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TECHNICAL DESCRIPTION OF THE SOURCES, DETECTION SYSTEMS AND DATA ACQUISITIONS FOR THE JET MULTICHANNEL REFLECTOMETER

by

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CONTENTS

1. INTRODUCTION

A multichannel reflectometer for JET [1,2,3] is described to measure density fluctuations and $n_e(r)$. The diagnostic is under construction at FOM and offers the following features:

1. Twelve channels in the frequency range of 18 - 80 GHz (corresponding electron densities to be probed of 4.10^{18} to 8.10^{19} m).

2. Measurement of plasma movements and determination of the direction of these movements in the fixed frequency mode (insensitive to signal amplitude variations).

3. Profile measurements with high resolution in the swept frequency mode (insensitive to signal amplitude variations).

4. Mode switching from fixed to swept frequency without restraint.

5. Raw interference signal outputs (homodyne) followed by computer controlled band-pass filters.

6. Automatic data recording and handling.

7. High sensitivity (max. acceptable loss 105 dB, with S/N = 25 dB, and Δf = 1 MHz).

8. Distance calibration using the inner wall of the vacuum vessel.

9. Modular set-up.

2. PRINCIPLE OF THE HETERODYNE REFLECTOMETER

The JET multichannel reflectometer diagnostic KG3 employs 12 microwave sources and heterodyne detection systems in the frequency range of 18-80 GHz. The principle of the heterodyne reflectometer is shown in Fig. 1.

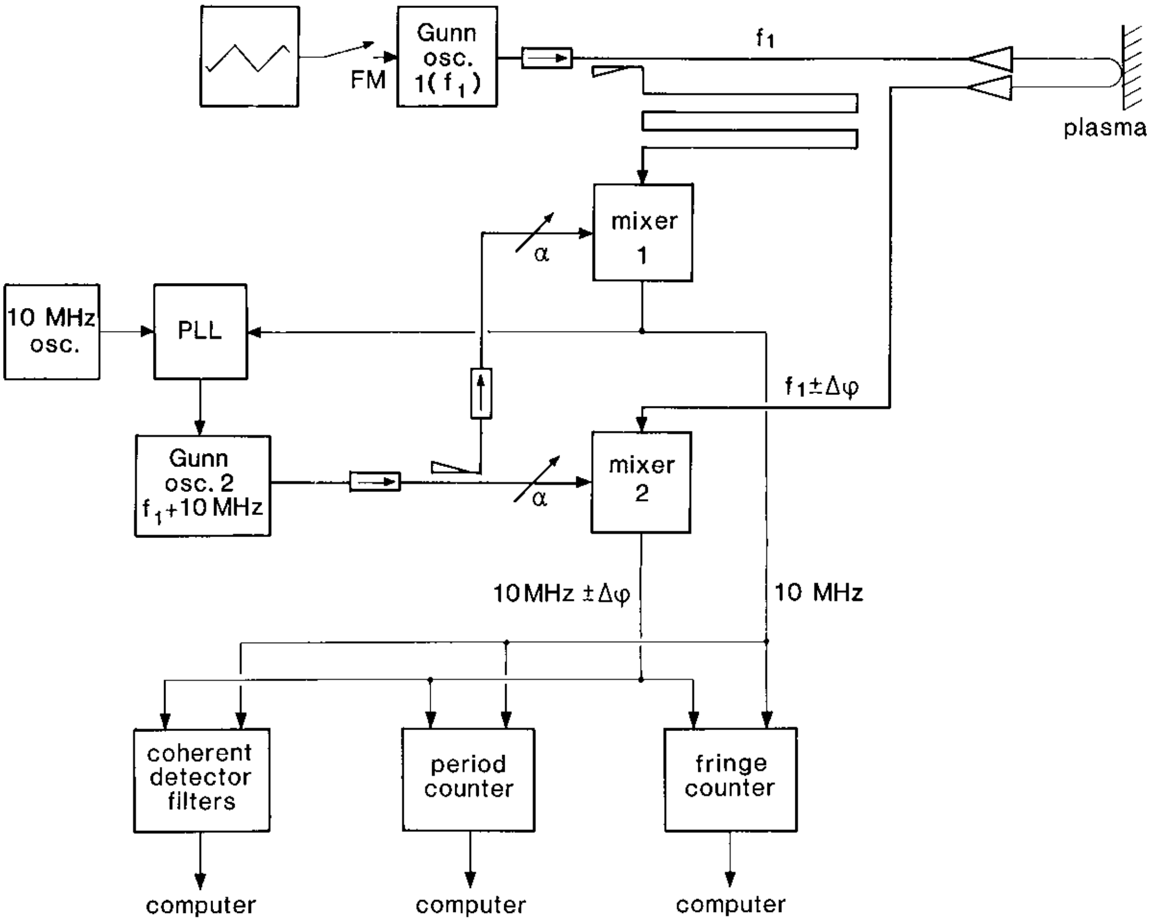

Fig.1. Heterodyne reflectometer.

The microwave source (osc. 1) transmits a wave toward the plasma, which is reflected by the critical density layer into the antenna of the heterodyne receiver. A part of the transmitted signal is split off to the reference waveguide. The frequencies of the reflected signal from the plasma and that from the reference waveguide are converted to 10 MHz using the local oscillator (LO, osc. 2) and the two mixers. Both the source and LO are Gunn oscillators. A phase lock loop (PLL) [4,5] maintains a frequency difference (the IF) of 10 MHz between the source and LO, even when the source frequency is swept to perform a density profile measurement. The maximum $\Delta F/\Delta t$ is 1000 MHz/ms.

The IF signal measured, at the reference mixer, with a Hewlett Packard spectrum analyzer is given in Figs 2 and 3. The first graph shows the IF signal in the unlocked state and the second graph shows the locked state of the PLL.

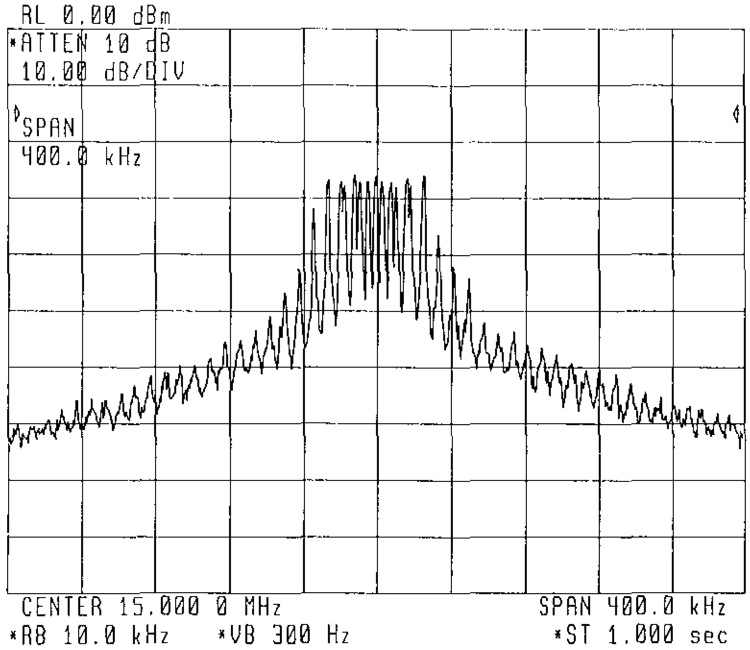

Fig. 2. IF signal in the unlocked state.

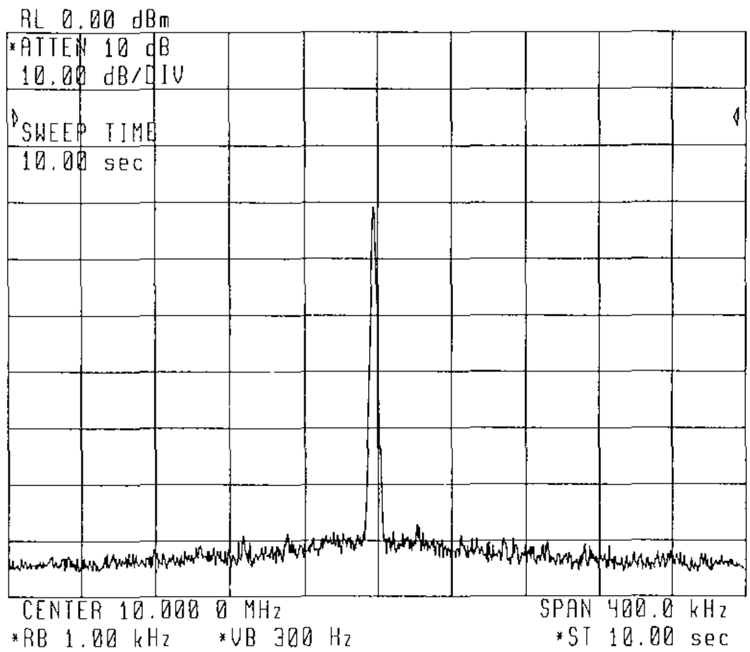

Fig. 3. IF signal in the locked state.

The fringe counter monitors the direction and amplitude of the movement of the critical density layer. Since the signal-to-noise (S/N) ratio of the heterodyne system is high, the resolution is only defined by the chosen fringe counter configuration and is 1/32 of the relevant wavelength.

When the source frequency (f1) is swept, a phase shift is generated which is proportional to the path-length difference in the arms of the reflectometer. This path-length difference is measured by the period counter with an effective resolution of less than 30 mm. The path-length difference can be calibrated simply if a signal reflected from the inner wall of the vacuum vessel can be measured.

The coherent detector will convert the two mixer signals to the D.C. intermediate frequency (homodyne) to follow density fluctuations, both amplitude and phase sensitive.

The measuring systems are described in more detail in Section 6 (page 11).

3. SCHEMATIC OVERVIEW OF THE MICROWAVE SYSTEM

An overview of the 12-channel reflectometer microwave hardware is given in Fig. 4.

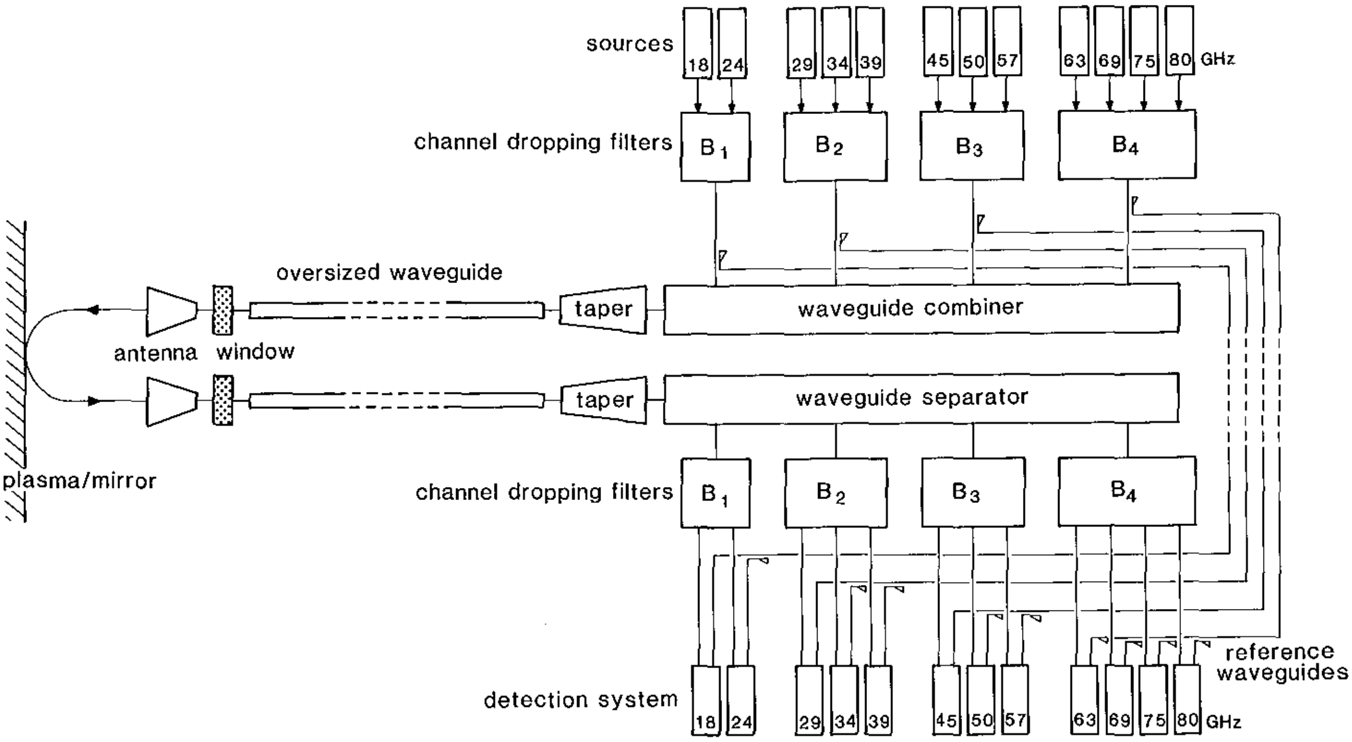

Fig. 4. Overview of the microwave system.

The combiner and separator system, the channel dropping filters and the antennae are designed and built by ERA Technology Ltd (UK). The source and detection modules are described in Sections 4 and 5.

The multichannel reflectometer employs four different reference waveguides. The sources are grouped together with channel dropping filters using waveguide bands WG20, WG22, WG24 and WG26. The reference guides are built in WG18. All bends are in fundamental waveguide with tapers to WG18. The signals from the four reference waveguides are split up with 3 dB directional couplers to the 12 reference detectors. The losses in the reference waveguides are below 30 dB. Thermal waveguide-expansion effects are negligible.

4. SOURCE MODULES

Twelve Gunn oscillators are employed as the sources (Hughes 4727xH). Table 1 gives the centre frequencies of the Gunn oscillators with the applied waveguide and flange number.

Table 1

FREQ. (GHz)	WAVEGUIDE	FLANGE
18.6, 24	WG20	UG-595/U
29, 34, 39	WG22	UG-599/U
45, 50, 57	WG24	UG-383/U
63, 69, 75, 80	WG26	UG-387/U

The Gunn oscillators (Fig. 5) are electronically tuneable over a band of 1 GHz, and have a minimum output power of 40 mW.

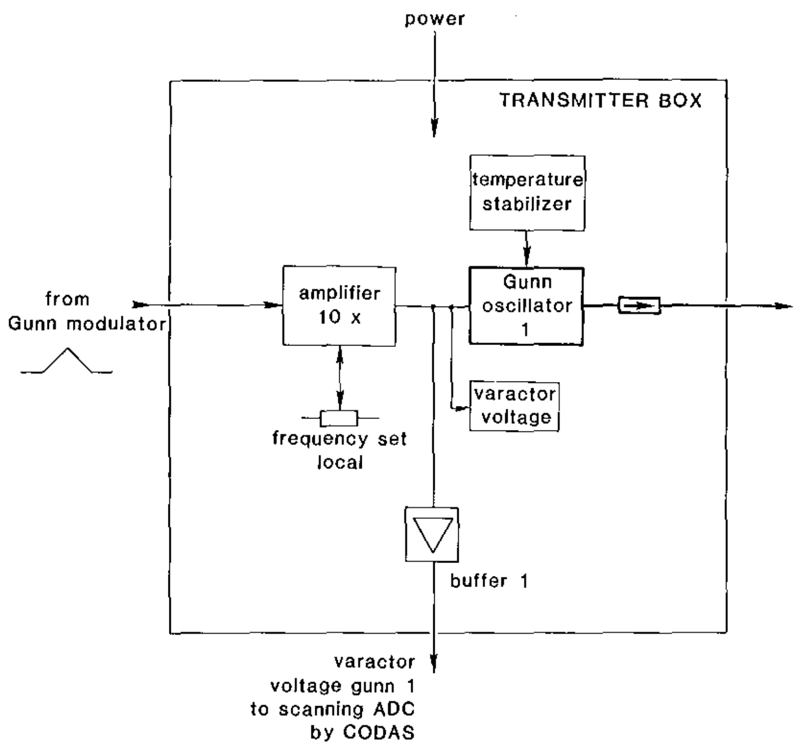

Fig. 5. Source module.

The exact frequencies can be read with the control program from the frequency/varactor voltage characteristics stored in the computer. The frequency/voltage characteristics are linear over a frequency range of 200 MHz within a few percent. When the reflectometer is working in the frequency sweep mode, a software correction can be made on the frequency/voltage characteristic. Temperature controllers will keep the centre frequencies of the sources stable within ± 10 MHz.

5. HETERODYNE RECEIVER MODULES

Figure 6 shows the heterodyne receiver module.

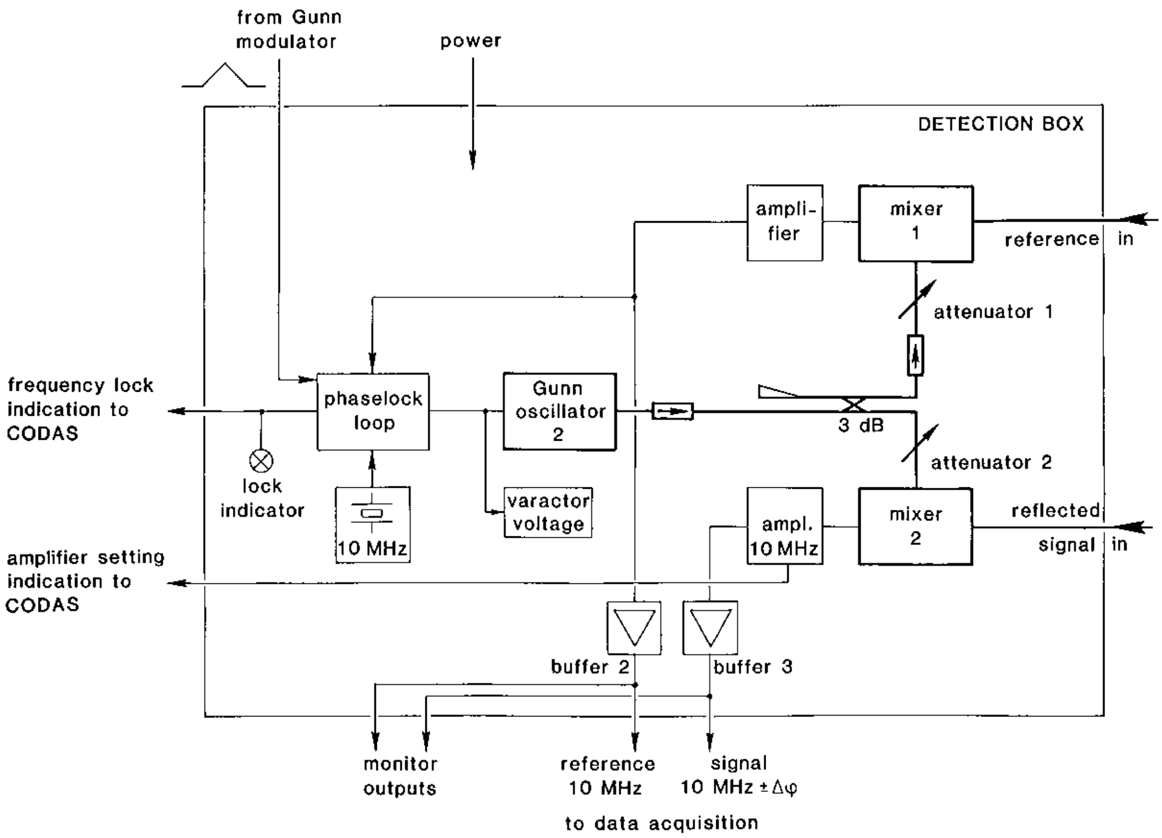

Fig. 6. Heterodyne receiver module.

The mixers are Hughes (4741xH) planar crossbar mixers using GaAs beam lead diodes which yield a conversion loss of less than 6 dB. The minimum detectable power with a S/N ratio of 100/1 and a bandwidth of 1 MHz is 1.10^{-12} W. This is about 105 dB under the power level of the sources. The LO power can be set with the attenuators. Two attenuators and an isolator are employed to provide maximum isolation between the reference and the signal. The reference mixer 1 is followed by a wideband 40 dB amplifier with two outputs; one for the PLL circuit and the other for the 10 MHz reference. The signal detector, mixer 2, is followed by a manually controlled and remotely monitored 10 MHz IF amplifier with 2 MHz bandwidth and voltage gains of 0, 10, 20 and 30 dB.

6. CONTROL AND DATA ACQUISITION

The scheme of the control and data acquisition is given in Fig. 7.

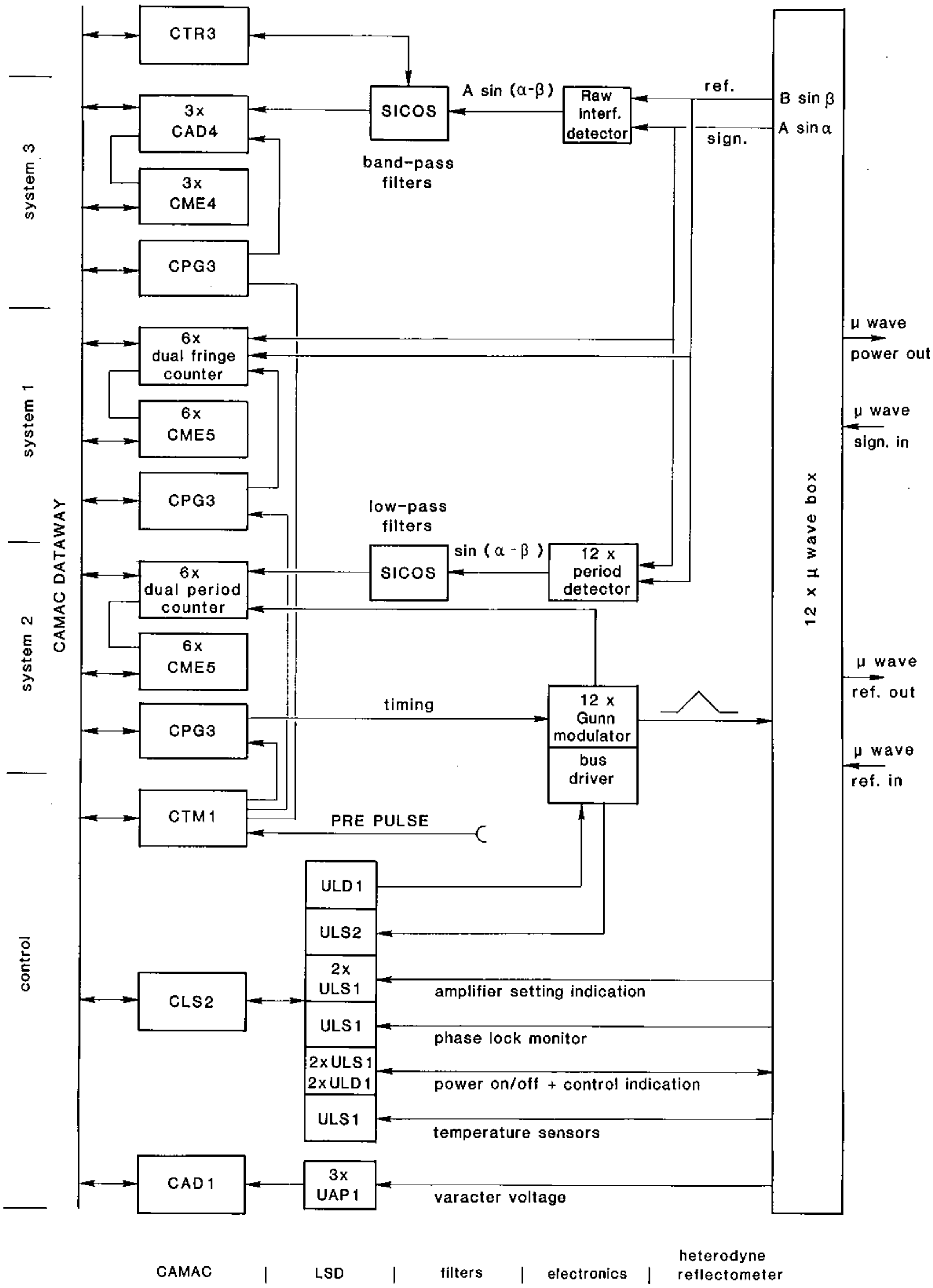

Fig. 7. Control and data acquisition.

6.1 Control

All relevant functions associated with the operation of the multichannel reflectometer are controlled and monitored via CODAS, the JET computer system. Monitor signals and switches are controlled via the line surveyor/driver module CLS2 via input/output cards ULS1,2 and ULD1. The varactor voltage of the Gunn oscillators (sources) are measured with a scanning ADC, the CAD1. The SICOS filter modules are controlled and monitored with the CTR3 interface, using RS232.

6.2 Data acquisition

The data acquisition system measure, digitizes and stores all relevant settings of the multichannel reflectometer diagnostic KG3.
There are two modes of operation:

1. the fixed frequency mode, and
2. the swept frequency mode;

and three measuring systems:

1. the fringe counter,
2. the period counter, and
3. the coherent detector.

6.2.1 Fringe counter

The CAMAC dual fringe counters CPD3 measure the direction and amplitude of plasma movements (Fig. 8). Each channel (A and B) can be enabled or disabled individually. The phase shift, during each sample time, will be converted to two 16 bit data words (channel A and B) which will be multiplexed and written into a 64 k memory CME5 (LeCroy dual-port memory module, model MM8206/n).

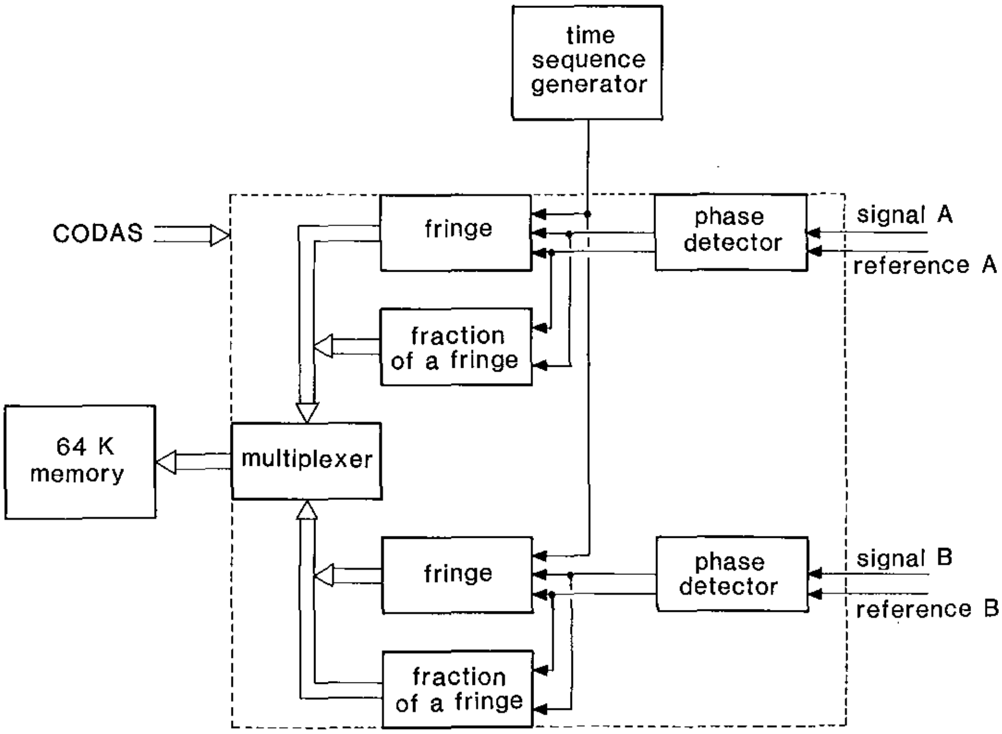

Fig. 8. Fringe counter system.

The fraction of the fringe, measured with an ADC, is stored in 6 bits and the fringes in 8 bits, both in 2's complement (Fig. 9). The most significant bit contains the channel information. The resolution is 1/32 of a fringe. A time sequence generator CPG3 (Culham) controls the sample rate.

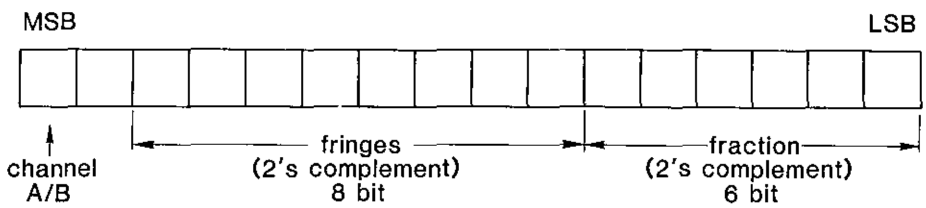

Fig. 9. Fringe counter data word.

6.2.2 Period counter

Profile measurements can be made in the swept frequency mode using the period counter CTD3 (Figs. 10,11).

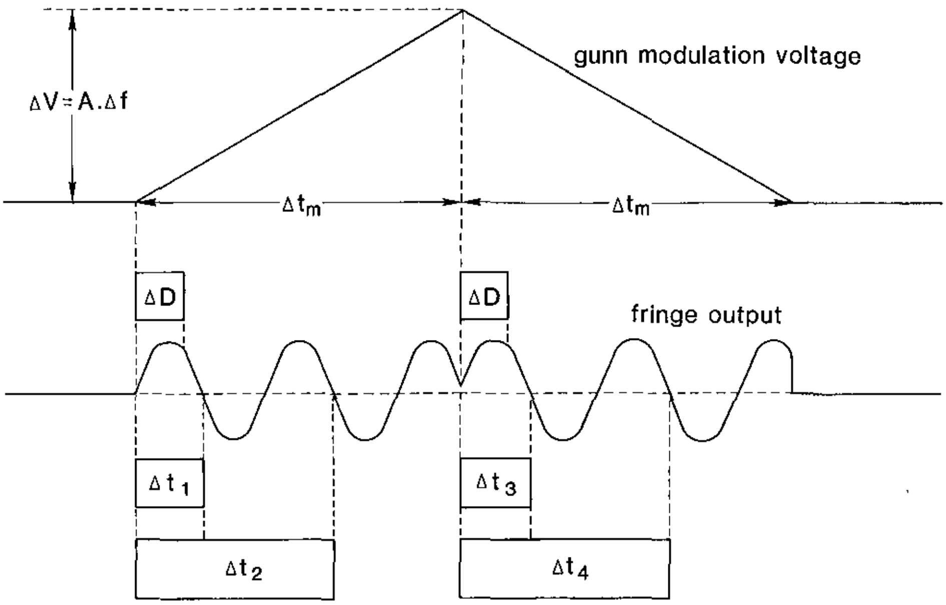

Fig. 10. Swept frequency mode.

In the simplified situation where the plasma density layer is a ideal mirror, the length difference between the reference and the plasma path is given by:

$$\Delta L = A \cdot \frac{1}{\Delta t_2 - \Delta t_1} \cdot \frac{\Delta t_m}{\Delta V} \cdot c ,$$

where:

ΔL = difference in length between reference and plasma path

A = calibration constant (Gunn oscillator)

$\Delta t_{1,3}$ = start measurement period time

$\Delta t_{2,4}$ = stop measurment period time

Δt_m = sweep time (set with computer)

ΔV = amplitude sweep voltage (set with computer)

c = speed of light

ΔD = dead time (set with computer).

The period counters are devided into two parts (period detectors and counters) with low-pass filters between the sections to filter out plasma MHD instabilities (Fig. 11).

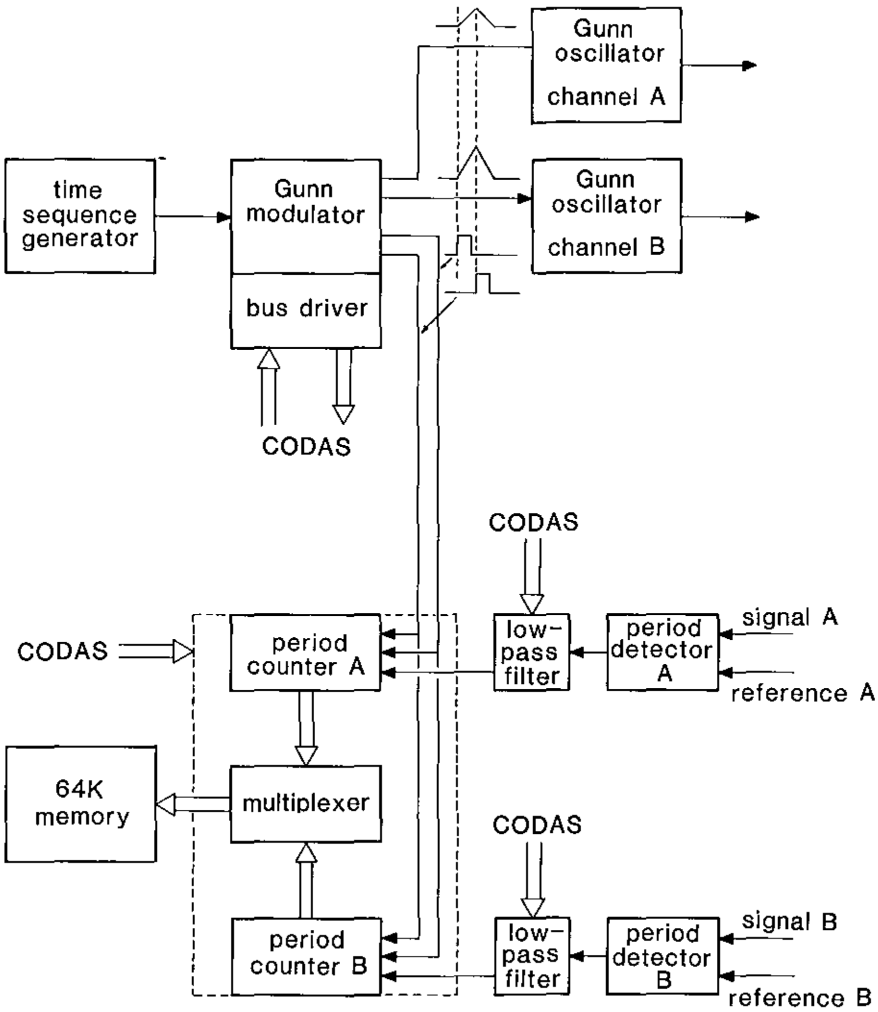

Fig. 11. Period counter system.

The CAMAC dual period counters (CTD3) can be pre-conditioned in the following way. The CAMAC period counters CTD3 are dual modules (A and B) in which each channel can be enabled or disabled individually. A dead time can be set from 1 to 255 × 20 μs with 8 bits to accomodate the filter delay. The clock frequency can be set in steps of 2× from 1.25 MHz to 20 MHz. With the different clock frequency settings, the maximum accuracy of the period counter can be chosen at a certain selected sweep time. The counter of the CTD3 starts at the up (c.q. down) of the timing pulse. At the first zero-crossing after the dead time, the counted number is stored in data word t_1 (c.q. t_3), the counting goes on until the end of one period.

The second time measured is stored in data word t_2 (c.q. t_4). This approach is chosen in order to correct the measurement for the unlinearities in the frequency/varactor-voltage characteristics of the Gunn oscillators which are stored in the computer memory. The frequency/voltage characteristics can be accurately measured with a hp 71200A spectrum analyzer and a 16 bit ADC under computer control.

The times measured when the source is swept up and down in frequency are stored in the memory CME5 in four 16 bit data words. The most significant bit in each word will identify the channel (A or B) (Fig. 12).

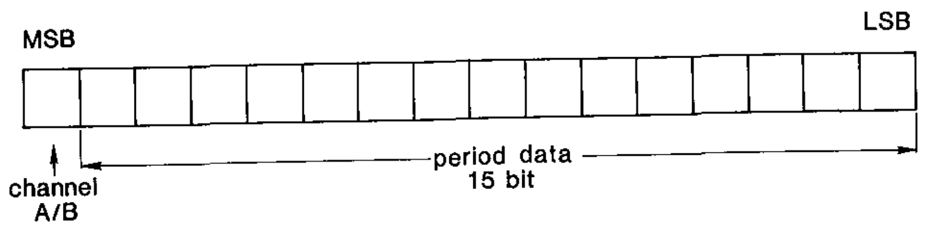

Fig. 12. Period counter data word.

The Gunn oscillator frequency modulator, associated with the period counter, is controllable via CODAS and yields the following features:

1. The sweep time of the modulator can be set in steps of 2× from 200 μs to 25.6 ms for a single sweep.
2. On a trigger from the time sequence generator CPG3 an up and a down ramp are performed.
3. The amplitude of the triangular voltage can be set with 8 bit accuracy to maximum 10 V.

6.2.3 Coherent detector

The analogue signal from the coherent detectors (bandwidth 1 MHz), are passed through programmable equal time delay filters and amplifiers, and are recorded by 12 bit analogue-to-digital converters CAD4's (LeCroy 8210) and memories CME4's (LeCroy 8800/12) (Fig. 13).

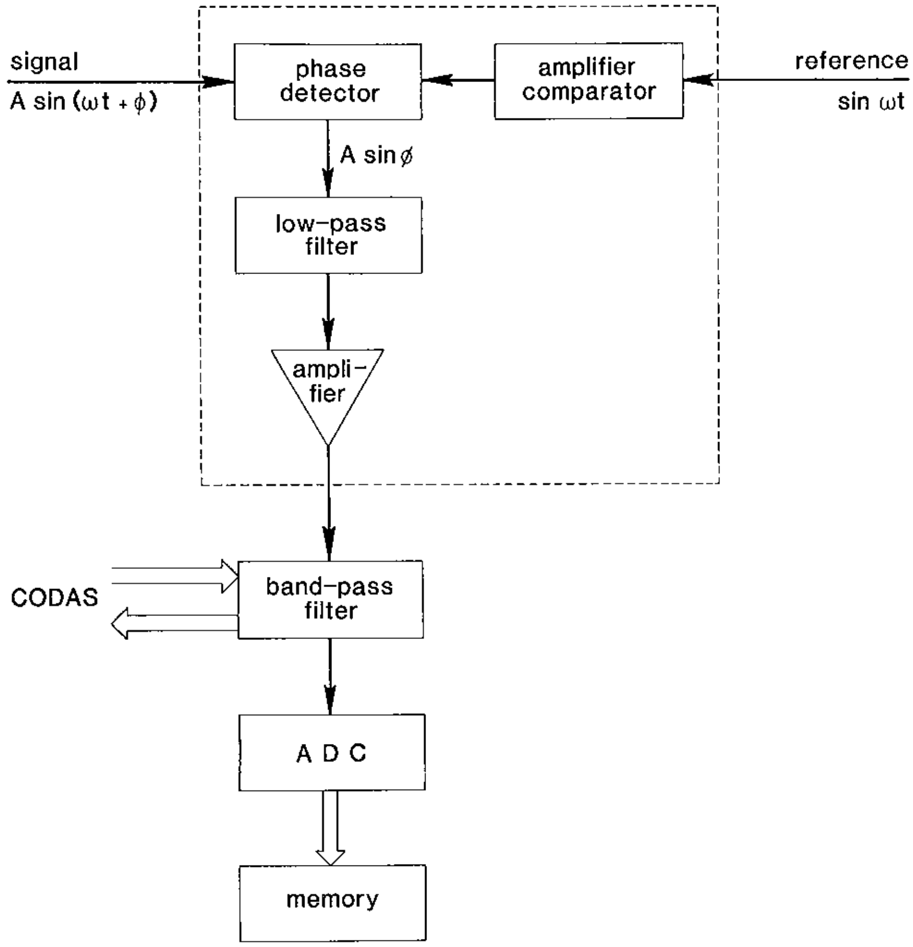

Fig. 13. Coherent detector system.

A time sequence generator CPG3 controls the sampling rate (up to 1 MHz). The data can be used to study plasma fluctuations.

7. ACKNOWLEDGEMENT

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8. REFERENCES

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