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SYSTEMATIC STUDY OF THE SOURCES OF ERROR IN THE HIGH SPATIAL RESOLUTION TWO-COLOR LASER INTERFEROMETER FOR THE TJ-II STELLARATOR

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I. INTRODUCTION.

Multichannel laser two-color heterodyne interferometry is a proven method for measuring electron density profiles in fusion plasmas [1]. Currently we are working on the design and installation of a multichannel, high spatial resolution, two-color (CO_2, λ=10.6 μm, He-Ne, λ=633nm) heterodyne interferometer for density profile measurements in the TJ-II Stellarator (R=1.5 m, a<0.2, B= 1T), based in the already operational single channel two color heterodyne interferometer installed in the machine [2]. The design objectives for such a system for the TJ-II Stellarator are 32 channels with a 4-5 mm chord lateral separation and line integral error measurements $< 10^{17}$ m^{-2}.

To obtain these performances, a systematic study of several sources of error of such a system has been carried out with the help of an expanded-beam heterodyne-homodyne interferometer [3] that has been set-up to study the heterodyne interferometric waveform and its influence in the lateral resolution of the measurement. One important error source identified as cause of poor mechanical vibration subtraction in two color heterodyne interferometers is electrical (RF) crosstalk between measurement and reference or adjacent channels [4]. Besides this, in our system, optical crosstalk between detection elements due to the small separation between array detectors (1 mm) has to be also taken into account due to the high spatial resolution required. The influence in the measurement of these two effects are evaluated with the aid of a high resolution phase measurement system that uses a FPGA-based phase detector, which allows us to integrate up to 20 channels in a single chip. The ultimate resolution of such detector is also evaluated in the framework of this work. The results obtained have allowed us to validate such components to be incorporated in the multichannel heterodyne interferometer of the TJ-II.

II. STUDY OF ERRORS IN DETECTION FOR HIGH SPATIAL ELECTRON DENSITY MEASUREMENTS IN THE TJ-II STELLARATOR.

The Stellarator TJ-II is the first Stellarator to incorporate a laser two-color heterodyne interferometer for density measurements [5]. For this reason, very good levels for mechanical vibration subtraction have to be achieved in order to resolve the small phase-shift induced by the relatively low-density plasmas [5]. In previous works, crosstalk between channels has been identified as a major source of poor mechanical vibration subtraction in two-color interferometric systems [4], and corrected, but for the new high spatial resolution system, that implies very small distance between detectors elements (photodiode and photovoltaic arrays), a systematic study of the optical and electronic (RF) crosstalk between channels has to be carry out in order to evaluate their influence in the resolution of the measurement.

In this new system, and compared to the single channel diagnostic already installed, the small spacing between detector elements and signal tracks from the photodiode (see Figure 1) allow new paths for interference that have to be evaluated. For this reason RF crosstalk has been measured for all the detectors in the 35 elements array displayed in Figure1. In Table 1 we show the results for channel 7. This channel is illuminated with a heterodyne signal (all other detectors covered) and the RF signal induced measured. RF signals appear not only in adjacent channels but also in channels 5 and, especially, 9. Note that the RF signal is still present in the channels with no illumination, demonstrating other paths for interference beyond detector-to-detector and between electrical tracks. These results have forced us to design new strategies in the design of the detectors boards and electronics, including shielding, to keep the signal/crosstalk ratio well below 30 dB.

Channel	Power (laser on) (dBm)	Power (laser off) (dBm)
5	-18	-20
6	-19	-22
7	+10	-19
8	-22	-25
9	-14	-17

Table 1

As mentioned earlier, small distance between array elements also allow some optical crosstalk between elements. In table 2 we show the results for the optical crosstalk evaluation for channels 1 to 4 (being the results for other channels similar). A CW laser beam illuminates only one element of the array, while keeping the other detectors covered. In this situation, some photocurrent is induced in the adjacent elements and thus some optical crosstalk is present (Table 2). The evaluation of the optical signal-to-crosstalk ratio gives a value around 20 dB (optical power) that is consistent with the data provided by the manufacturer.

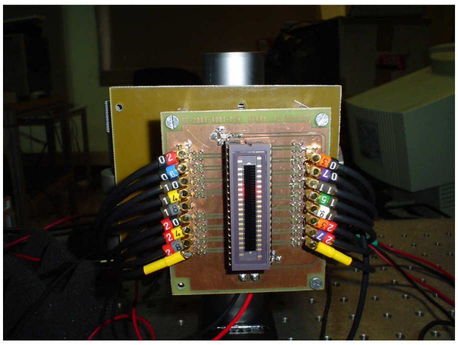

Figure 1

Array element	Ch. 1 (mV)	Ch. 2 (mV)	Ch. 3 (mV)	Ch. 4 (mV)	Ch. 5 (mV)
Ch. 1	-120	-10,9	0	0	0
Ch. 2	-1,5	-132	-0,1	0	0
Ch. 3	0	-0,2	-147	-0,8	0
Ch. 4	0	0	-0,3	-134	-0,8

Table 1

III. HIGH RESOLUTION PHASE MEASUREMENT USING AN INTEGRATED PHASE DETECTOR.

As mentioned previously, the small phase shifts due to the plasma density and the necessity of high level of mechanical vibration subtraction require high resolution phase measurements. The actual system installed at the TJ-II already presents a 1/300 of a fringe resolution, enough for the measurement of low density plasmas (< 10^{19} m^{-3}), but suffers from some crosstalk between channels, and the necessity of previous demodulation to an intermediate frequency. To avoid these problems and to obtain the performances and resolutions needed for the multichannel system we have conceived, designed and tested a new integrated phase detection system implemented on a FPGA that makes the phase measurement directly at the modulation frequency (80 MHz and 40 MHz). FGPA technology, on the other hand, allows integration of many channels (up to 20) in a single chip.

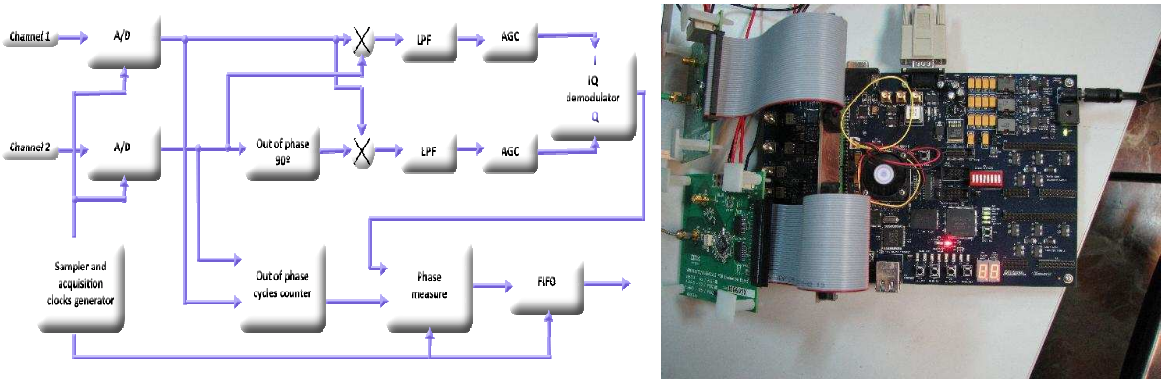

Figure 2

In figure 2 (left) the block diagram of the phase detection is shown. The output signal from the interferometer is directly sampled while the phase measurement is done in two steps: fringe counting and IQ demodulation. A digital AGC (Automatic Gain Control) is incorporated for a 20 dB dynamic range in the measurement. Figure 2 also shows a picture of the evaluation board used to calibrate the phase detector. The detector is fully programmable and allows sampling frequencies up to 100 KS/s (phase data) for fast event measurements.

To evaluate the resolution in the phase measurement we have calibrated the detector using a DDS (Direct Digital Synthesizer, AD9954) to obtain two signals with a fixed phase lag. The results for the first two channels are shown in table 3. We can see in this table that the error associated to the measurement (for both channels) is below 0.1º or 1/3600 of a fringe. This high performance detector will give us enough resolution to identify other sources of errors in the phase measurement to match the required specification for mechanical vibration subtraction.

DDS angle(º)	**Measured angle (mean)(º)**		**Measured angle (standard deviation)(º)**	
	Channel 1	**Channel 2**	**Channel 1**	**Channel 2**
45	44.579	44.913	0.030	0.028
90	90.007	90.489	0.034	0.053
135	134.720	135.161	0.062	0.063
180	179.275	179.886	0.053	0.056
225	224.472	225.061	0.039	0.031
270	270.136	270.511	0.044	0.036
315	315.054	315.230	0.067	0.060

Table 3

The complete system, photodiode array and phase detector, have been incorporated to an expanded-beam heterodyne-homodyne interferometer [3] used to study the heterodyne interferometric waveform and the lateral resolution of the phase measurement. The systematic study of the crosstalk between channels and the development of the new phase detector is allowing us to make high spatial resolution (1 mm) measurements of the heterodyne wavefront and its calibration through comparison with a homodyne phase front.

IV. REFERENCES.

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