Suppose you have an FPGA-downconverted reading in counts, which gets divided by its digital full-scale to yield a complex number $\vec{x}$, where radius 1 corresponds to the ADC full-scale. Note two things here: the ADC can clip slightly below this abstract value, due to noise and DC offsets, so the full-scale measurement is made slightly below the maximum value and extrapolated. Second, once the the ADC goes into clipping, the measured value can continue to increase beyond unity radius. This reading is, however, strongly nonlinear and phase-dependent.

Bench measurements will record the RF power (in dBm) needed to reach that unit circle. Let d be that full-scale reading looked up from a calibration database, typically around +10 dBm. Let $\vec{x}$ be a digital measurement with nominal maximum absolute value of 1. Then the corresponding incoming RF wave at the rear of the chassis is computed by

$$\vec{A} = \vec{x} \cdot 10^{(d-30)/20} \sqrt{\text{Watts}} \quad .$$

An overall attenuation in dB will be measured for forward and reverse waveguide pickups in the 3.8 kW cavity drive system. It is a combination of directional coupler sensitivity, cable losses, and fixed attenuator(s). Expected values are around -57 dB forward, -63 dB reverse. Again, the exact values must be looked up from a database. Call that calibration value g; including it turns the equation for RF amplitude in the waveguide to

$$\vec{A} = \vec{x} \cdot 10^{(d-g-30)/20} \sqrt{\text{Watts}} \quad .$$

Calibrating the cavity pickup probe channel is special. In theory,

$$\vec{V} = \vec{x} \cdot 10^{(d-g-30)/20} \cdot \sqrt{Q_P(R/Q)} \text{ Volts}$$

where g is the attenuation from the pickup probe to the chassis rear panel, and (R/Q) is the cavity shunt impedance (1036 Ω), and Q_P is the probe Q. Note that the units are correct: $\sqrt{\text{Watts}} \cdot \sqrt{\Omega} = \text{Volts}$. In practice, unfortunately, the value of Q_P is not considered accurately known.

An independent estimate of $\vec{V}$ can be derived from forward and/or reverse waveguide measurements. In particular, the total emitted energy from the cavity after the SSA output is forced to zero is

$$U = \int_0^\infty |\vec{A}|^2 dt$$

where $\vec{A}$ is the reverse wave measurement discussed above, although an additional small correction term could be included to cover attenuation in the coupler and waveguides. Again, note the units: Watts $\cdot$ seconds = Joules. The cavity voltage just before shutoff is given by

$$V = \sqrt{U(R/Q)\omega_0}$$

where ω_0 is the cavity frequency ($2\pi \cdot 1.3 \times 10^9$ /s). This cavity voltage measurement can be used to establish a provisional and empirical scale factor (we hope close to one) for the "live" measurement based on the probe reciever channel.

Once beam is threaded through the machine, experiments using beam position monitors can establish a second empirical scale factor (also hoped to be close to one) for the "live" cavity voltage measurement.