20.6dB
S22 -42.3dB

I also made some calculations about the dissipated power in the circulator when operated with 200W @2.4GHz:

Operation from port 1 to port 2 with port 3 terminated with 50 Ohm:

Insertion loss S21=-0.4dB	Dissipated power due to insertion loss: 17.6W
Isolation S12=-20.6dB	Dissipated power in port 3: 1.7W
Input return loss S11=-19.3dB	Reflected power at port 1: 2.4W

Thus, the effective dissipated power in the circulator is $P_{dissipated}$=17.6W-1.7W-2.4W=13.5W

As the circulator device is directly soldered to the copper heatspreader, which will be screwed to an adequate heatsink, I assume that the setup should be well suited to operate at the maximum specified power of 200W.

I have not yet tested this but will do so when tuning my next PA for the 13cm band.

I always appreciate feedback. Many thanks in advance.

Best regards

Matthias DD1US

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