IC Calibration

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0.1 Setup

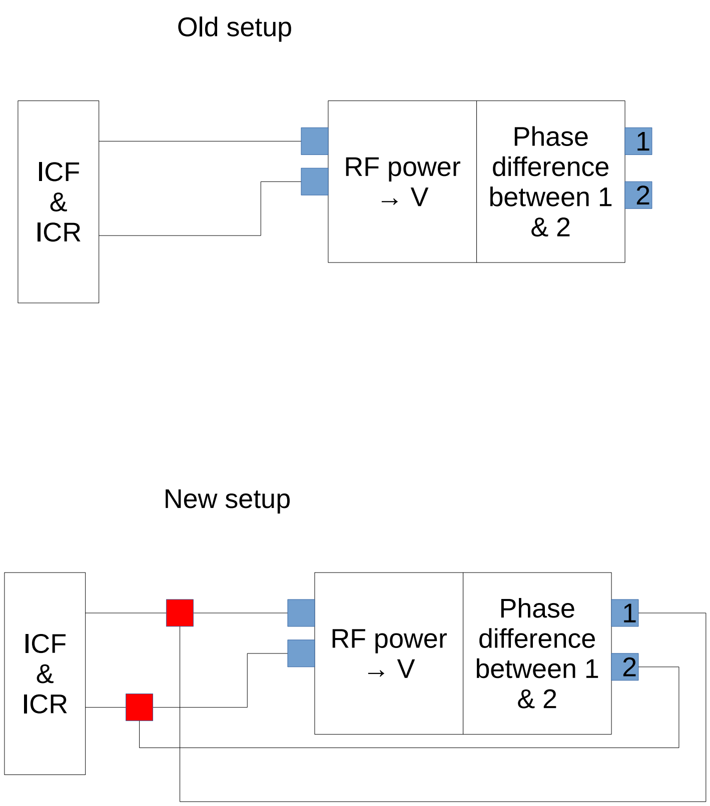
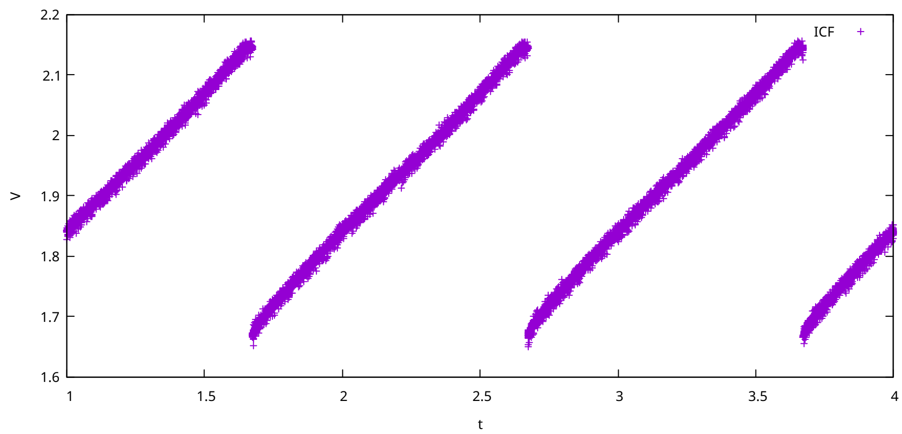


Figure 1: The new setup splits the signals of the forward and reflected in two, using one side to measure power and the other side to measure the phase

0.2 Procedure



The connectors normally connecting to the directional coupler where connected to the VNA, after which power ramps for different frequencies were performed, for the above shown picture this was a ramp from -20dbm to -2dbm which covers the range of 100W to 6310W as the directional coupler induces an attenuation of -70db (this was measured, all S-parameters and original calibration files are available on the TOMAS github).

I then proceeded to fit a straight line to one of the ramps, this results in a relation between time and voltage

$$V = at + b \tag{1}$$

For this specific ramp we chose, the time is related to the input power as:

$$P = \omega t + \rho \tag{2}$$

As the ramp takes 1 second and the power difference is 18dbm, we have that

$$\omega = P_{fin} - P_{init} = 18 \tag{3}$$

Now using the end time of the ramp t_{fin}, we can find ρ:

$$\rho = P_{fin} - (P_{fin} - P_{init})t_{fin} = -2 - 18t_{fin} \tag{4}$$

Now we can fill these into the relation with the voltage:

$$V = \frac{a}{\omega}P - \frac{\rho a}{\omega} + b := a'P + b' \tag{5}$$

I.e the relation we need is:

$$P = \frac{V - b'}{a'} \tag{6}$$

0.3 Results

0.3.1 Old setup

This part is useful for the people who did measurements whilst the new box was installed prior to 13/03/24. Note that some of the accuracy of b is lost when transforming to b' due to the inaccuracy of t_{fin} even though this is the case, a' is still as accurate as a, and as such I try to keep as many significant digits as possible.

Signal	a	error on a (%)	b	error on b (%)	ω	t_{fin}
ICF	0.457843	0.17	0.713159	0.32	18	3.348
ICR	0.442106	0.27	0.890641	0.36	18	3.198

So the power we get from the voltage is:

$$\mathrm{P}_{ICF}(\mathrm{dBm}) = \frac{V_{\mathrm{ICF}}-2.296889}{0.02543572} \tag{7}$$

$$\mathrm{P}_{ICR}(\mathrm{dBm}) = \frac{V_{\mathrm{ICR}}-2.353619}{0.02456144} \tag{8}$$

0.3.2 New setup

This setup is in effect as of the 13th of march 2024.

25MHz

Signal	a	error on a (%)	b	error on b (%)	ω	t_{fin}
ICF	0.4636	0.037	0.910352	0.040	18	2.673
ICR	0.453835	0.083	0.791354	0.126	18	3.144

So the power we get from the voltage is:

$$\mathrm{P}_{ICF}(\mathrm{dBm}) = \frac{V_{\mathrm{ICF}}-2.200913}{0.02575556} \tag{9}$$

$$\mathrm{P}_{ICR}(\mathrm{dBm}) = \frac{V_{\mathrm{ICR}}-2.268637}{0.02521306} \tag{10}$$

35MHz

Signal	a	error on a (%)	b	error on b (%)	ω	t_{fin}
ICF	0.464247	0.016	0.982976	0.031	18	2.503
ICR	0.447934	0.09703	0.667036	0.1896	18	3.431

$$\mathrm{P}_{ICF}(\mathrm{dBm}) = \frac{V_{\mathrm{ICF}}-2.196569}{0.0257915} \tag{11}$$

$$\mathrm{P}_{ICR}(\mathrm{dBm}) = \frac{V_{\mathrm{ICR}}-2.253668}{0.02488522} \tag{12}$$

$$\tag{13}$$

45MHz

Signal	a	error on a (%)	b	error on b (%)	ω	t_{fin}
ICF	0.459813	0.039	0.595329	0.051	18	3.353
ICR	0.446204	0.09459	0.935934	0.1042	18	2.822

$$\mathrm{P}_{ICF}(\mathrm{dBm}) = \frac{V_{\mathrm{ICF}}-2.188172}{0.02554517} \tag{14}$$

$$\mathrm{P}_{ICR}(\mathrm{dBm}) = \frac{V_{\mathrm{ICR}}-2.2447}{0.02478911} \tag{15}$$

0.3.3 ICV0-3

Signal	a	error on a (%)	b	error on b (%)	ω	t_{fin}
ICV3	0.707133	0.04609	0.328061	0.2369	28	2.764
ICV2	0.706039	0.02707	-0.138149	0.4025	28	3.4346
ICV1	0.702135	0.02917	0.576769	0.06987	28	2.4675
ICV0	0.694397	0.03	0.123464	0.4494	28	3.1335

$$\mathrm{P}_{V0}(\mathrm{dBm}) = \frac{V_0 - 2.333086}{0.02525475} \tag{16}$$

$$\mathrm{P}_{V1}(\mathrm{dBm}) = \frac{V_1 - 2.333738}{0.02521568} \tag{17}$$

$$\mathrm{P}_{V2}(\mathrm{dBm}) = \frac{V_2 - 2.35944}{0.02507625} \tag{18}$$

$$\mathrm{P}_{V3}(\mathrm{dBm}) = \frac{V_3 - 2.348957}{0.02479989} \tag{19}$$

0.3.4 Remarks and usage example

The relations given for ICF and ICR power are after the directional coupler (i.e the powers given were what is observed by the circuit), to thus get a power going into the machine you first need to add the 70dBm which gets attenuated by the directional coupler. To get the power in watts you can use the relation :

$$P(W) = 10^{P(dBm)/10-3} \tag{20}$$

As an example, let's convert an ICF voltage recorded on the DAQ of $V_{\mathrm{ICF}} = 2$ near 35MHz (of the new setup) to the power in watts it corresponds to:

$$P(W) = 10^{\frac{1}{10}[\text{eqn } 11+70-30]} \tag{21}$$

$$P(W) = 10^{\frac{1}{10}\left[\frac{V_{\mathrm{ICF}}-2.196569}{0.0257915}+70-30\right]} \tag{22}$$

$$P(W) = 10^{\frac{1}{10}\left[\frac{2-2.196569}{0.0257915}+70-30\right]} \tag{23}$$

$$P(W) = 1729.235W \tag{24}$$

0.4 New System plug-in equations

as requested, a lookup table for the new system, per frequency

0.4.1 Near 25MHz

$$P_f(W) = 10^{\frac{V_{\mathrm{ICF}}-2.200913}{0.2575556}+4} \tag{25}$$
$$P_r(W) = 10^{\frac{V_{\mathrm{ICR}}-2.268637}{0.2521306}+4} \tag{26}$$

0.4.2 Near 35MHz

$$P_f(W) = 10^{\frac{V_{\mathrm{ICF}}-2.196569}{0.257915}+4} \tag{27}$$
$$P_r(W) = 10^{\frac{V_{\mathrm{ICR}}-2.253668}{0.2488522}+4} \tag{28}$$

0.4.3 Near 45MHz

$$P_f(W) = 10^{\frac{V_{\mathrm{ICF}}-2.188172}{0.02554517}+4} \tag{29}$$
$$P_r(W) = 10^{\frac{V_{\mathrm{ICR}}-2.2447}{0.02478911}+4} \tag{30}$$

0.5 Old System plug-in equations

$$P_f(W) = 10^{\frac{V_{\mathrm{ICF}}-2.296889}{0.02543572}+4} \tag{31}$$
$$P_r(W) = 10^{\frac{V_{\mathrm{ICR}}-2.353619}{0.02456144}+4} \tag{32}$$