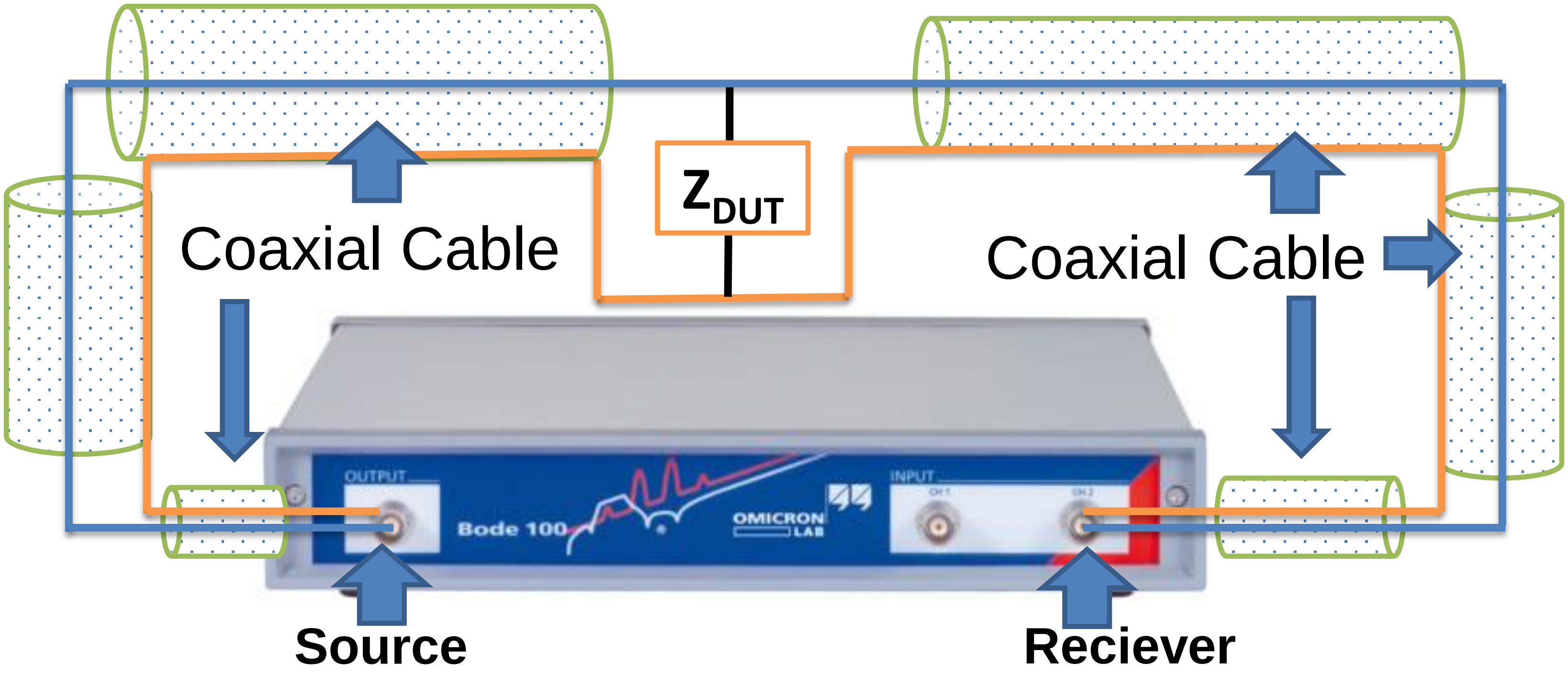
The 2-Port Shunt-Thru Measurement and the Inherent Ground Loop

Authors

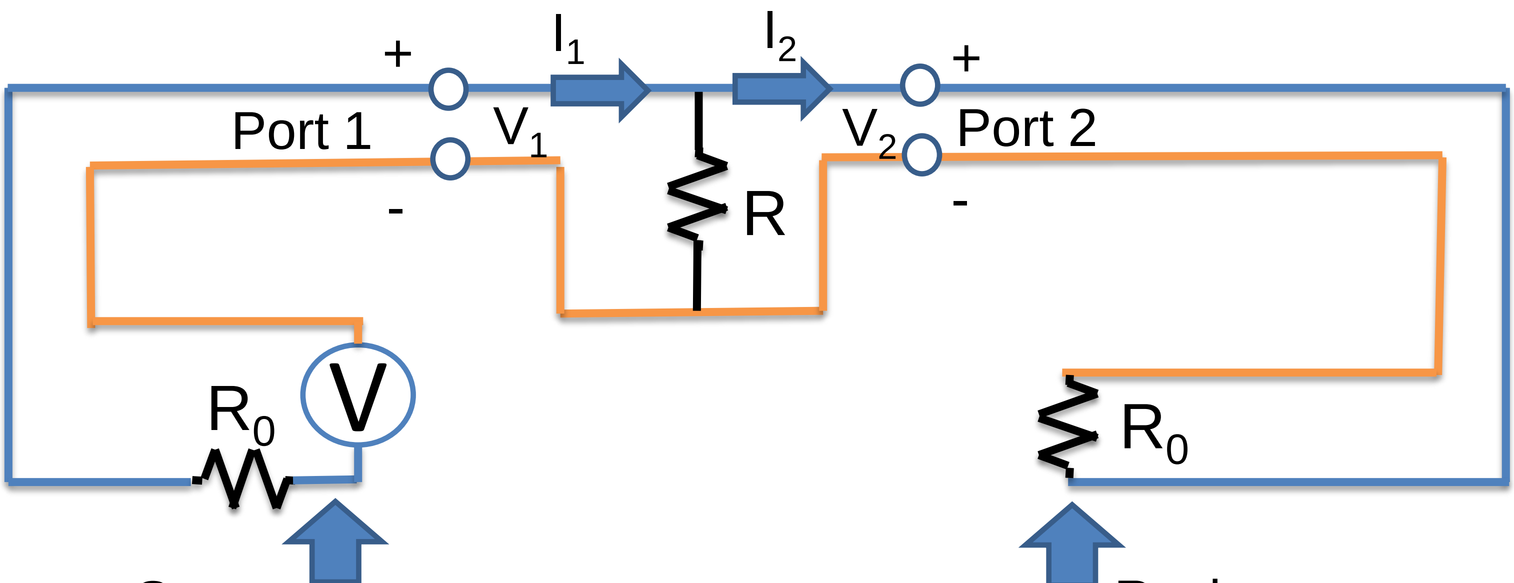
Anto K Davis
Steven M Sandler

2 Port Shunt Through Measurement with VNA



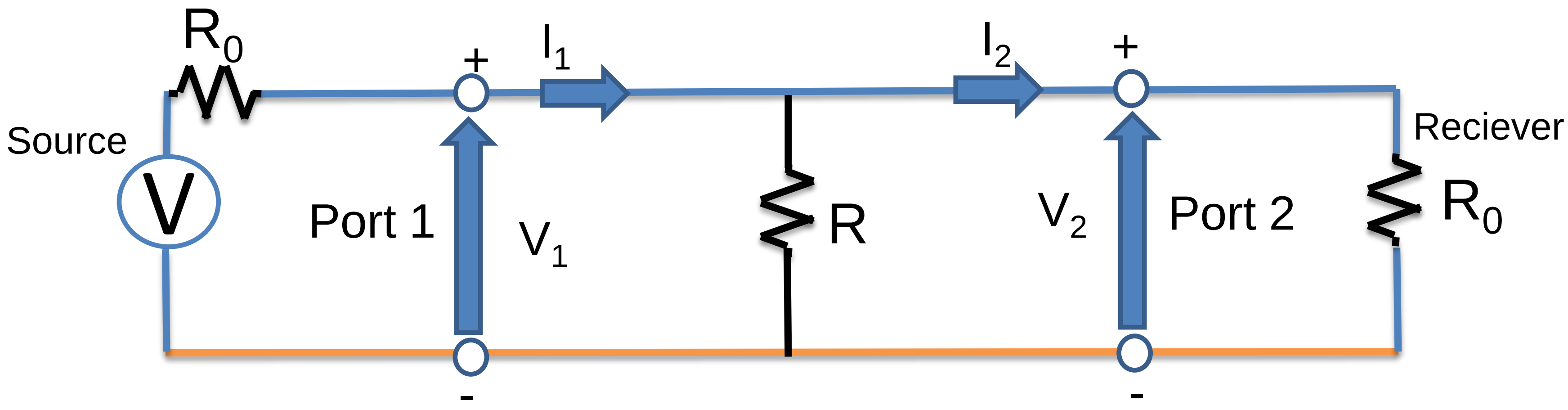
- To measure very small impedances (in the order of mΩ) accurately

2 Port Shunt Through Measurement with VNA – Ideal case



- Sources and receivers are inside the VNA
- VNA measures at very narrow band frequency at a time and sweeps frequency. So the measurement accuracy is very high
- VNA sensitivity is very high

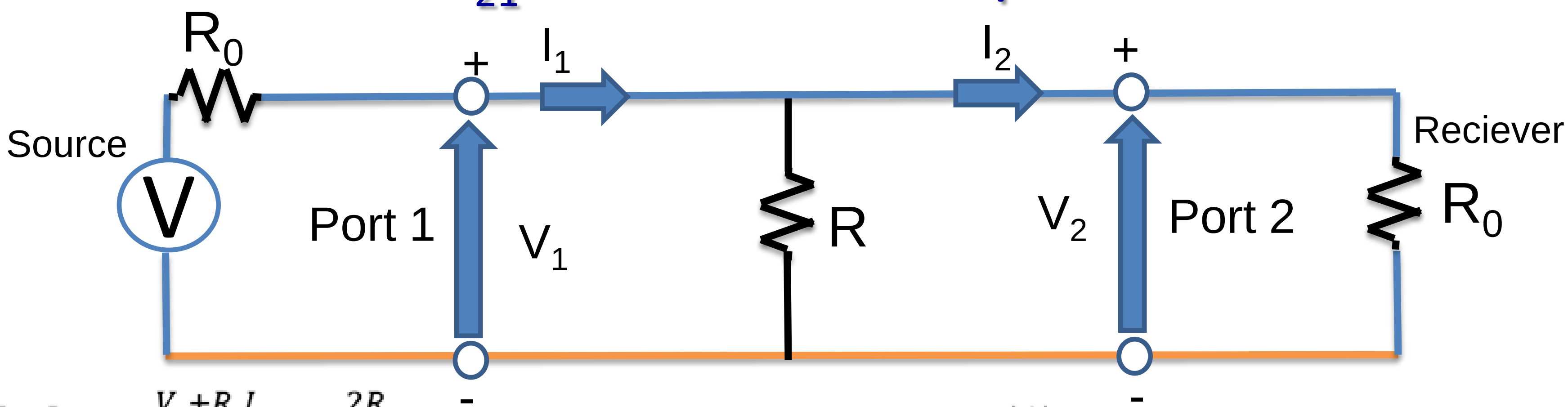
S parameters



- VNAs measure scattering (s) parameters[1]
- S parameters are easy to measure[2]
- To measure R accurately, only S_{21} needs to be measured (Method is shown in the next slides)

[1] K. Kurokawa, *"Power waves and scattering matrix",* IEEE Trans. Microwave Theory and Tech., vol. MTT-13, pp. 194-202, Mar. 1965
[2] [p. 2] Richard W. Anderson, "*S-parameter techniques for Faster, More Accurate Network Design*", HP applicaton note 95-1, February 1967

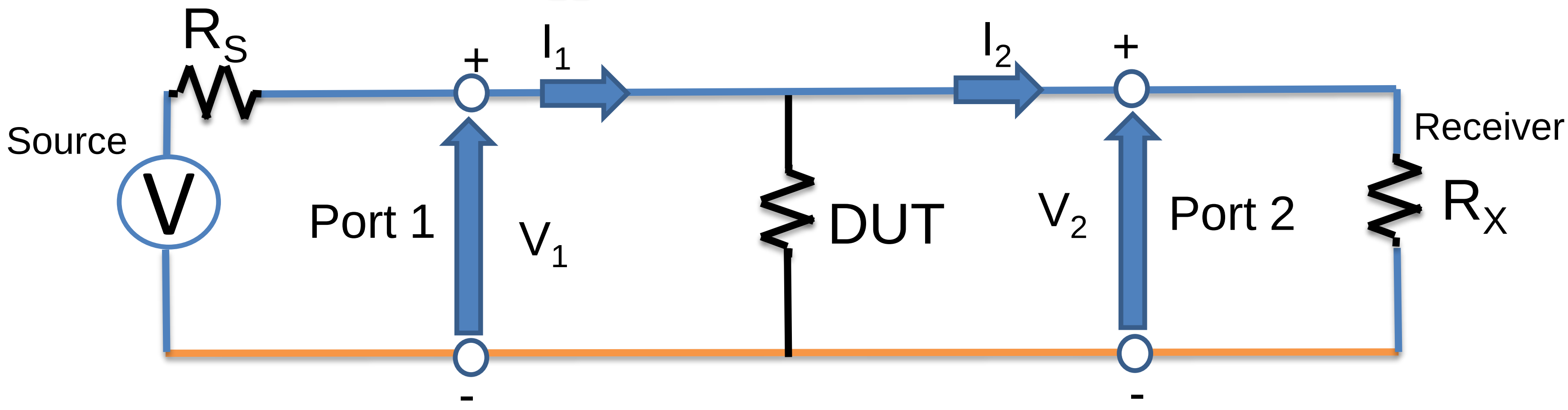
S_{21} - Conventional equation



- $S_{21} = \frac{V_2+R_0I_2}{V_1+R_0I_1} = \frac{2R}{2R+R_0}$ (1)
- $R = \frac{25S_{21}}{1-S_{21}}$ For R_0 = 50 Ω
- R = $25S_{21}$, for R << R_0
- Equation (1) is the commonly used one, but less intuitive impedance (R) measurements

[2] [pp. 2-3] Richard W. Anderson, "*S-parameter techniques for Faster, More Accurate Network Design*", HP applicaton note 95-1

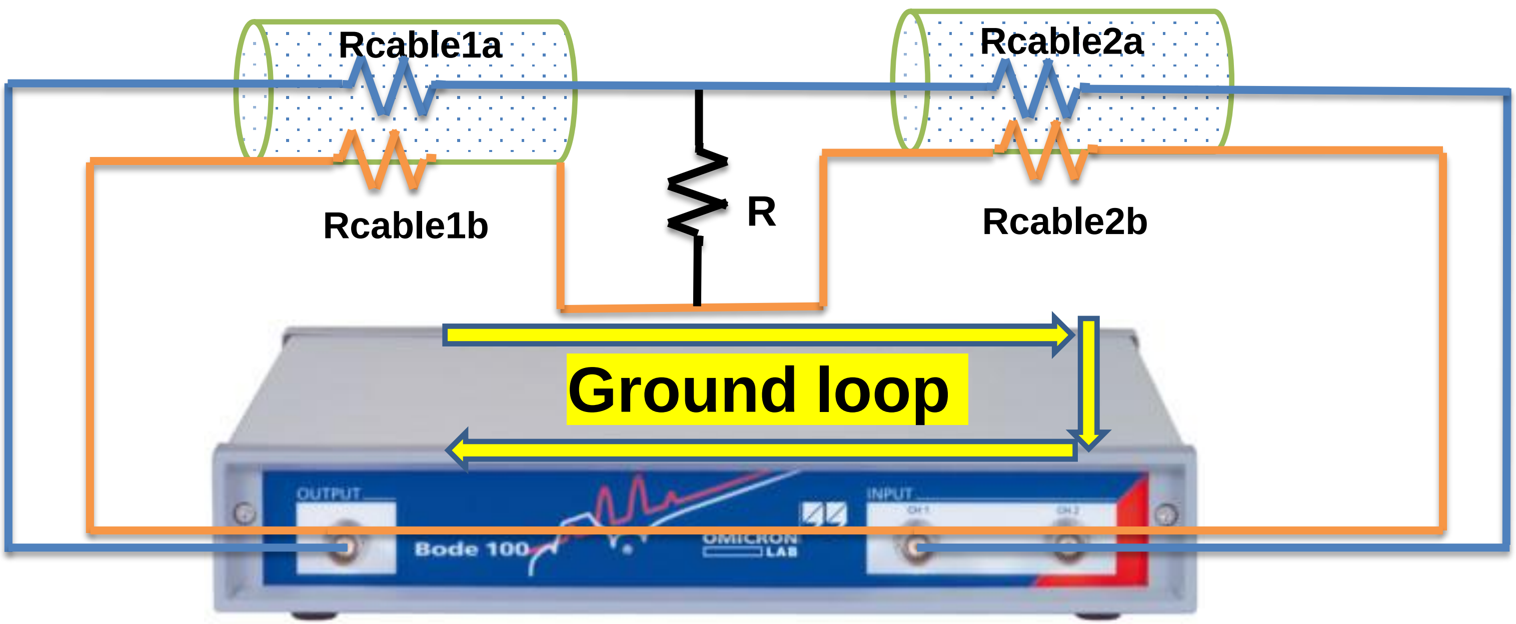
S_{21} - Intuitive Equation



- $S_{21} = \frac{\sqrt{(Power\ absorbed\ by\ RX\ when\ DUT\ is\ present)}}{\sqrt{(Power\ absorbed\ by\ RX\ when\ DUT\ is\ absent)}} = \frac{2R}{2R+R_0}$ (2)
- Equation (2) is intuitive
  - If DUT is value is small, power transferred to R_X is very small → S_{21} is very small → Measured resistance is very small

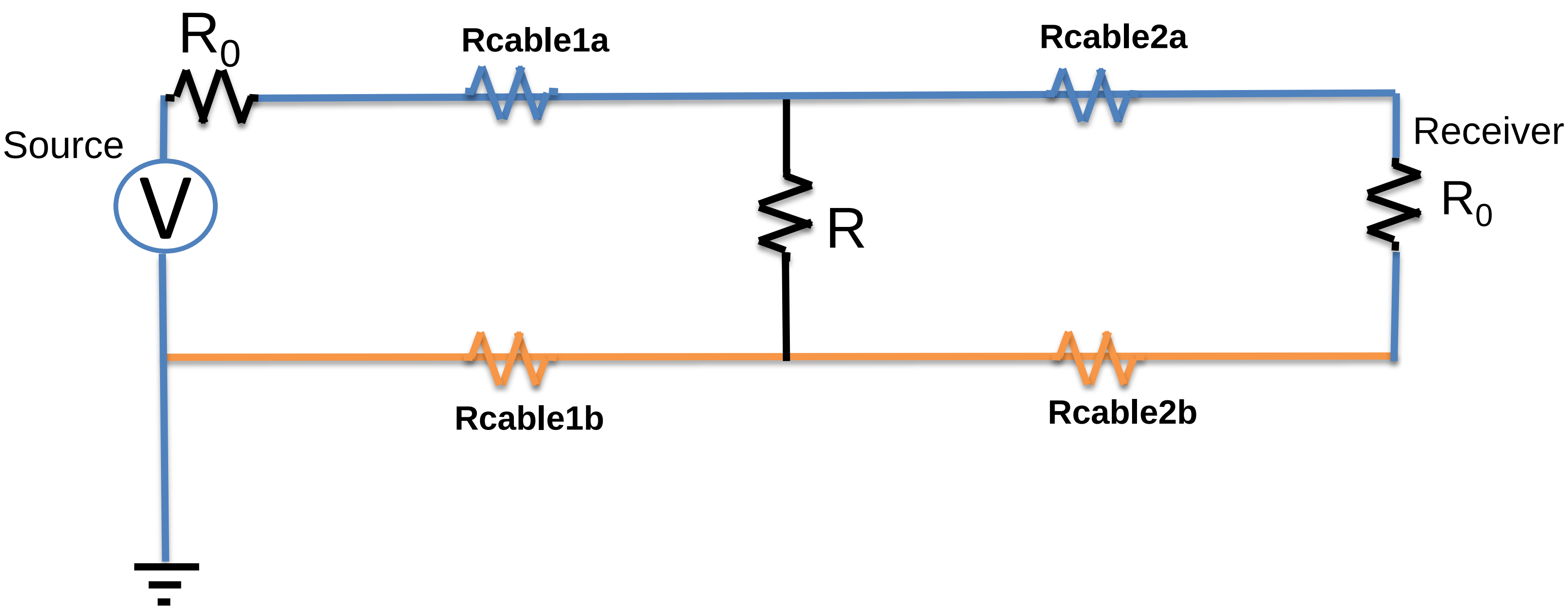
[2] [p. 2] Richard W. Anderson, "*S-parameter techniques for Faster, More Accurate Network Design*", HP applicaton note 95-1
[3] S. M. Sandler, "*Extending the usable range of the 2-port shunt through impedance measurement,* IEEE MTT-S Latin America Microwave Conference (LAMC), Dec. 2016

Non-idealities



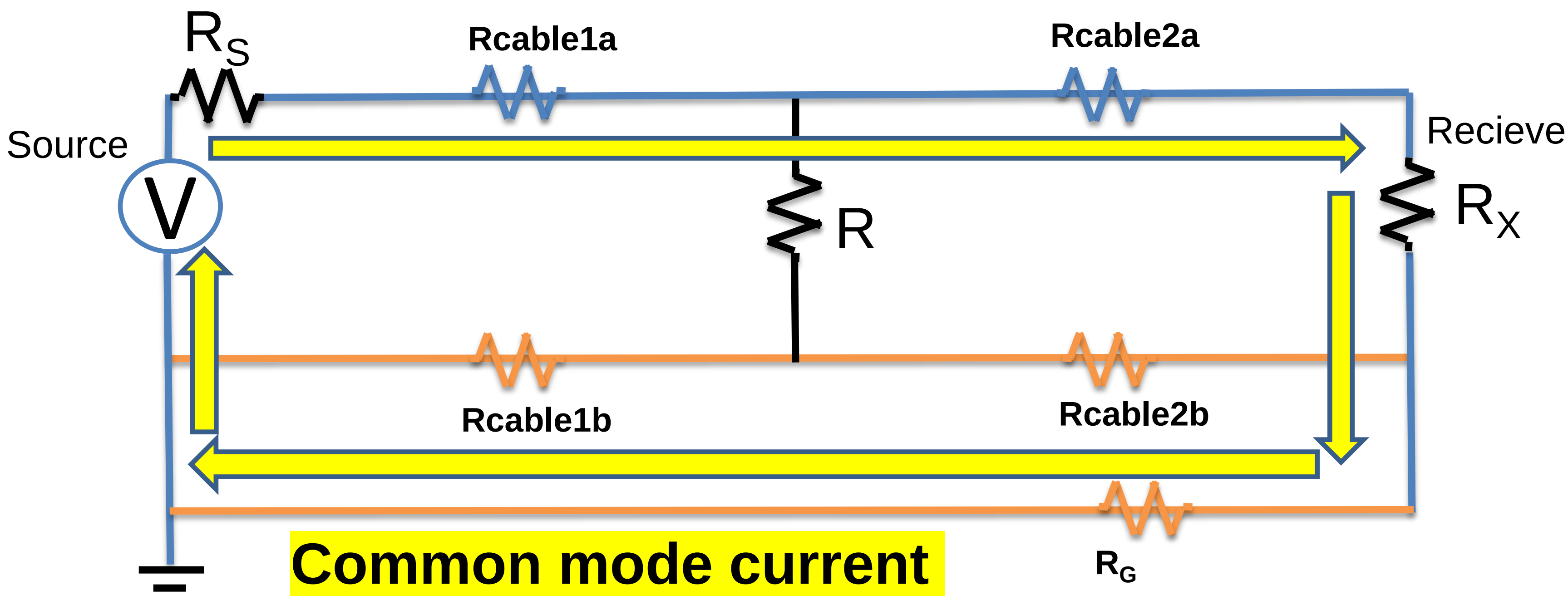
1. Cables have losses
2. Due to safety (NEC) reasons, all grounds are connected together internally – Creates ground loop in all VNAs

Problem



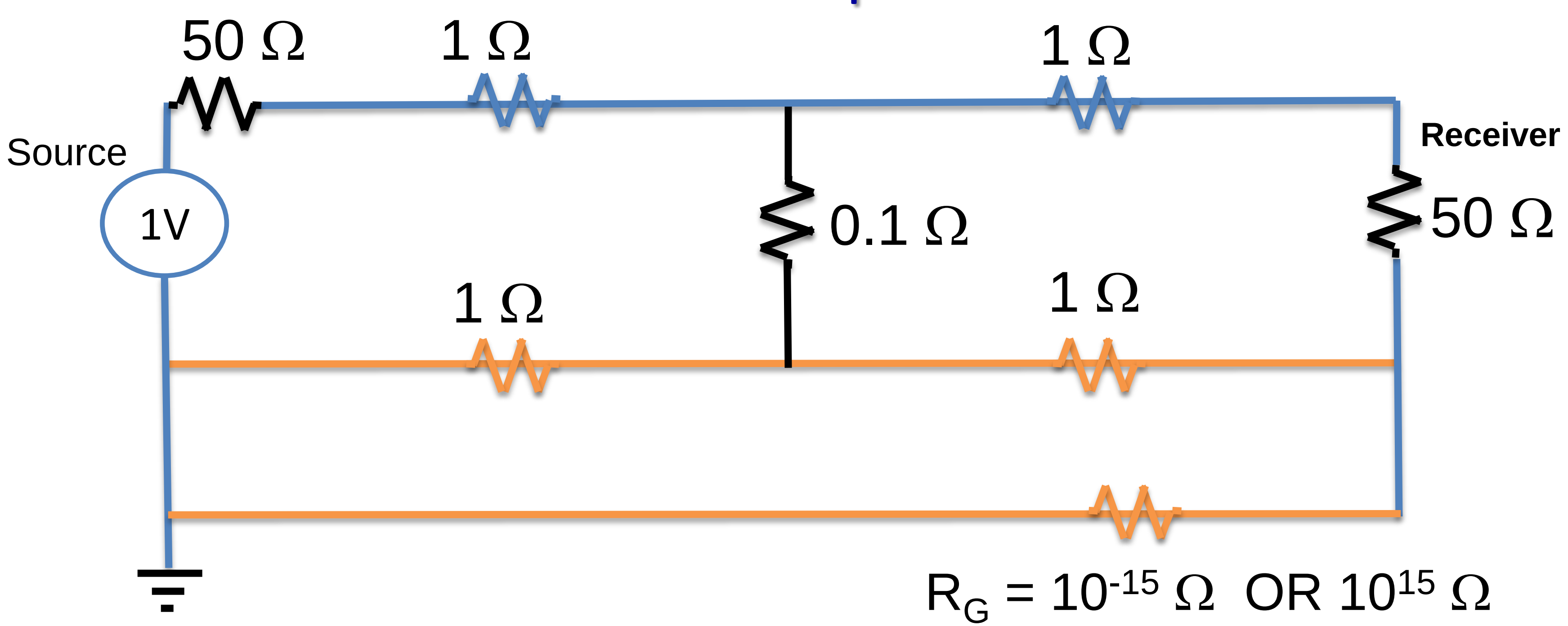
- Even if Rcables > R, the measurements are accurate as long as Rcables << R_0
- Reason – VNA sensitivity is good enough to detect small difference due to R

Problem



- If R_G << Rcable1b and Rcable2b (which is usually the case with any VNA), larger power (current) flows through R_X via R_G as shown as common mode current
- According to Equation (2), this increases the power received in R_X which incorrectly increases measured S_{21} and measured R – This results in measurement errors

Example



$R_G = 10^{-15}\ \Omega$ OR $10^{15}\ \Omega$

- The above can be solved (DC operating points) in SPICE to estimate the values in two cases
  - A) $R_G = 10^{-15}\ \Omega$
  - B) $R_G = 10^{15}\ \Omega$

Example

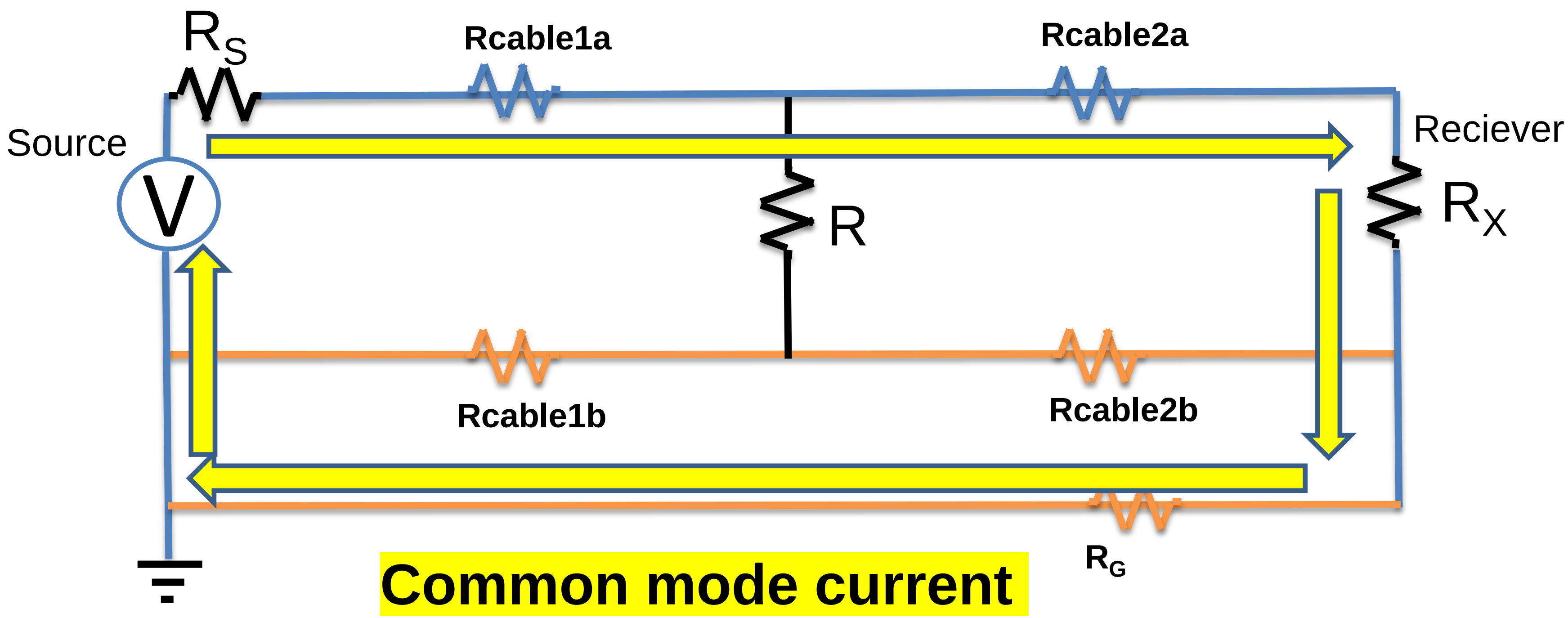
- Using Equation (2),
- *Power absorbed by RX when DUT is absent* = 5 mW (cable losses are neglected and is assumed that no port extension through calibration) = The maximum power that can be transferred from the source

- Therefore S_{21} = ,
  - A)√(2.539751µW/5mW) = 0.022538
  - B) √(67.861312nW/5mW) = 0.0036841

- Numerator values are obtained from SPICE simulations

- The corresponding measured resistance, R = $25S_{21}$
  - A) 0.56344 → Error is 460 % due to ground loop
  - B) 0.092101 → additional error due to the assumptions & approximations
- A similar approach can be followed for AC simulation - cable inductances can also be added to the simulation

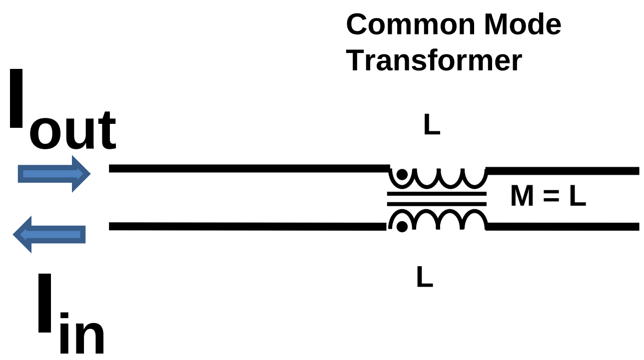
Solution for measurement Error



- ❑ Reduce the common mode current due to the ground loop without affecting safety

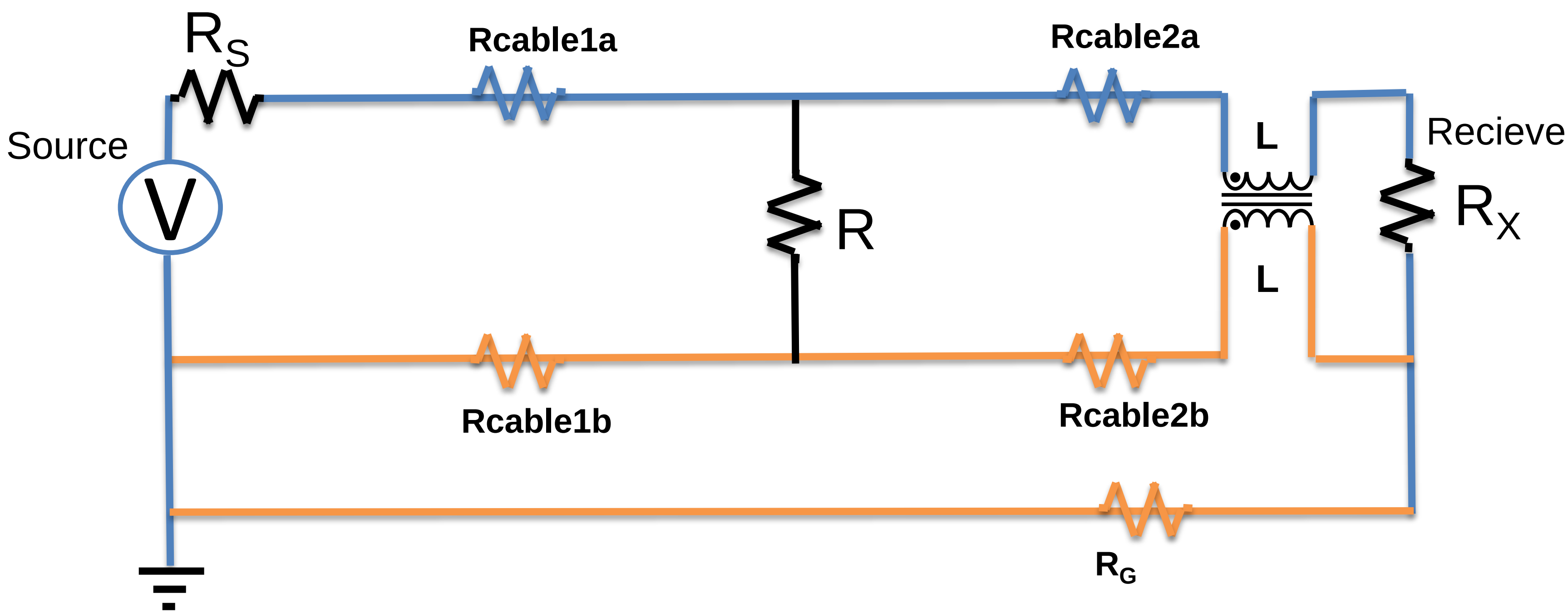
J2102A – Common Mode Transformer

- Common mode transformer shows large inductance (L) to a current if I_{in} not equal to I_{out}
- Zero inductance if $I_{in} = I_{out}$



- In the previous figure, common mode current flows in Rcable2a, but does not return through Rcable2b
- If we place, common transformer to Rcable2a and Rcable2b, ………

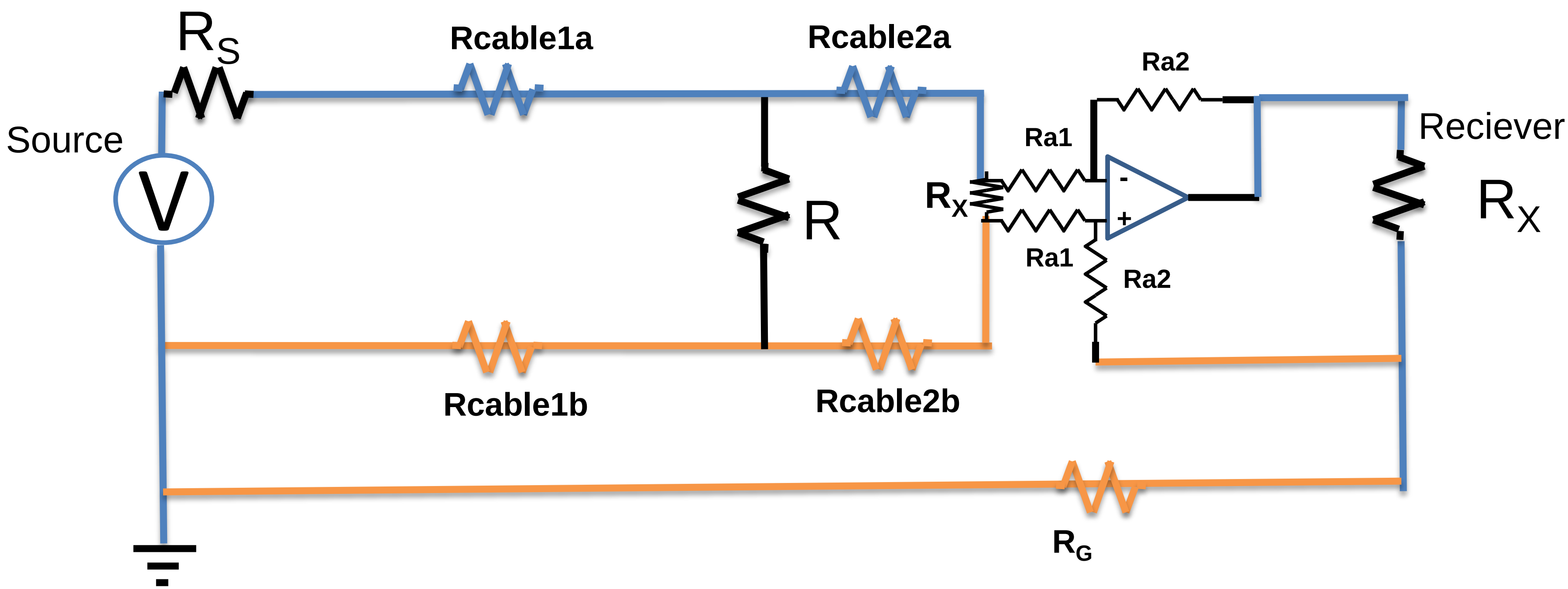
Solution 1



Common mode current faces large inductance L

- Common mode choke (**J2102A**) is not useful at frequencies less than 3 kHz

Solution 2

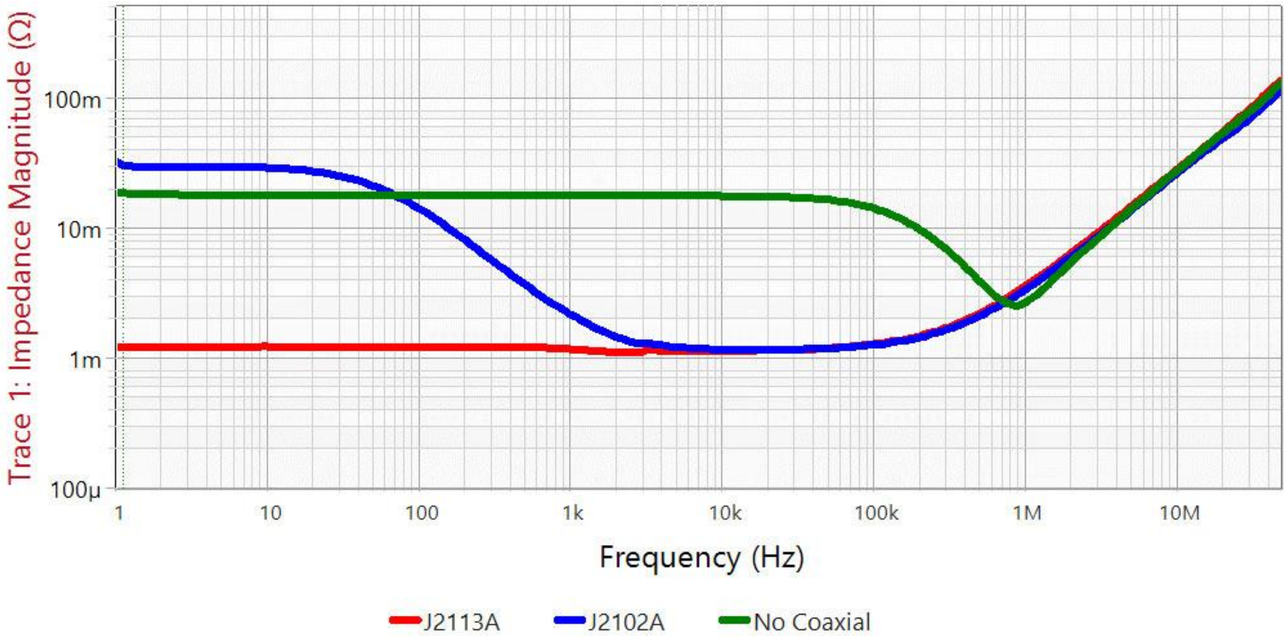


Common mode current faces large resistance $Ra1 + Ra2$

- Semi-Floating Differential Amplifier (**J2113A**) is useful in the frequency range DC – 800 MHz

Measurement Results

- J2102A – Common mode transformer
- J2113A – Semi Floating Differential Amplifier



[3] https://www.picotest.com/products_J2102A.html
[4] https://www.picotest.com/products_J2113A.html

Conclusion

- Ground loop breaker is necessary accurate measurement of ultra low PDN impedances (milli ohm and lower)
- Professional measurements need good ground breakers, like J2102A & J2113A which provide good frequency characteristics with uniform 50 ohm impedances
- Handmade/home made solutions affect the measurement fidelity due to
  - Low quality core
  - Uneven winding

Thank you