Six-point calibration method of VNA-O-Mizer by Daniel Marks KW4TI

The raw data output of the VNA is captured using the IMACQ command. The IMACQ command has three parameters:

```
IMACQ <# frequencies> <start frequency> <end frequency>
```

which captures the raw data for <# frequencies> from <start frequency> to <end frequency>. The result is in the following format, which is the raw data captured using quadrature demodulated samples:

```
<frequency>,<channel 1 in phase voltage>,<channel 1 quadrature
voltage>, <channel 1 in phase current>,<channel 1 quadrature
current>, <channel 2 in phase current>,<channel 2 quadrature current>
```

Three complex numbers are formed from this data (which are not actual voltage and current, but will be used to calibrate it):

$$V_1 = (\text{channel 1 in-phase voltage}) + j(\text{channel 1 quadrature voltage})$$
$$I_1 = (\text{channel 1 in-phase current}) + j(\text{channel 1 quadrature current})$$
$$I_2 = (\text{channel 2 in-phase current}) + j(\text{channel 2 quadrature current})$$

The number of averages which influences the dynamic range is set by

```
AVERAGES <# averages> <timeout in ms>
```

where the default number of averages is 64 for a 40 to 45 dB dynamic range, which increases to about 50 to 55 dB for 1000 averages which slows down the acquisition.

The calibration method is as follows:

For the one-port cal, capture the raw data for an open, short, and load (usually 50 ohms) fort channel 1. These will form six complex numbers $V_1^{(open)}$, $I_1^{(open)}$,$V_1^{(short)}$, $I_1^{(short)}$,$V_1^{(load)}$, $I_1^{(load)}$.

Divide these to form three trial impedances using complex division:

$$Z_1^{(open)} = \frac{V_1^{(open)}}{I_1^{(open)}},\ Z_1^{(short)} = \frac{V_1^{(short)}}{I_1^{(short)}},\ Z_1^{(load)} = \frac{V_1^{(load)}}{I_1^{(load)}}$$

When you actually measure an impedance at channel 1, you will measure a complex-valued voltage and current which is $V_1^{(dut)}$ and $I_1^{(dut)}$. These are divided to form $Z_1^{(dut)} = V_1^{(dut)}/I_1^{(dut)}$. The actual impedance is then calibrated from the following bilinear transformation

$$Z_1^{(estimated)} = \frac{Z_1^{(dut)} + B}{CZ_1^{(dut)} + D}$$

where *B*, *C*, *D*, are the three complex-valued calibration parameters for port 1. These parameters are captured for each frequency. These are calculated using:

$B = -Z_1^{(short)}$

$C = \frac{1}{Z_0} \frac{Z_1^{(short)} - Z_1^{(load)}}{Z_1^{(open)} - Z_1^{(load)}}$ where Z_0 is the characteristic impedance (usually 50 ohms)

$$D = -\frac{Z_1^{(open)}}{Z_0} \frac{Z_1^{(short)} - Z_1^{(load)}}{Z_1^{(open)} - Z_1^{(load)}} = -Z_1^{(open)} C$$

For port two calibration, first the isolation between port 1 and port 2 is found. The raw complex-valued current at port 2 is I_2. I measure the current at port 2 during the port 1 short-circuit measurement step:

$$S_2 = \frac{I_2}{\# \text{ averages}}$$

The total amount of signal leaking from port 1 to 2 scales with the number of averages, so the calibration is stored normalized by the number of averages.

To calibrate the impedance and gain at port 2, port 1 is connected to port 2. The raw current at port 2 is I_2. The calibrated voltage and current at port 2 from port 1 are calculated from the raw samples V_1 and I_1 when they are connected together by

$$V_1^{(calib)} = V_1 + BI_1$$
$$I_1^{(calib)} = CV_1 + DI_1$$

and the following two parameters are captured:

$$Z_2 = \frac{V_1^{(calib)}}{I_2 - S_2 < \# \text{ averages} >}$$

$$G_2 = \frac{I_1^{(calib)}}{I_2 - S_2 < \# \text{ averages} >}$$

To calculate the complex-valued S_{11}, use

$$S_{11} = \frac{Z_1^{(estimated)} - Z_0}{Z_1^{(estimated)} + Z_0}$$

from which SWR, dB, and degrees may be determined.

To calculate S_{21}

$$S_{21} = (I_2 - S_2 < \# \text{ averages} >) \frac{Z_2 + Z_0 G_2}{V_1^{(calib)} + Z_0 I_1^{(calib)}}$$

To calculate the thru impedance in series impedance mode

$$Z_{series} = \frac{V_1^{(calib)} - Z_2\left(I_2 - S_2 < \# \text{ averages} >\right)}{G_2\left(I_2 - S_2 < \# \text{ averages} >\right)}$$

and the thru impedance in shunt mode

$$Z_{shunt} = \frac{Z_2\left(I_2 - S_2 < \# \text{ averages} >\right)}{I_1^{(calib)} - G_2\left(I_2 - S_2 < \# \text{ averages} >\right)}$$