Direct-Reading Type Microwave Interferometer

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Abstract

A new microwave interferometer has been developed and applied to the electron density measurement on JIPP T-II plasma device. The interferometer generates an output voltage proportional to the number of fringe shifts and also output pulses which indicate the change of electron density for the convenience of data processing, where the resolution is a quarter of fringe shift. The principle is based on the digitization of fringe shifts utilizing the phase detection of microwave signals with two-level modulation of source frequency. With this system and 70 GHz microwave source, a change of electron density as rapid as about 2×10^{13} cm^{-3} in 1 ms has been measured at the tokamak operation of JIPP T-II.

§1. Introduction

A microwave interferometer has been widely used to measure electron density of plasmas.[1] Several techniques have also been developed to display the evolution of electron density on an oscilloscope. The most familiar one among them is of the zebra stripe pattern, which utilizes an intensity modulation at the oscilloscope to visualize the fringe shifts. Though the zebra stripe system is convenient to visualize the electron density of time-varying plasma, it is not suitable for data processing with digital computer. Futhermore, we often encounter with a difficulty in finding out the exact number of fringe shifts when the density changes too rapidly over many fringes, as in the case of an initial rise or disruptive decay of electron densities in a large plasma device like tokamak. When the electron density is high and the nonlinear relation between the electron density and the number of fringe shifts becomes significant, the correction by means of data processing with digital computer will be needed for an accurate measurement. The effect of spatial distribution of electron density can be also taken into account more easily by the use of digital computer.

In order to overcome the difficulties mentioned above, a new interferometer has been developed and brought into operation. The interferometer generates an output voltage proportional to the number of fringe shifts for visualizing purpose, and also ouput pulses corresponding to the increase or decrease of electron density with a resolution of a quarter of fringe shift. The latter is convenient in processing an electron density evolution with digital computer.

The purpose of this report is to describe the principle and the circuits of newly developed microwave interferometer. An application of this interferometer to an actual plasma device and related remarks are also presented.

§2. Principle of a New Interferometer

In an ordinary zebra stripe system, the oscillation frequency of the microwave source is modulated with sawtooth wave to generate fringe patterns utilizing the difference in path length; plasma path and reference path. In a new system, the microwave frequency is instead modulated with square wave (two-level modulation) so that the microwave signal detected contains two envelopes corresponding to each frequency. This is simply achieved by replacing the sawtooth wave generator of the zebra stripe system with square wave generator. Two envelopes are easily separated with synchronized detection referring the modulation waveform. A schematic diagram of the interferometer is shown in Fig.1. Since the phase difference due to the difference of path length is a function of source frequency, we can adjust the degree of modulation so that the phase difference caused by the two-level modulation is $\pi/2$. Then, one of the envelope (A) shows for example, a sinusoidal change for linearly increasing density, while the other (B) shows similar change but with a phase lag of $\pi/2$. Thus, if the density is increasing with time, signal A(B) crosses zero with positive (negative) slope when B(A) is negative, and with negative (positive) slope when B(A) is positive. On the other hand, if the density is decreasing with time, the situation is completely opposite. Relations among these waveforms as well as zero-crossing pulses are illustrated in Fig.2, where the linear change of electron density is simulated by triangular-wave modulation of source frequency. These relations are valid in general cases where the density changes not linearly with time. Accordingly, a discrimination of zero-crossing pulses of each signal with the polarity of the other signal provides increasing and decreasing pulses of the electron density. As each signal crosses zero twice in one fringe shift and four pulses are generated altogether, the resolution of the interferometer is a quarter of fringe. An evolution of electron density is visualized as a histogram either by integrating these pulses or by using up-down counter and digital-analog converter. The output of up-down counter is directly accessible to the computer-based data processing system.

§3. The Circuit of the Interferometer

In the schematic diagram shown in Fig.1, the signals from each crystal at magic-tee are amplified by IC amplifiers I_1 and I_2 respectively, and led to a differential amplifier I_3. The output of I_3 is demodulated by means of an amplifier I_4 with low pass filter (summing amplifier) and a differential amplifier I_5 with an analog switch S_1 to produce two signals which have a phase difference of $\pi/2$ each other. These signals, A and B, are converted into rectangular waveforms with comparators I_6 and I_7. Capacitors C_1 and C_2 are charged or discharged following the rise or fall of each signal. Switches S_2 and S_3 actuated respectively by the outputs of I_7 and I_6 discriminate the pulses from the capacitors according to the phase relation between signals A and B. The pulses are added partly through a polarity invertor I_8 to form a pulse train of positive (increasing) and negative (decreasing) pulses, following the conditions described in the previous section. An integrator I_9 generates an output voltage for a histogramic display of electron density.

§4. Application to JIPP T-II Device

JIPP T-II device[2)] is a hybrid of stellarator and tokamak, and has a major radius of 91 cm and a limiter radius of 19 cm. Maximum toroidal field is 30 kG. The vertical field is feedback-controlled to maintain a plasma position at the center of discharge tube. The peak electron density of the plasma produced is several times 10^{13} cm^{-3} so that a 4 mm-microwave interferometer generates fringe shifts more than thirty. A zebra stripe system so far used has been replaced by this new interferometer since July of 1977. Several precautions were taken to bring this interferometer into a good working condition. Each crystal mount was electrically isolated from magic-tee with thin insulator film in order to reduce the induced noises which might destroy phase relation between demodulated signals. A careful adjustment of the gains of two amplifiers I_1 and

I_2 was also necessary to cancel the unbalance in the sensitivities of two crystals from the following reason. The unbalance of crystal sensitivities results in an offset level of demodulated signal A, so that the zero-crossing pulses from the comparator do not represent the original phase. A repeller voltage was adjusted to deliver the maximum power from the klystron and minimize the amplitude modulation (A.M.) accompanied with the frequency modulation (F.M.). The AM results in an offset level at the demodulated signal B.

An integrator is used to obtain the histogram for the visualizing purpose. The integrator is gated synchronizing with the generation of the plasma in order to set the zero level. The use of integrator is found practical because it is usually insensitive to residual noise pulses.

An example of the histogram obtained is shown in Fig.3. The rate of an initial rise of electron density is about 10^4 fringes per second. The time response of this system has been found good enough to display such a rapid change of electron density.

§5. Concluding Remarks

A new microwave interferometer has been designed and constructed based on a digitization of electron density evolution, utilizing the phase detection of microwave signals with modulation technique. The system has been applied to the density measurement of JIPP T-II plasma device, and found to be practical provided that proper care is taken to keep the exact phase relations of the detected signals. That is; reduction of induced noises by the isolation of the crystal mounts, cancellation of the offset levels at the demodulators by equalizing the crystal sensitivities and by eliminating the A.M. accompanied with F.M.. The time response of this system is limited by the modulation frequency of microwave source. A rate of 10^4 fringe shifts per second is attained with modulation frequency of 200 kHz at present.

The limitation on the operation of this system comes naturally from the reduction of fringe amplitude due to the attenuation or the scattering of microwave by the plasma, especially when the electron density gets close to the cut off density. This limitation is fatal to any kind of interferometers.

The second system is now under construction to improve the first version. A modulation frequency is increased to 3 MHz in order to obtain better time response. An AC amplifier is employed at the summing amplifier to eliminate the effect due to the offset caused by the unbalance of crystal detectors. In this case, it is necessary to bring the level of operation to a proper one by generating an artificial fringe shifts until just before the plasma is produced, with deeper modulation of 60 Hz triangular waveform superposed on the square-wave modulation at the klystron.

In the second system, the output of the up-down counter is interfaced to a parallel-input register, one of the CAMAC modules which are now in use as a data acquisition system at JIPP T-II project. It is planned to make correction for the nonlinear relation between the electron density and the number of fringe shifts by the computer. The system is also designed to be blinded while the fringe amplitude becomes less than a critical value as the density approaches the cutoff density, and to eliminate miscounting of fringe shift due to random noise pulses.

A feedback stabilization of the source frequency will be adopted in order to eliminate the A.M. which is accompanied with F.M.

It is also possible to improve the resolution in the density measurement by the use of n-level F.M., where the resolution becomes 1/2n fringe. This is especially useful in the case of small number of fringe shifts.

Acknowledgements

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References

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2) Proc. VI Int. Conf. on Plasma Phys. and Cont. Nuclear Fusion Res., IAEA CN-35/D-3, IAEA, Vienna, 1977.
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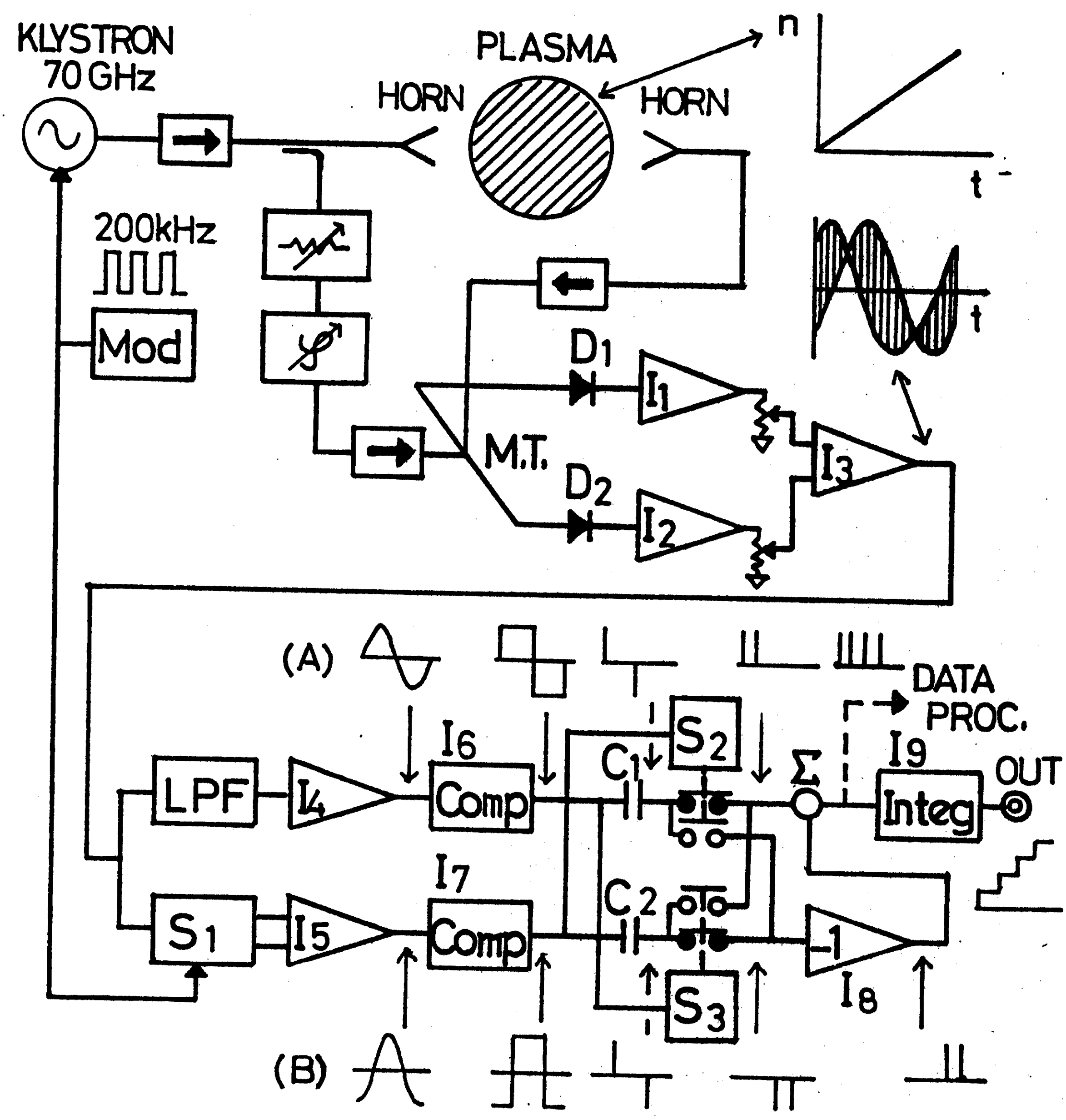
Figure Captions

Fig.1 Schematic diagram of direct-reading type microwave interferometer. M. T.: magic-tee, D_1, D_2: crystal detectors, I_1, I_2, I_3, I_4, I_5, I_8: IC amplifiers, I_6, I_7: comparators, I_9: integrator, S_1, S_2, S_3: analog switches, LPF: low pass filter. Waveforms to be observed for linearly increasing density are also shown.

Fig.2 Oscillograms which show the relations between demodulated signals, outputs of the comparators, up- and down-pulses, and analog output, when the electron density evolution is simulated with triangular-wave modulation of the klystron frequency.

Fig.3 An example of the histogram obtained at the electron density measurement of JIPP T-II plasma.



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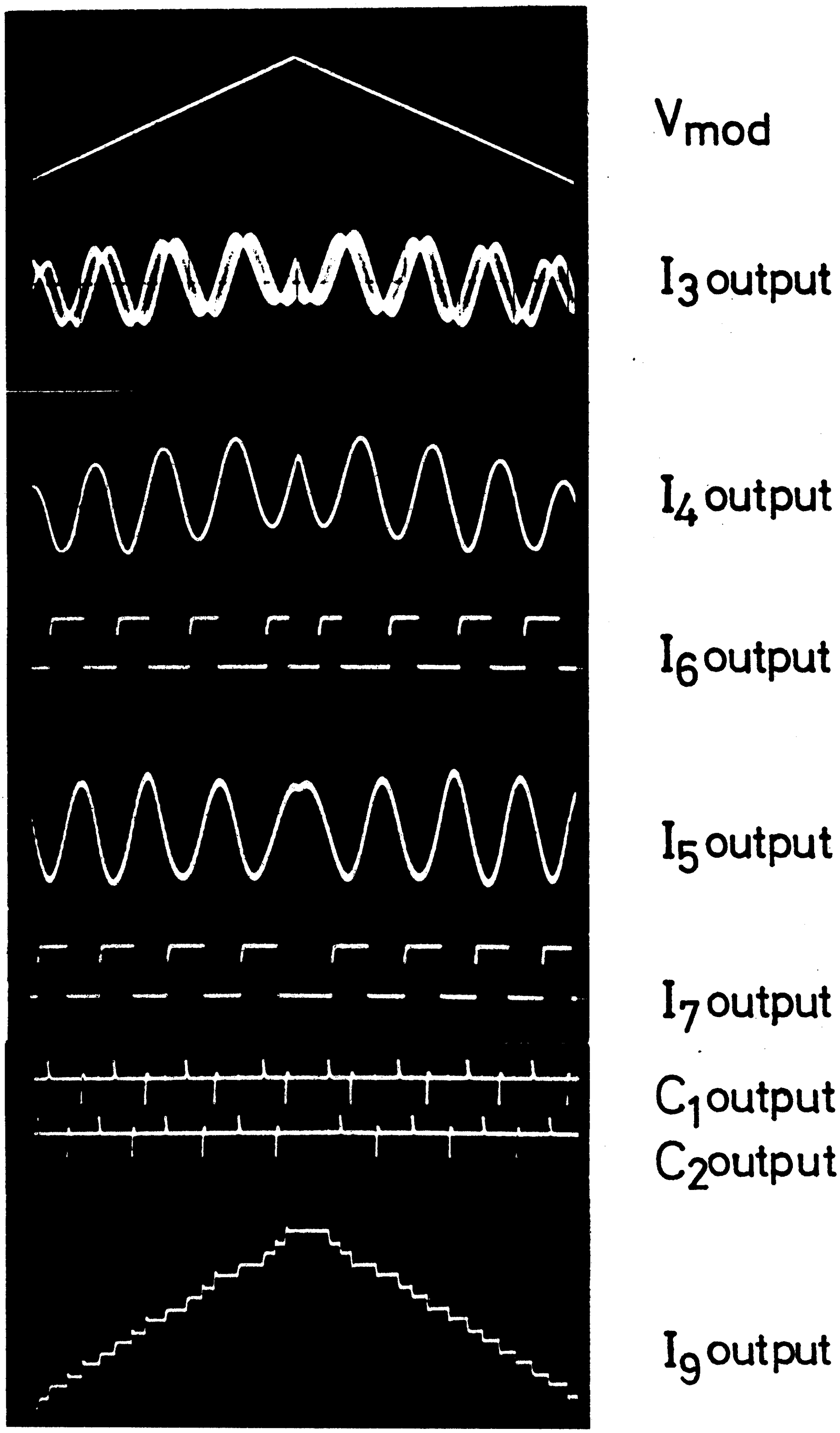

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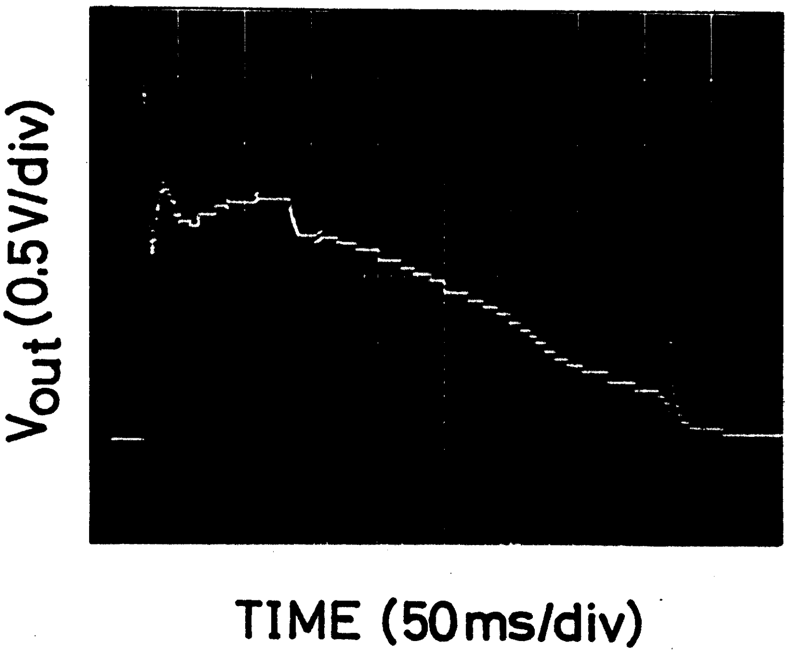

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