Errors in the Ripple Technique due to Pin Gap

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The ripple technique [1] is a rather old technique for verifying the measurement errors of a VNA. It consists of measuring a load with an ideal transmission line and a short with an ideal transmission line. The resulting measurement data has some ripples on it and these ripples are attributed to imperfect calibration. This technique is correct as long as the used transmission line is ideal. If the transmission line is is not ideal, these imperfections have to be taken into account. The imperfections have more severe effects for higher frequencies. For this reason only the connector types N-Type and 3.5 mm are considered here.

All air lines have a non-zero pin gap. The pin gap pa of an air line, see Fig. 1 represents an imperfection of an air line which has to be taken into account. Ideally the air line and the standard are connected as depicted in Fig. 2. Without the use of Kapton discs, the mounting process of the air line yields a configuration as depicted in Fig. 3.

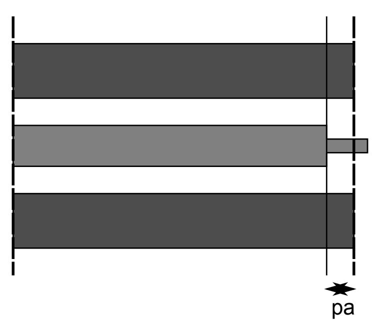

Figure 1: Air line with pin gap pa.

The recession of the center conductor in the test-port is called pt, the recession of the air line is called pa, the diameter of the inner conductor is called di, the diameter of the pin is called dp and the diameter of the outer conductor is called do. In order to estimate the reflection caused by pushing the center conductor into the test port two phenomena will be considered. The first phenomenon is that a section of plain line is replaced by a section of line with reduced diameter of the inner conductor. Looking at the difference in inductance

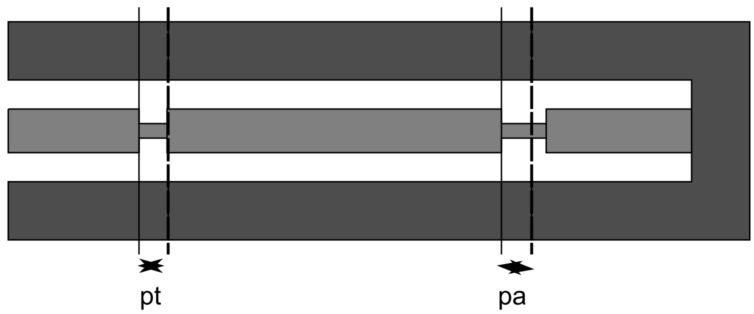

Figure 2: Ideal setup which can be achieved by using Kapton discs and specially shimmed test-ports to ensure the distance pt.

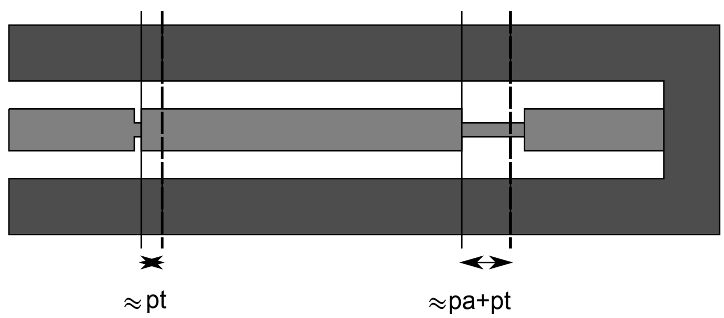

Figure 3: Result of mounting the air line without Kapton disk. The center conductor protrudes into the test-port.

per length, see [2] of the two situations yields

$$\Delta L' = \frac{\mu}{2\pi} ln \frac{do}{dp} - \frac{\mu}{2\pi} ln \frac{do}{di}. \tag{1}$$

Simplification shows that the inductance depends not on do but the permeability μ of the dielectric stays in the equation

$$\Delta L' = \frac{\mu}{2\pi} ln \frac{di}{dp}. \tag{2}$$

Given the small size of the pin gap (small with respect to wavelength) one can neglect its effect on the electric field and sum up the effect in a lumped element. Here a worst case value is investigated and thus the pin gap $pg = pt + pa$ is set. This is the length of the longest gap.

$$L = pg \frac{\mu}{2\pi} ln \frac{di}{dp}. \tag{3}$$

Additionally a minimum inductance due to the N-Type or 3.5 mm connector has to be accounted for. The minimum inductance of an N-Type connector is

$L_{min} = 1.16\,\text{pH}$. The minimum inductance of a 3.5 mm connector is $L_{min} = 1.05\,\text{pH}$. Combining the respective minimum inductance and the inductance caused by pg yields

$$Z = j\omega(L + L_{min}). \quad (4)$$

with $\omega = 2\pi f$, f denoting the frequency. This causes a reflection of

$$\Gamma = \frac{Z}{Z + 2Z_{ref}}. \quad (5)$$

Note that Z_{ref} is the reference impedance of the calibration. In most cases this is $50\,\Omega$. By shifting the center conductor into the test-port the pin gap in the test port is diminished and on the other side of the air line the pin gap is enlarged. These pin gaps may interfere constructively. The positive gap on the DUT side and the negative gap on the test-port side do not have the same size. In order to allow for errors in pin depth measurements, the lower error bound in the ripple method is approximated as $2|\Gamma|$.

The magnitude of Γ can be very well approximated with a simplified expression

$$|\Gamma| = \left(7.29 \cdot 10^{-14} + 7.67 \cdot 10^{-9} pg\right) f \quad (6)$$

for Type-N and

$$|\Gamma| = \left(6.60 \cdot 10^{-14} + 6.21 \cdot 10^{-9} pg\right) f \quad (7)$$

for 3.5 mm. It is assumed that $Z_{ref} = 50\Omega$.

The second effect which has to be taken care of is that there is as well capacitive coupling between the top ends of the inner conductors of the air line and the test-port, see [3]. This capacitive coupling is difficult to estimate because by pushing the center conductor into the test port a non specified but small pin gap is created. One might be tempted to think that this gap should be zero but this is not correct. The elasticity of the contact fingers prevents a connection with zero pin gap. Due to the difficult to measure gap it is best to reconnect under different connector orientations at least three times each measurement which involves an air line. The spread of the three results should be included in the minimum error

$$MinError = 2|\Gamma| + |S11_{min} - S11_{max}|. \quad (8)$$

References

[1] E. C. 2, "Guidelines on the evaluation of vector analysers (vna)," July 2007.

[2] J. A. Stratton, *Electromagnetic Theory*. Hoboken, USA: John Wiley & Sons, Inc., 2007, ch. IX. Coaxial Lines, pp. 549–551.

[3] J. Hoffmann, P. Leuchtmann, and R. Vahldieck, "Pin gap investigations for the 1.85 mm coaxial connector," in *European Microwave Conference*, Munich, Oct. 2007, pp. 388–391.