PHASE DETECTION USING AD8302 EVALUATION BOARD IN THE SUPERHETERODYNE MICROWAVE INTERFEROMETER FOR LINE AVERAGE PLASMA ELECTRON DENSITY MEASUREMENTS

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Abstract

In this paper the use of AD8302 evaluation board from Analog Devices for phase detection and consequently line average electron density measurement in the super-heterodyne microwave interferometer is described. The phase is directly measured from this chip. This method is very cheap and easy to integrate. For the measurement, signals that were obtained from the IF of both the mixers in the interferometer were fed as inputs to the evaluation board. The output was connected to an oscilloscope to capture the voltage trace. The voltage reading was then converted to phase angle by using the calibration data provided with the evaluation board. The plasma used to test the phase detection system was a microwave plasma discharge. The phase measurements were obtained very quickly without the use of computer. These were then translated to line average electron density. The values were agreeable to published results.

Keywords : Plasma Diagnostic, Interferometer, Phase Measurement.

Introduction

Interferometer is a common diagnostic tool for measuring the line average electron density of plasma. It is a device in which two or more waves are allowed to interfere by coherent addition of electric fields [1]. The interferometer chosen in this work is the microwave super heterodyne having the Mach Zahnder type set-up. The microwave signal from the source is split into two beams using a power divider or a directional coupler. One of the beams is for probing and the other serves as the reference. The probing microwave signal passes through the plasma and will be phase shifted which is dependent on the path length of the signal and the refractive index of the plasma [1]. The microwave interferometer discussed in this paper has a frequency of 35GHz. The cut-off density at this applied frequency is $1.52X10^{13}$ cm^{-3}. The other microwave source also having centering frequency of 35 GHz and shifted by 40 MHz are mixed with the probing and reference signals to produce the IF 40 MHz signal. For the phase analysis, the usual technique of using the in-phase and quadrature (IQ) phase sensitive detector is however not used in this work and instead the direct phase measurement is employed. This is realized by using a single phase/gain evaluation board (AD8302) manufactured by Analog Devices. The IF reference and probing signals from the mixers of the interferometer are fed as inputs to AD8302. The output of AD8302 gives the gain and phase readings in volts. The calibration chart that translates voltage to absolute phase is provided by the manufacturer. The operation of the phase detection system is emphasized in this paper.

From the phase difference the electron density of plasma, n_e can be calculated [2] using

$$\bar{n}_e = \left(\frac{\lambda N_C}{\pi L} \right) \delta \qquad (1)$$

where λ is the wave length of 35 GHz signal, L is the length of the path of wave going through plasma, and the cut-off density N_C is given by

$$N_C = \frac{\varepsilon_0 m_e \omega^2}{e^2} , \qquad (2)$$

At 35 GHz, the cut-off density is $1.52X10^{13}$ cm^{-3} , where ε_o equal to permittivity of free space, m_e is the electron mass, ω is the angular frequency of 35GHz signal and e is the charge of electron.

The plasma source diagnosed in this paper is a low density argon plasma that is generated by microwave discharge. The magnetron produces a pulse of 2.45GHz microwave at 20ms cycle time. The plasma is generated and kept in a 10cm diameter cylindrical chamber which is keep at constant pressure of 2 Torr.

Very quick and inexpensive mean of line average electron density measurement as compared to the more complicated and expensive phase sensitive detectors of the IQ types is reported in this paper. The accuracy and consistency of the phase measurement with the plasma source is also included.

Interferometer set-up

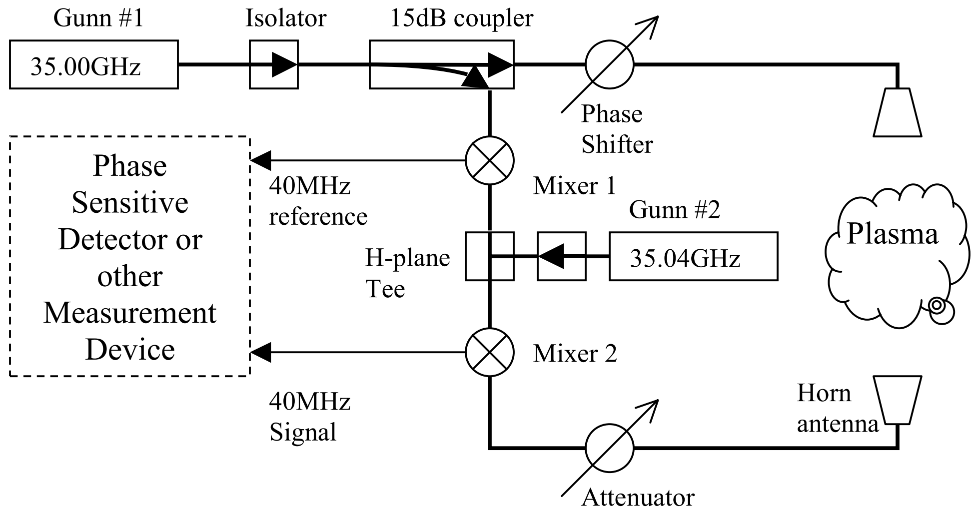

Figure 1 : Schematic of the Interferometer Constructed.

Figure 1 shows the construction of the microwave super-heterodyne interferometer. It is constructed using WR28 waveguide components. The Gunn oscillators are mechanically tunable with a tolerance of ±100 MHz from the center frequency of 35GHz. Each of the oscillator is integrated with a 20 dB isolator that has an insertion loss (IL) 0.5 dB. Gunn oscillator #1 is tuned at 35 GHz. The power from this oscillator is divided into two ways by the 15dB directional coupler; the wave that propagates through the collinear arm travels through the plasma chamber as the probing signal and the coupled power serves as the reference. The attenuator and phase shifter that are connected in the probing arm are to lower the power to Mixer 2 and nullify any phase difference between the probing and reference arms. Two 10 dB horn antennas are used to direct the wave into chamber and receive on the other end. The Gunn oscillator #2 which is the local oscillator (LO) is tuned to operate at an offset frequency of 35.04GHz, and its output power is divided equally by the H-plane Tee. The LO power are then fed to Mixer 1 and 2 and mixers with the RF power from Gunn oscillator #1 to produce the 40 MHz IF signals. The mixers have been pre-adjusted to give a maximum output at 40MHz. The phase information is reflected in the IF signals and will be electronically derived.

The super heterodyne interferometer has the advantages of making the output independent of amplitude and eliminates the need to sense the dc level of the wave [1]. These factors ensure that the interferometer can be made very insensitive to the change of amplitude in either plasma or reference beam or in the phase contrast [1] and hence increase sensitivity. As a very large heat sink is attached directly to the Gunn diode, the operating temperature is kept quite constant and the frequency drift after 4 hours of operation is less than 1 MHz which eliminates the need of the phase lock loop (PLL) circuit or other frequency control loop [3,4].

Phase detection

The information obtained from an interferometer is the phase shift. There are several ways [5,6] to extract the phase information from the interferometer. The usual technique is by using the conventional quadrature phase detector (QPD). Figure 2 shows the phase detector [1]. The set-up shows several components integrated together for the purpose of phase measurement. In this set-up, the art of designing the 40 MHz IF amplifier and band pass filter is utmost important. These front-end components determine the quality of the output dc signals of the phase detector. Hence, long durations are usually spent to obtain reasonable and credible results. As higher cost is also involved to construct the complete set hence it can be a major problem to acquire them. In order to obtain the phase δ, an indirect method of analysis whereby the arctangent of the I and Q signals are required. Therefore a personal computer (PC) or a digital signal processing (DSP) chip is needed for the task of the data analysis. A calibration work is also required before any phase reading is obtained [7].

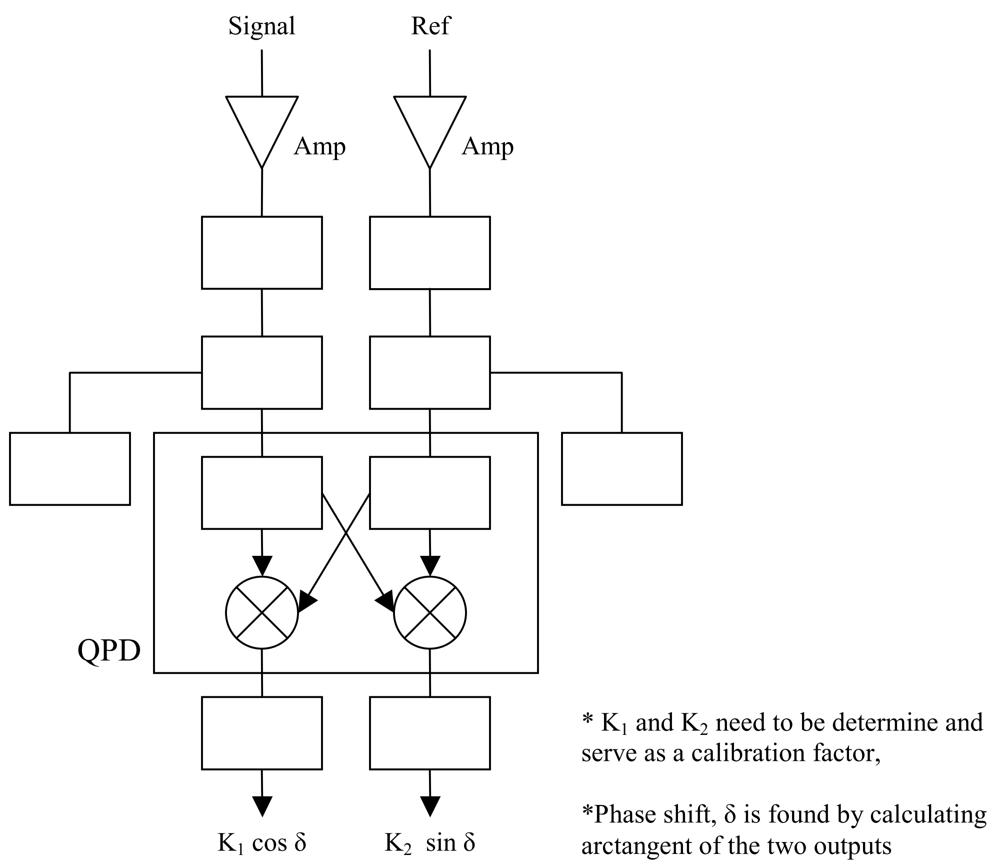

Figure 2 : Quadrature Phase Sensitive Detector.

In view of the problems associated with the conventional phase detector, the technique for phase detection by using the AD8302 evaluation board is strongly recommended. This component is the only component needed for the measurement besides the power supply. It is 6 cm x 6 cm in size, equivalent to the size of a match box. The overall cost is less than USD 100.00. Moreover, there is no need for any filter and amplifier hence simplifying the construction. The output of this phase detector is in volts that can be obtained using a low-end oscilloscope with a bandwidth of just 20 MHz. The voltage can then be translated to absolute phase using the calibrated chart provided by the manufacturer, hence no-calibration is required as oppose to the conventional phase detector. Figure 3 shows the schematic block diagram of the circuit of the AD8302 chip. Other earlier methods of finding the phase shift by a plasma also involve calibration work and computer aided data analysis [5,6]. An added advantage of using AD8302 IC is the reduction of (data acquisition) DAQ channel per interferometer from two to one. This is realized by the built-in 60db log-amplifier [8] that allows input to connect directly to the mixer which makes the overall system less susceptible to noise.

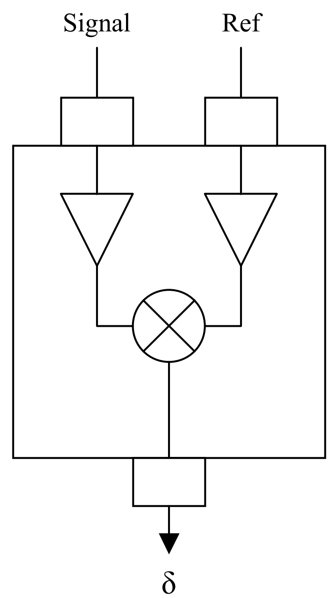

Figure 3 : AD8302 connection diagram.

AD8302 specification

The AD8302 is a fully integrated system for measuring gain/loss and phase. The evaluation board used requires no external components and a single supply of 2.7 V–5.5 V for operation. The outputs provide an accurate measurement of phase over a 0°–180° range scaled to 10mV/degree [8]. The

AD8302 includes a phase detector of the multiplier type, but with precise phase balance driven by the fully limited signals appearing at the outputs of the two logarithmic amplifiers. Thus, the phase accuracy measurement is independent of signal level over a wide range [8]. Although the chip is capable of measuring gain/loss [8], its generally ignore in this discussion as only the phase carry the information needed to calculate electron density. Table 1 summaries some important specification extracted from the data sheet.

Table 1 : Specification of the AD8302 [8]

Parameter	Conditions	Min	Typ	Max	Unit
Input Frequency range		>0		<2.7	GHz
Input Voltage range	Re=50Ω	-60		0	dBm
Output Voltage Minimum	Phase different 180°		30		mV
Output Voltage Maximum	Phase different 0°		1.8		V
Slew rate			25		V/us
Output bandwidth			30		MHz
Response time	Any 15 Degree Change, 10%–90%		40		ns
	120 Degree Change to 1% Settling		500		ns
Phase output dynamic range	Less than ±1 Degree Deviation from Best Fit Line		143		°
Phase output Slope	From Linear Regression about –90° or +90°		10		mV/°
1.8V ref output	Load = 2k Ω	1.7	1.8	1.9	V
	Vs=2.7V to 5.5V		0.25		mV/V

Experimental setup

The experiment carried out involves diagnostic of a microwave generated plasma. The setup is in Figure 1. The outputs of Mixer 1 and Mixer 2 are connected directly to INA and INB of the AD8302 evaluation board by using two coaxial cables. The Gunn diode is biased by a highly regulated constant voltage power supply. The AD8302 output is connected directly to an oscilloscope for display. The initial phase shift is adjusted to about 60°. The value is chosen by referring to the graph below.

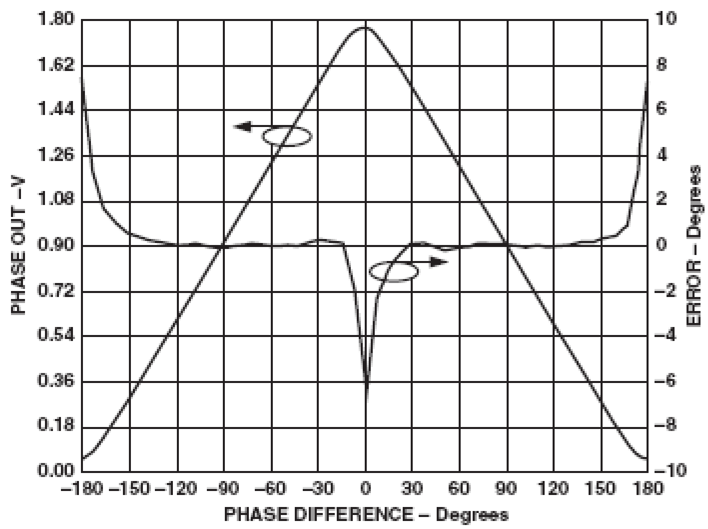

Figure 3 : AD8302 VPHS output and error at 100MHz [8]

It is clear from 60° to 120° the non-linearity error is the smallest, even smaller than the specification of 1°. And from the initial data, it is found that this range is sufficient to cover the highest phase shift produced by the plasma. By using equation 1, it is found that every 1° of phase difference (10mV shown on oscilloscope) corresponded to an electron density of 7.20 X 10^9 cm^{-3}. This multiplication factor is used to convert the output from phase shift to electron density.

Result and Discussion

Figure 4 shows the oscillograph of the time domain for the switch-on phase of the microwave plasma. This phase corresponds with the pulse time of the magnetron which is about 10 msec (that can be obtained from magnetron suppliers). When the plasma is on, the 35 GHz microwave signal is phase shifted from the initial set point of 60° (ie. without plasma) to a higher value of ~90°. The electron density found at this point is 2X$10^{11}$$cm^{-3}$ and deviates from this value by 0.3 X$10^{11}$$cm^{-3}$. When the power of the magnetron is switched off, the phase returns instantly to initial set point. The noise level reflected on to the waveform is low and only 0.25°. The resolution is ±0.25° but can be improved by using higher resolution DAQ. As lesser components are used for the phase measurement, it is quite certain that the phase error which is mainly due to the noise from the overall system is less with the AD8302 chip than other conventional system [9].

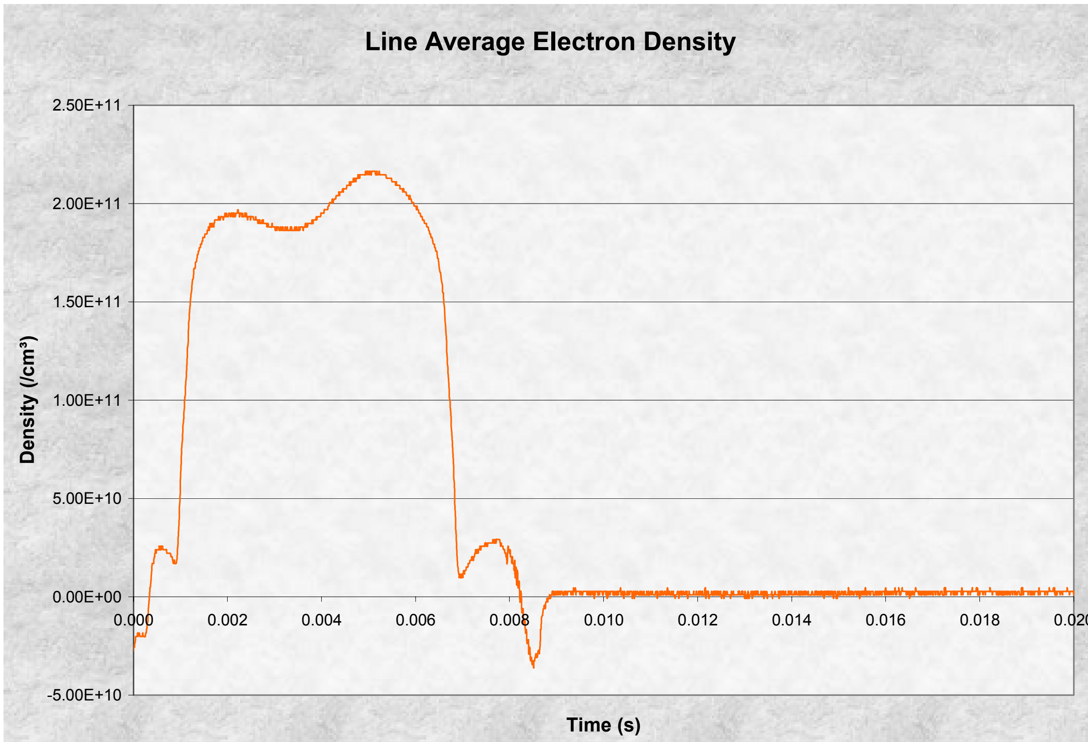

Figure 4 : Electron density of 3 Torr argon plasma generated by 2.45GHz microwave.

Conclusion

This paper has shown an alternative way of acquiring the phase shift from a superheterodyne microwave interferometer used for line average electron density measurements. The use of AD8302 evaluation board requires no in-house calibration and computation of arctangent. The phase output bandwidth of 30 MHz is adequate to give good resolution to the magnetron cycle time of 20ms. The system developed can measure phase shift to a resolution of ±0.25° with noise of 0.25° The output IFs from the mixers of the superheterodyne microwave interferometer are fed directly to the inputs of the evaluation board. The AD8302 chip superb performance in the evaluation board had eliminated the need of the bandpass filters and IF amplifiers, and had significantly reduced the cost and development time of the super-heterodyne microwave interferometer system.

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