DESCRIPTION OF THE OPERATION AND CALIBRATION OF THE MILLIMETER I/Q PHASE BRIDGE-INTERFEROMETER

Overview of Interferometer Operation

The block diagram of the I/Q Phase Bridge-Interferometer is shown below in Figure 1.

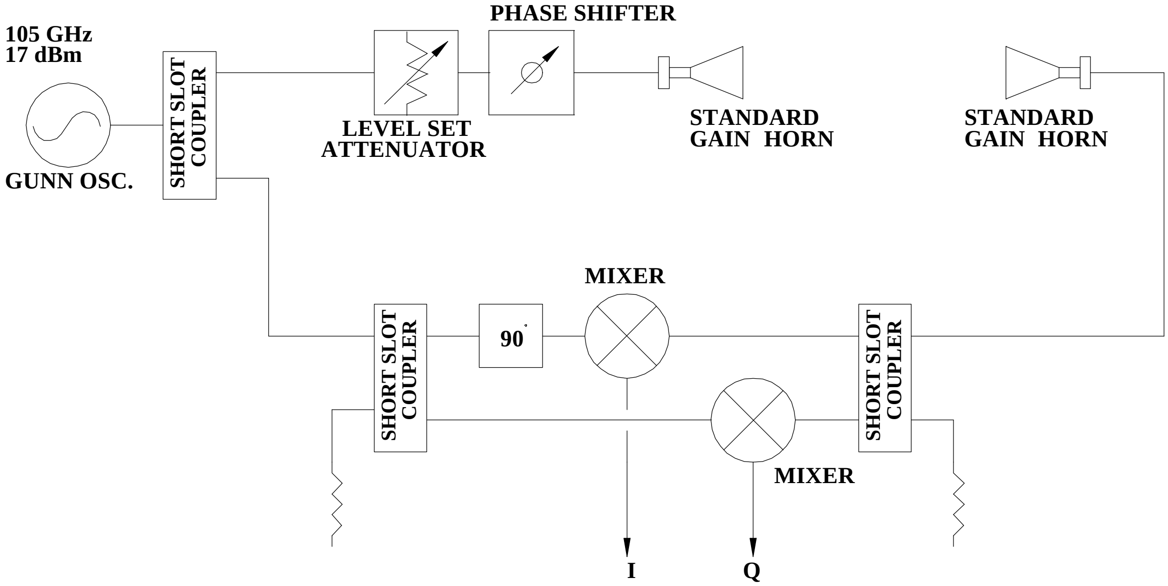

Figure 1: Block Diagram of I/Q Interferometer

The Phase Bridge works on a coherent signal principal. A GUNN Oscillator provides approximately 17 dBm of RF power at 105 GHz. A power divider channels approximately 13dBm to the transmit portion of the phase bridge as shown below.

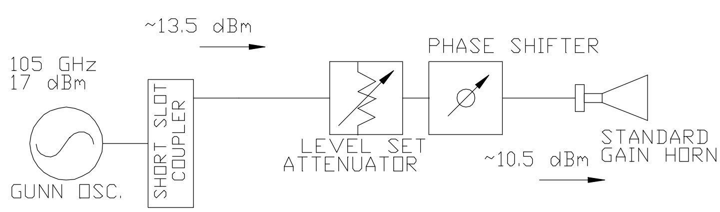

Figure 2: Transmit Hardware

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The remaining power is channeled to a second power divider which again splits the signal and provides the LO power to the two I/Q mixers.

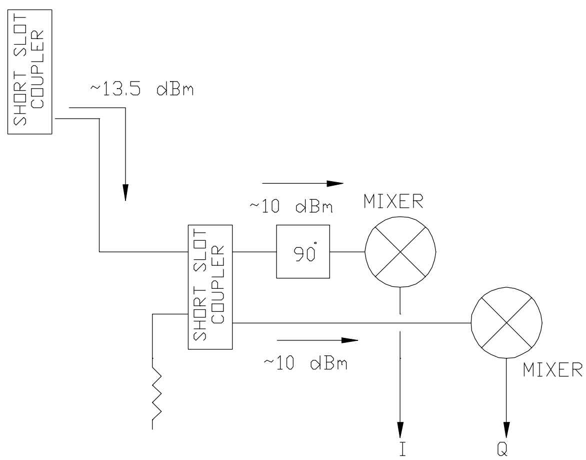

Figure 3: Provision of LO Power to I/Q Mixers

The input receive horn antenna of the phase bridge gathers the RF signal transmitted through the plasma. The signal power is then divided and provides the RF signal to the I/Q mixers.

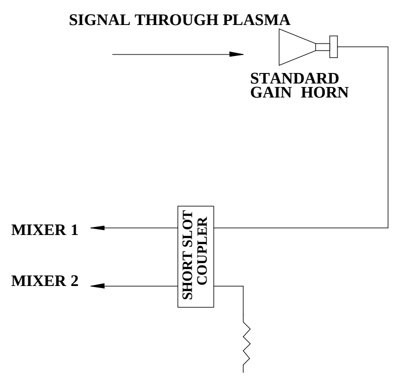

Figure 4: Test Signal Reception

Since the LO and RF signals are at the same frequency and from the same source, the LO and RF signals are mixed down (in the mixer) to provide a DC voltage at the IF output of the mixers. A 90° phase shift is introduced to the LO signal path of one mixer and cancels the 90° phase shift inherent to the Short Slot Coupler thus insuring the correct signal phase relationship into the LO port of the mixer.

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The IF output is DC (voltage output) provided through a SMA connector. Voltage measurements can be obtained through the use of a suitable voltage acquisition device with input impedances greater than 1000Ω.

Choice of Suitable Voltage Acquisition Device

The choice of an appropriate voltage acquisition device will be dependent on how fast the phenomenon under observation is temporally varying. For variances on the order of 1 second or greater, a good digital voltmeter or oscilloscope is adequate; a unit with a GPIB card could be used that would allow for computer data acquisition. For variances of less than 1 second, a data acquisition card (DAC) is highly recommended. These come in a variety of options and allow the user to specify gain and temporal response.

Calibration

Calibration is achieved by setting the Level Set Attenuator to the maximum attenuation position with the GUNN Oscillator turned on and measuring the DC voltage output of both of the mixers; this is done without any sample in the transmit/receive path. One of the mixer outputs will serve as the I ordinate while the other will serve as the Q ordinate in a Cartesian coordinate system. Note that the initial voltage output measurements of the I and Q ports will not necessarily yield a 0 reading; some 0 offset will occur due to the mixer imbalance. However, these measurements will serve as the reference (relative zero) point for all future measurements. All future measurements will vary above or below these reference values.The initial voltage readings should be plotted in a Cartesian coordinate system as shown below in Figure 5.

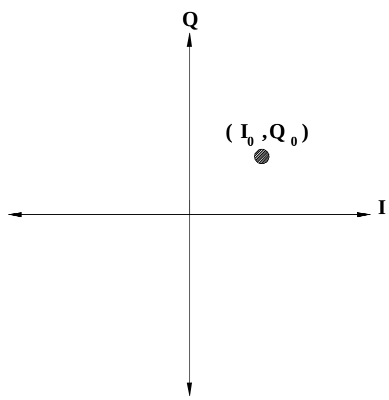

Figure 5:Determination of Relative Zero

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The point (I_0,Q_0) has been chosen to fall in the 1st quadrant for the sake of argument. The simple transformation,

$$I' = I - I_0$$
$$Q' = Q - Q_0,$$

where I' and Q' are the ordinates in the new coordinate system and I and Q are the measurements out of the two mixers, yields a coordinate system with (I_0,Q_0) now at the origin. In the description that follows, it is assumed that this has been done.

Once this has been done, the Level Set Attenuator and Direct Reading Phase Shifter (DRP) should to be set to zero[1] (yielding a transmit power P_0). I/Q readings should be recorded while the DRP is rotated through the full 360° of phase. When plotted on the I/Q graph, these measurements should yield a calibration circle as shown in figure 6 below.

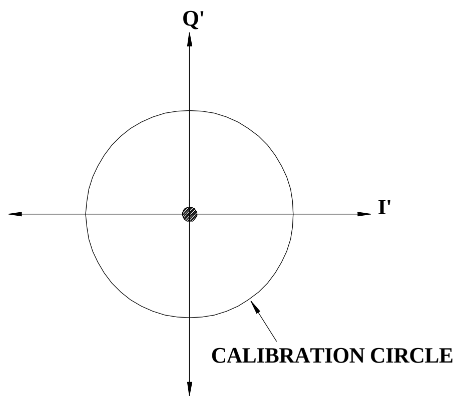

Figure 6: Calibration Circle Generation

[1] The mixers work optimally with an RF input power of –20 dBm (.01 mW) and have a 1dB compression point of approximately -3 dBm (.5 mW). Depending on path losses, the LSA may need to be set at a higher attenuation value than zero to insure linear operation of the mixer.

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Ideally, the point of zero phase will fall on the I' axis. In all likelihood, this will not be the case and the zero phase point will be displaced somewhere along the calibration circle as indicated below.

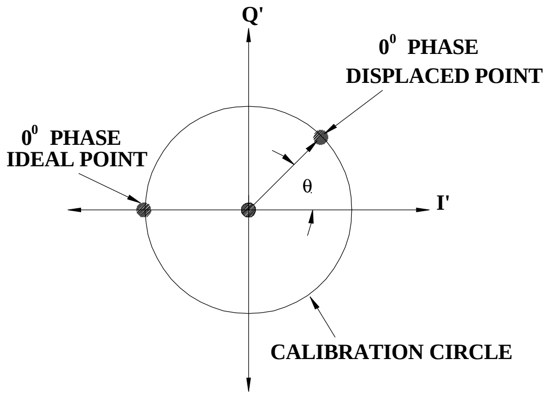

Figure 7: Ideal verses Displaced 0° Phase Point

Calibration circles can and should be repeated for varying levels of attenuation producing a set of calibration vectors that can then be used to analyze experimental data as shown below.

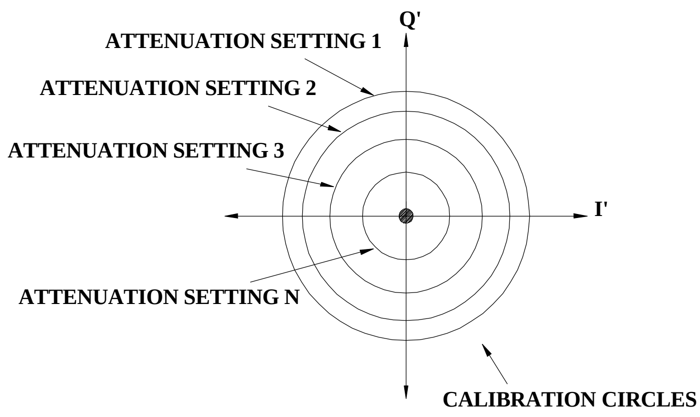

Figure 8: Set of Calibration Circles

For phenomenological measurements, phase can either be measured from the displaced point or the I'-Q' axes can be rotated via the rotational transformations,

$$I'' = I' \cos\theta + Q' \sin\theta$$

$$Q'' = -Q' \sin\theta + I' \cos\theta$$

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Once the calibration circle has been generated, phenomenological measurements can commence. It should be noted that, unless absolute power measurements that take into account signal path losses are obtained during the calibration process, all measurements will be relative to the calibration value.

Assume that an I/Q voltage reading of (I'_1, Q'_1) is obtained during an experiment. The phase, φ, can be obtained from the displaced 0° phase point discussed above (or the I" axis if a rotational transformation has been applied) and the magnitude of the relative power $|P_1|$ derived from the vector connecting the origin and this point. This is diagrammatically shown in Figure 9.

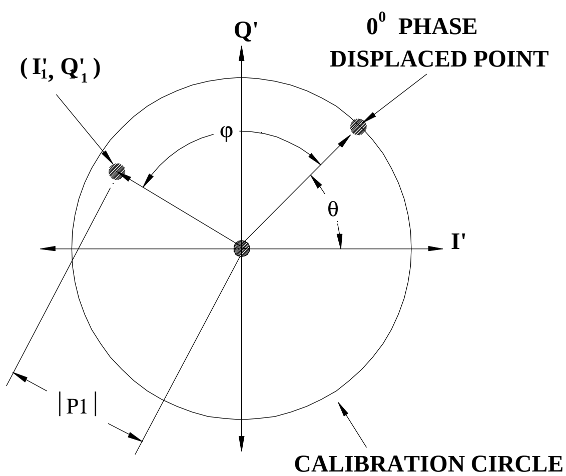

Figure 9: Phase Measurement

A Brief Discussion of the Noise Floor

For operation where a DAC is used, the dynamic range of the I/Q Phase Bridge-Interferometer will be determined by the op-amp employed, and the video bandwidth used in the signal processing. Millitech suggests the use of an OP-27 low noise amplifier with $\frac{2\text{nV}}{\sqrt{\text{Hz}}}$ of noise. Assuming approximately $\frac{10\text{ nV}}{\sqrt{\text{Hz}}}$ of noise contribution from the mixer and amplifier, a 1 kHz video measurement bandwidth and a detector response of $\frac{.2\text{ V}}{\text{mW}}$:

$$\text{Noise Floor} \equiv \frac{10\text{ nV}}{\sqrt{\text{Hz}}} \cdot \sqrt{1000\text{ Hz}} \cdot \frac{1\text{ mW}}{.2\text{ V}} = 1.58 \cdot 10^{-6}\text{ mW}$$

Wider video bandwidths will produce a higher noise floor.

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For operation with a voltmeter or oscilloscope (longer signal acquisition time), the acquisition time involved in the signal acquisition will yield a noise floor similar to that described above.

Theoretical Derivation of the Phase Resolution

A theoretical derivation of the phase resolution attainable with the I/Q Phase Bridge is included below. The following two important assumptions have been made. Firstly, that there is a 30 dB loss of power when the signal traverses the phenomena under observation. Secondly, that the time constant, or temporal variability, of this phenomena is on the order of one second. Greater path loss and/or smaller integration time will reduce the signal to noise ratio leading to a reduction in the phase resolution.

A transmit power level of 10 dBm (10 mW) is assumed. With a path loss of 30 dB, this yields a receive power level of –20 dBm (.01 mW). The mixer response is typically $\frac{2000\,\text{mV}}{\text{mW}}$ yielding a mixer voltage output level of,

$$\frac{2000\,\text{mV}}{\text{mW}} \cdot .01\,\text{mW} = 20\,\text{mV}.$$

The noise power at the output of the op-amp (OP-27) is $\frac{10\,\text{nV}}{\sqrt{\text{Hz}}}$ as described in the previous section. With a 1 second integration time, this yields a noise voltage level of 10 nV and a signal to noise ratio of,

$$\frac{\text{Signal}}{\text{Noise}} = \frac{20 \cdot 10^{-3}\ \text{V}}{10 \cdot 10^{-9}\ \text{V}} \Rightarrow 63\,\text{dB}.$$

How the above quantities translate into a phase resolution is best described diagrammatically. If the I/Q voltage point is plotted on Smith Chart, the resultant coordinate point will not be a single point (infinite resolution) but will occupy a circle as shown below:

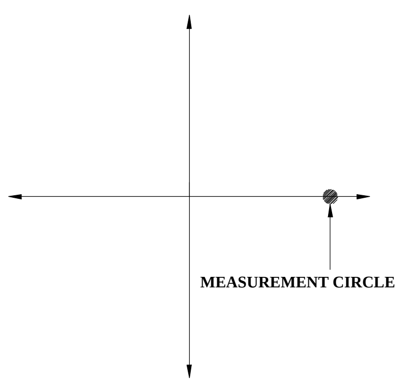

Figure 10: Measurement Circle

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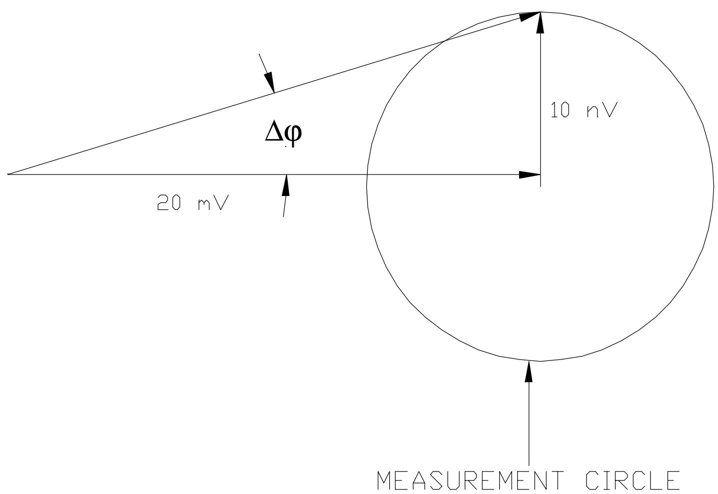
The distance from the origin to the point represents the mixer output voltage level while the noise level defines the radius of the circle. The phase resolution can then be derived as shown below:



$$\Delta\varphi = \tan^{-1}\left(\frac{20\cdot 10^{-3}}{10\cdot 10^{-9}}\right) = 30\cdot 10^{-6}\ \text{Degrees}$$

Figure 11: Determination of Phase Resolution

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