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USER OPERATION AND MAINTENANCE MANUAL

D-band one channel Interferometer
Part No. MMI-170

1ˢᵗ Edition
June 2007

Table of Contents.

1. INTRODUCTION.

This instruction manual contains information on installation and operation of the D-band Interferometer.

1.1 General Description.

D-band interferometer is intended for measuring the line-averaged density of a plasma along the path through which the mm-wave beam is passed, through phase shifts in the propagated beam.

Base principle of operation is an effect of change of phase speed of electromagnetic waves of a millimeter range in plasma depending on density.

2. SPECIFICATIONS.

2.1 Electrical Specifications.

1. RF Frequency   168 GHz;
2. LO Frequency   170.4 GHz;
3. Frequency Stability   10 ppm;
4. Time Phase Analyze   5 µs;
5. Time collection   131 ms;
6. Phase error measurement   0.3 radian;
7. Output RF Power   +12 mW;
8. IQ Detector Frequency   50 kHz;
9. RF to IF Gain   70 dB with AGC system;
10. Conversion Loss of Mixer   11 dB;
11. Noise Figure   14 dB;
12. Gain of Horn   30 dB;
13. Waveguide   WR-06
14. Flange   UG-387/U-M
15. Data interface   TCP/IP Ethernet;
16. External trigger   TTL;
17. Input impedance of trigger input   500 Ohm;
18. Extension waveguides   WR-28;
19. AC Power   220 VAC
20. Operating temperature range: +10°C…+ 50°C;

2.2 Mechanical Specifications.

1. Transmitter   170x360x50 mm;
2. Receiver   300x380x50 mm;

2.3 Block-diagram of the interferometer.

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                            ┌────────────────────────────────────────────────────────────────────────────┐
100 MHz in                  │ ┌─────────────┐   ┌─────────┐   ┌─────────┐   ┌─────────────┐   ┌──────────┐ │
RJ-45                       │ │ Synthesizer │→→ │ Coupler │→→ │ Doubler │→→ │   IMPATT    │→→ │   BPF    │ │
                            │ │    7 GHz    │   │         │   │         │   │ Multiplier  │   │ 168 GHz  │ │
7 GHz out                   │ └─────────────┘   └────┬────┘   └─────────┘   │     x12     │   └──────────┘ │
SMA                         │                        │                      └─────────────┘               │
                            └────────────────────────┴────────────────────────────────────────────────────┘
                                              TRANSMITTER                                      Horn

                                                                                             TOKAMAK

                                                                                              Horn
                                              RECEIVER
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TRANSMITTER

Horn

TOKAMAK

Horn

RECEIVER

| VCO 7.1 GHz | Coupler | Doubler | IMPATT Multiplier x12 | BPF 170.4 GHz | Balance Mixer |

7 GHz in SMA

Balance Mixer

IF=100 MHz

Phase Detector

LNA 2.4 GHz

PA with AGC

100 MHz RJ-45

Reference Crystal Oscillator 100 MHz

Synthesizer 2.40005 GHz

IQ Detector

Sin / Cos, AGC signal, 4 pins connector

50 kHz

Controller TCP/IP

Controller With ADC

TCP/IP interface, RJ-45

TTL, External trigger, Opto-isolated, BNC

2. 4 Principle of operation.

The interferometer operates at fixed frequency. Due to all built-in oscillators are phase-locked by one reference Cristal oscillator 100 MHz, there is a possibility to control phase shift of mm-wave signal is passed through plasma.

Mm-wave oscillators (transmitter and LO for receiver) are built on one principle. The transmitter consists of synthesizer 7.0 GHz, direction coupler 1:10, doubler and multiplier x12 with integrated high power amplifier at 14 GHz. The synthesizer is built on DRO 7 GHz with varactor tuning and uses external 100 MHz reference, which comes from the receiver. The direction coupler provides 7 GHz signal for receiver. The transmitter generates output frequency at 168.00 GHz (7 GHz x24) is phase-locked by the reference Cristal oscillator 100 MHz.

The mm-wave receiver consists of DRO 7.1 GHz with varactor tuning, direction coupler 1:10, doubler, multiplier x12 with integrated high power amplifier at 14 GHz and balance mixer. For stabilization IF signal and phase-locking LO frequency, the signal 7 GHz from transmitter is used. After down conversion the signal from transmitter we have IF frequency 2.4 GHz. Then this signal is amplified by LNA and comes to power amplifier with built-in AGC system. AGC system allows to keep stable amplitude of IF signal in 30-70 dB attenuation range in mm-wave channel. Response time of AGC system is 2.5 microsec. Then stabilized IF signal is applied to IQ mixer, where as LO oscillator synthesizer 2.40005 GHz is used. The synthesizer 2.400005 GHz is also phase-locked by reference Cristal oscillator 100 MHz. IQ mixer provides two IF signals 50 kHz (sin and cos), which are digitized by built-in 12 bits ADCs. The controller converts digital data in Ethernet pockets and transfers them via TC/IP interface to PC station.

PC station collects data from the interferometer and calculates absolute phase changing during discharge of plasma. The software operates the following way: as 50 kHz signals and trigger of ADC converters are locked by one reference, we can control only pass zero points of IF signals without any additional reference signal, i.e. relation between period of IF signal and quantity of digitized points inside of this period is constant in anytime (without plasma). Such way we get absolute rate Pi / (digitized points) φo and can control phase shift of signal during discharge of plasma. As we have two 50 kHz signals from IQ detector (sin and cos) total pass zero points is twice more and finally time phase analyze is 5 microsec. The software calculates time different between close pass zero points and compare it with absolute rate. Then sum different between actual and absolute rate:

$$\sum_{N}^{0}\left(\varphi o + \varphi(n-1) - \varphi(n)\right)$$

Where,
n - number of current pass zero point from the beginning of discharge.
N – total quantity pass zero points during of discharge

After collection data and calculation total drift of phase the software recalculate phase in absolute changing of density of plasma with rate pi = 1.264*10^(19) / m^3.

3. INSTALLATION AND FUNCTIONAL TEST.

3. 1. Assembly procedure.

The interferometer can be installed directly near windows of TAKAMAK or removed from it by extension WR-28 waveguides, as it presented on picture below.
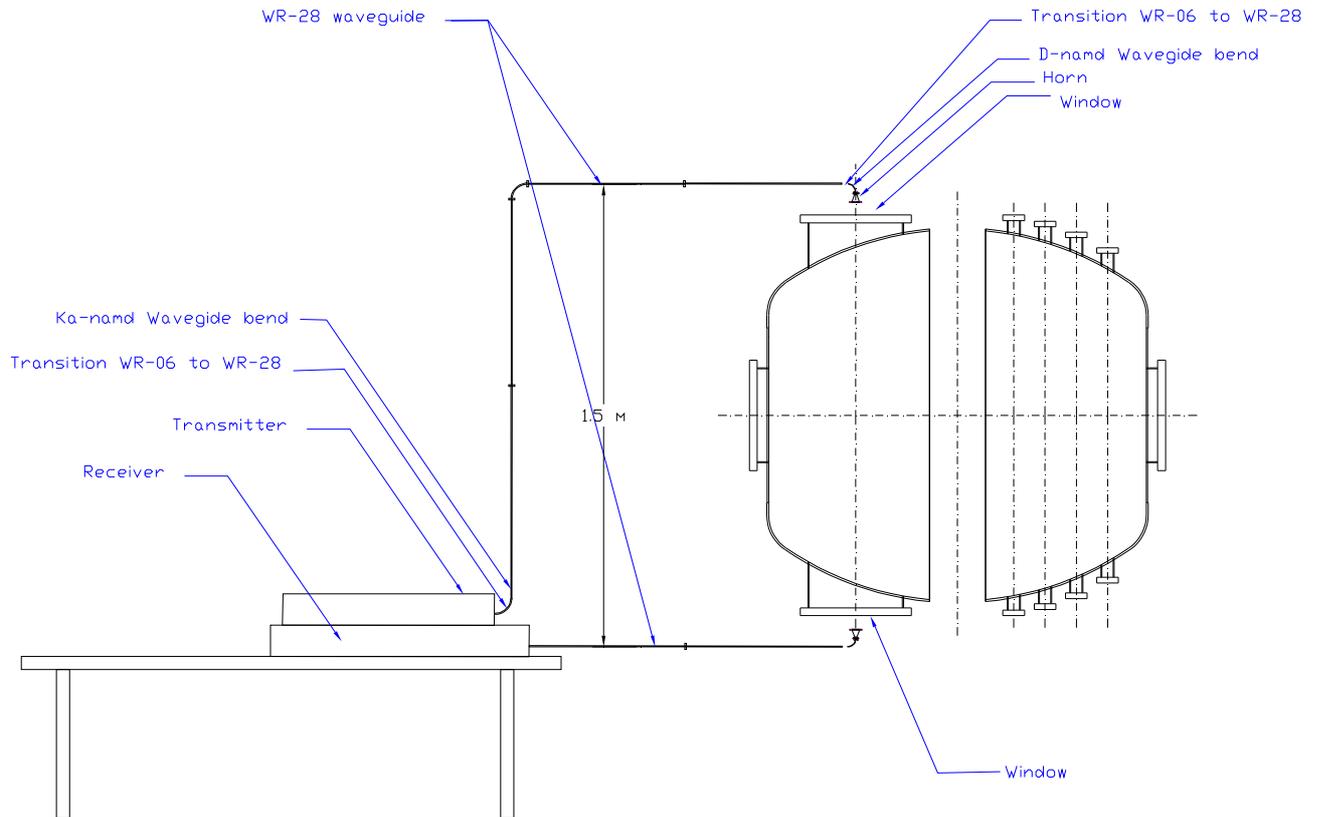
Waveguide's set of the interferometer consists of the following components:

- Waveguide transition WR-06/ UG-387/U-M to WR-28 / UG-599
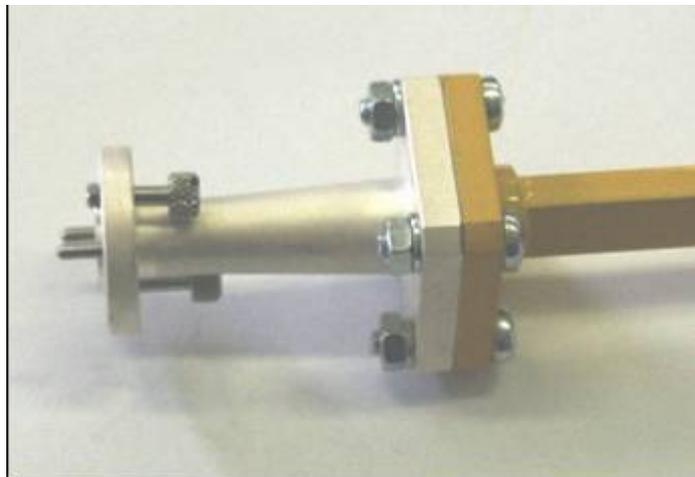
- Waveguide bend WR-06/ UG-387/U-M for horn

- Waveguide bend WR-28/ UG-599

- Extension WR-28 waveguides, length 50-70 cm

The user can assemble waveguides in any order according to presented situation. Presented waveguide configuration on the picture has the following order:

      Receiver:

Receiver input – waveguide transition WR-06 to WR-28 – extension waveguides WR-28 - waveguide transition WR-28 to WR-06 – D-band bend – Horn

Transmitter:
Transmitter output – waveguide transition WR-06 to WR-28 – WR-28 bend - extension waveguides WR-28 - WR-28 bend - extension waveguides WR-28 - waveguide transition WR-28 to WR-06 – D-band bend – Horn
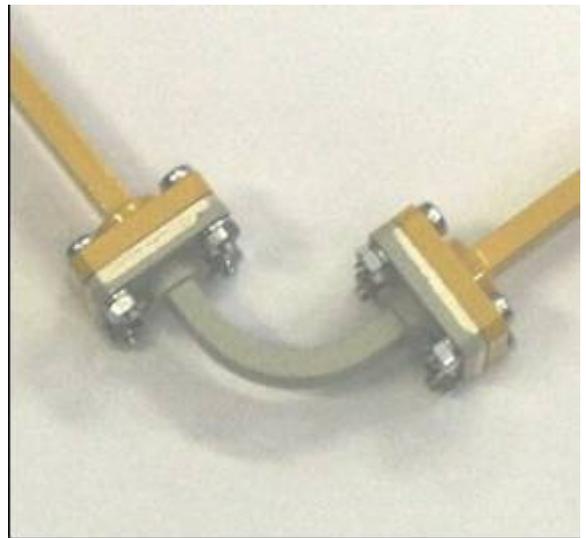
After setting waveguides the following connection according block-diagram of the interferometer should be done:
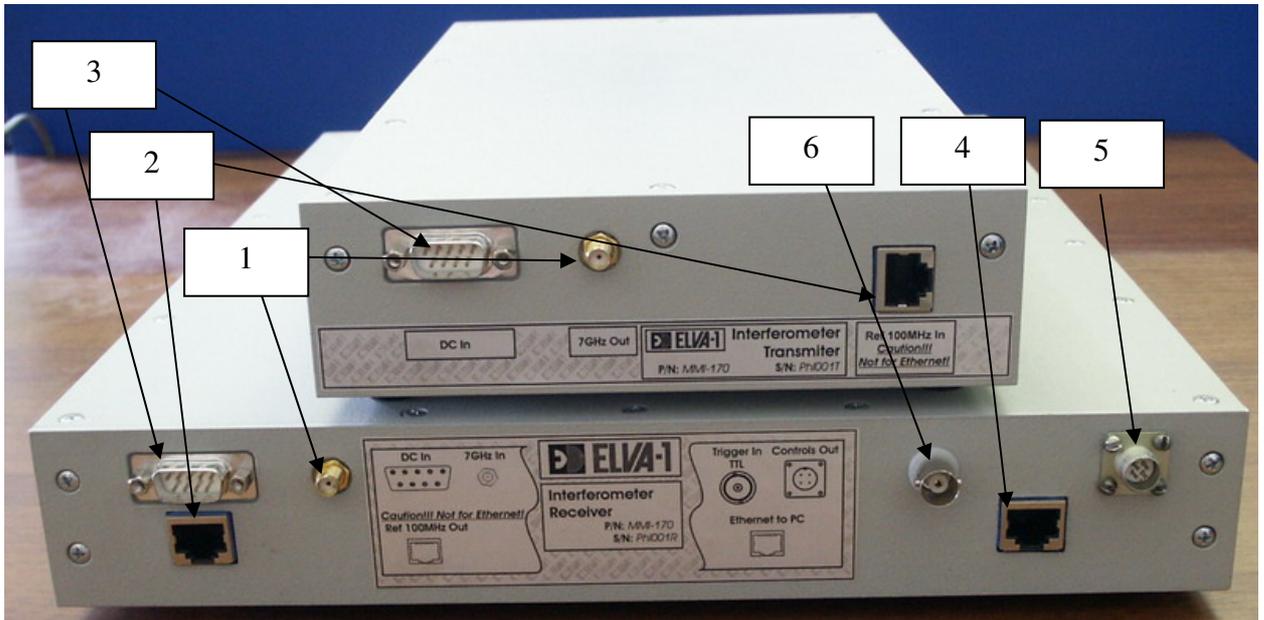
1. 7 GHz reference signal from the transmitter to receiver by coaxial cable with SMA connectors.

2. 100 MHz reference signal from the receiver to transmitter to receiver by TP5 cable with RJ-45 connector. Be careful to use correct socket on receiver.

3. Power supplies via applied cables with DB-9 connectors. Power supplies are equal and can be used any for transmitter and receiver.

4. Receiver to PC station by TP5 cable with RJ-45 connector. Be careful to use correct socket on receiver.

5. Special cable for control IF signals 50 kHz and AGC signal. BNC connectors – IF signals, pin connectors – AGC signal.

6. Connect pin connectors (red – signal, black - common) of special cable to DC voltmeter. Estimated voltage range measurement < +10DCV. BNC connectors to any oscilloscope for control 50 kHz IF signals.

When all connections are done, complete PC station with standard monitor, keyboard and mouse and switch ON all power supplies and PC.

3. 2. Test and tuning procedure.

Before starting to work with system, the user has to test and tuning horns (if it is needed). For that the user should switch on system in free running mode and check form of IF signals and level of AGC system.

After switching power supplies and PC, wait while PC automatically connect with interferometer. The icon connection should appear in task bar:

Then run program 'Interferometer' (placed on desktop), the main menu of program appears:

For setting free running mode (don't wait external trigger for starting, operation in cycle), press by mouse button 'Settings', the following menu appears:

Then remove marker from Trigger mode window by mouse and press 'OK' or 'enter' on keyboard and program comes back to main menu. Press 'Test mode' button and real time oscilloscope window with 50 kHz IQ signals appears:

To control sinusoidal wave form of IQ signals and AGC signal tune horns such way to get maximum available level of AGC signal. Below dependence of AGC signal vs attenuation in waveguide channel is presented. For reference, total attenuation in assembling system and distance 1.5m between horns in open area should be about 30 dB, that corresponds to about +2.78V output of AGC signal.

AGC voltage vs. Attenuation in path
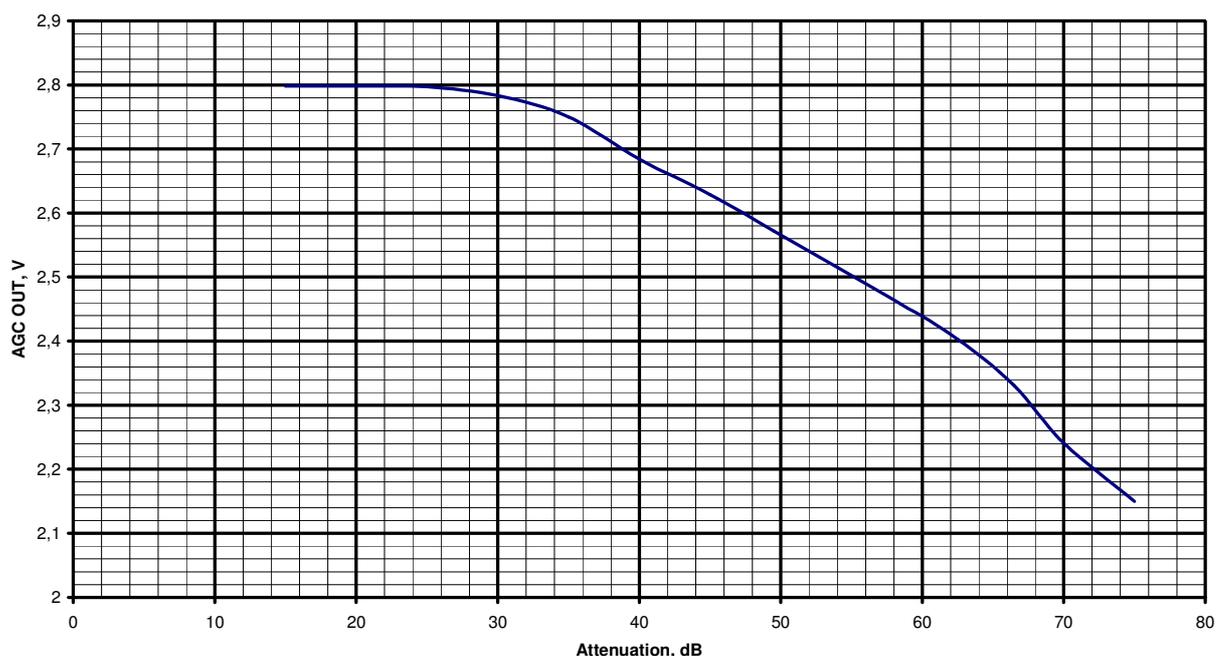
After tuning procedure the user should test operation of system in free running mode, for that press 'Measure' button from main menu and software stars to collect data and then prepares data for viewing. During operation software shows actual procedures and then presents final result.
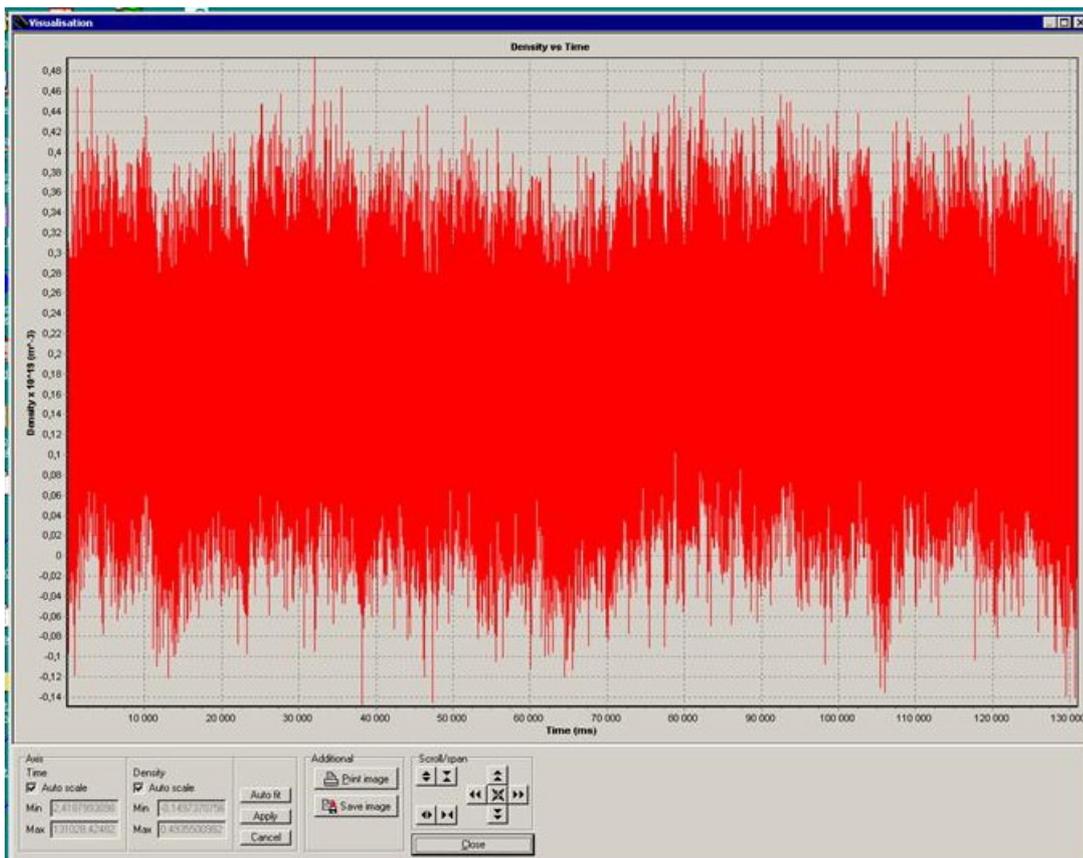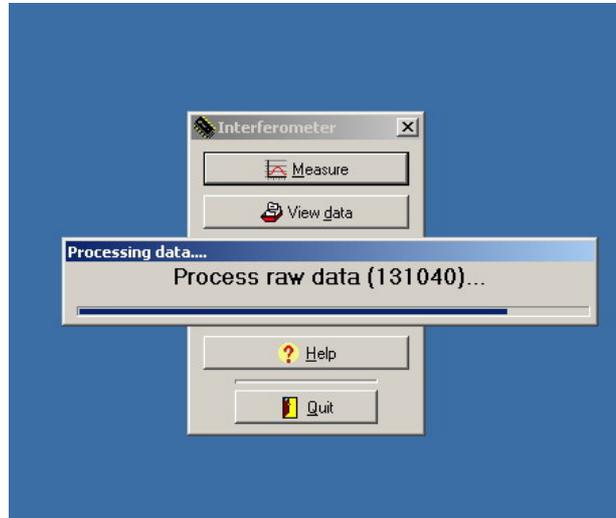
4. MEASUREMENTS.

4. 1. Put into operation.

1. Connect cable with trigger signal from TOKAMAK control system to opto-isolated BNC connector (6) on the receiver. The trigger pulse should be TTL standard and has duration no less then 1 ms. The interferometer starts to collect data with rise front of the trigger pulse.

2. Set external trigger mode from settings menu.
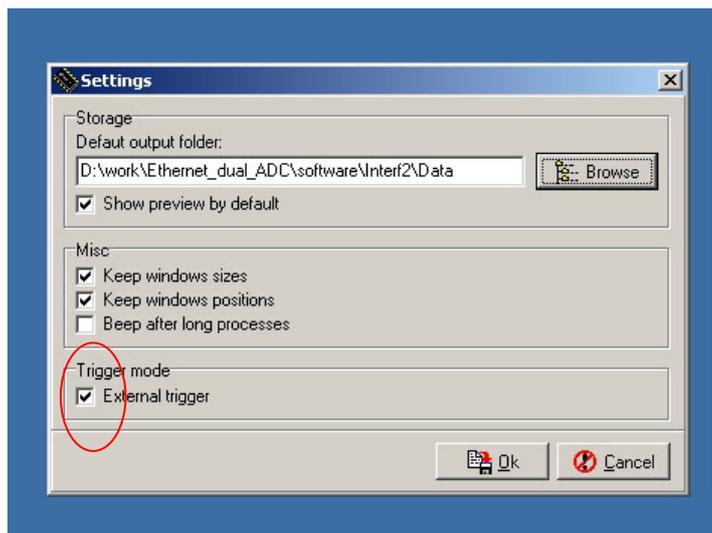
3. Select folder for default saving data. The folder can be chosen via button 'Browse'.
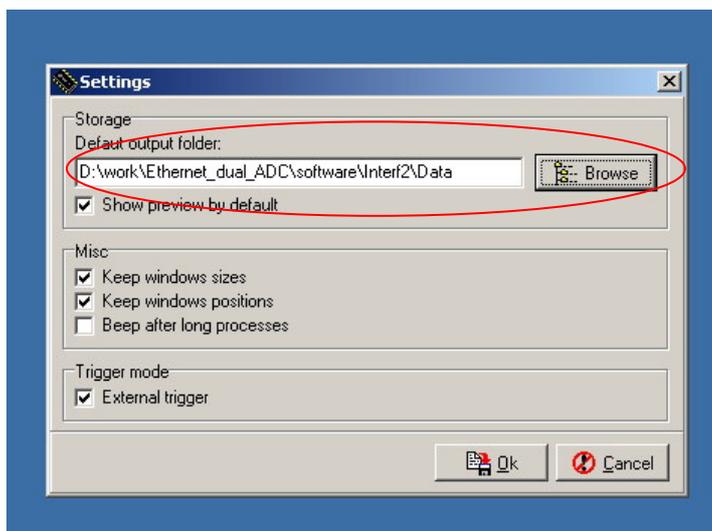
4. Return to Main menu, after setting press 'OK'.

4. 2. Measurements.

Press button 'Measure' from main menu

The system comes into waiting for trigger regime
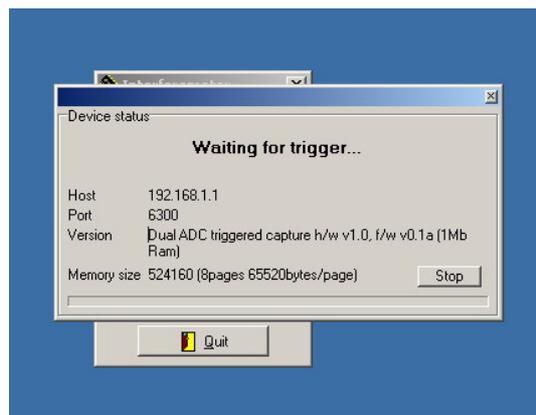
After receiving trigger pulse, software begins to collect data
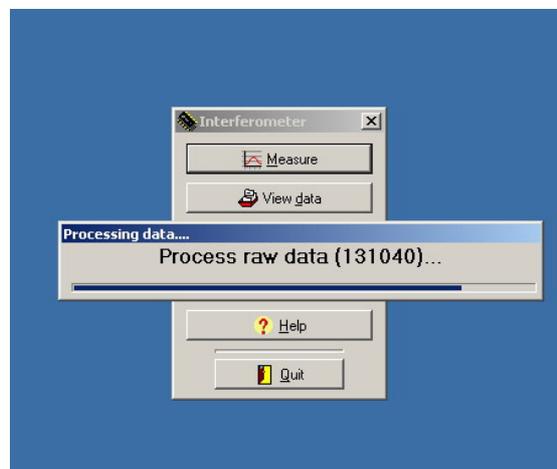
When software collects and proceeds data density curve vs time discharge is presented.
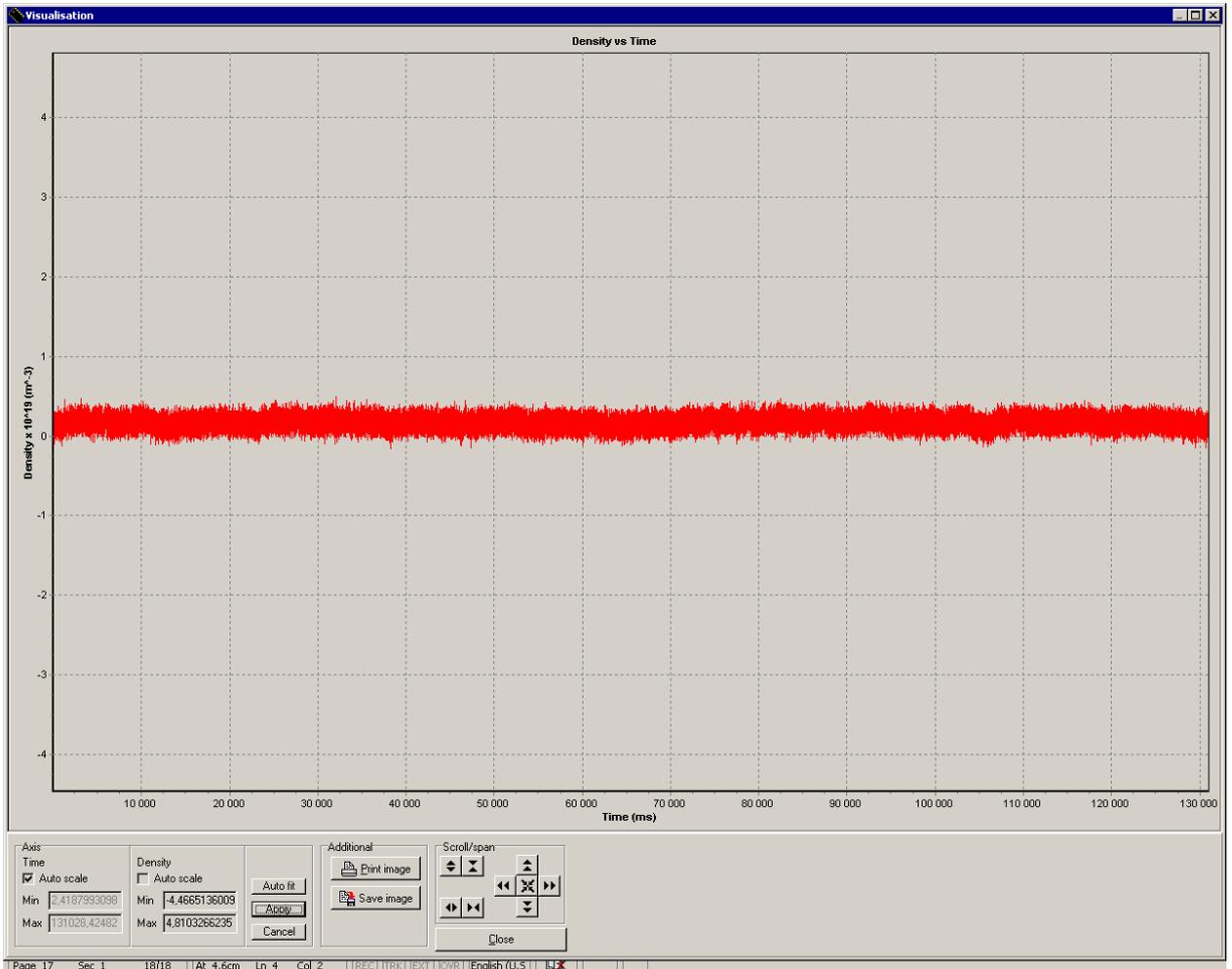
4. 3. Save data.

After proceeding data, press button 'Close' and save menu appears
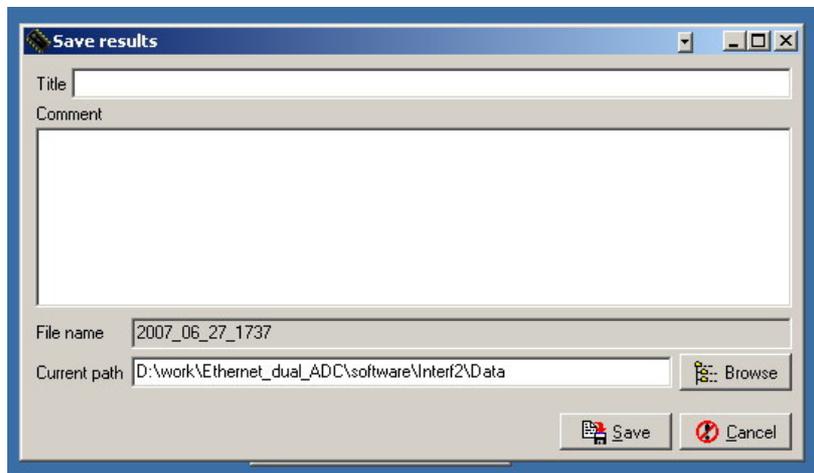
The software automatically generates name of file in real time format: year_month_date_current time of measurement (hrmin). Optionally the user can add title, any comments in saved file and select directory. Then press button 'Save', software saves data and returns to Main menu.

If the user doesn't want to save this data, he should press 'Cancel' and software comes into Main menu.

The software saves data for one measurement in three files with following extension and contains:

- *.ch – raw digital data from IQ channels vs number of sampling;
- *.cm – title and comments of data;
- *.rz – density vs real time (µs).

4. 4. View data and software tools.

To view saved data press button 'View data' from Main menu and preview window appears:
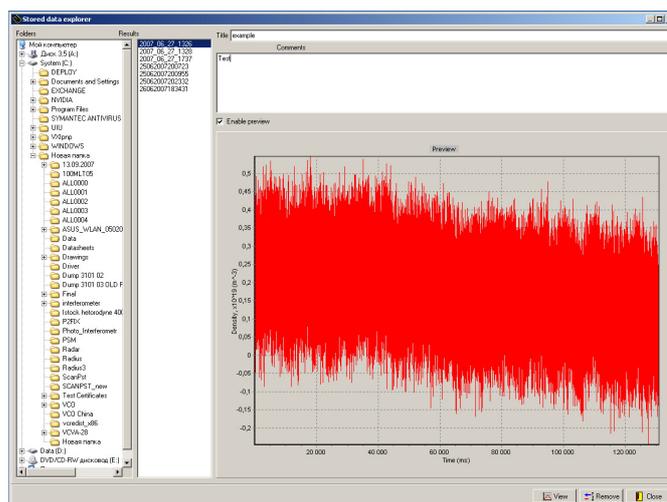
Optionally the user can lock the primary preview. Remove marker.
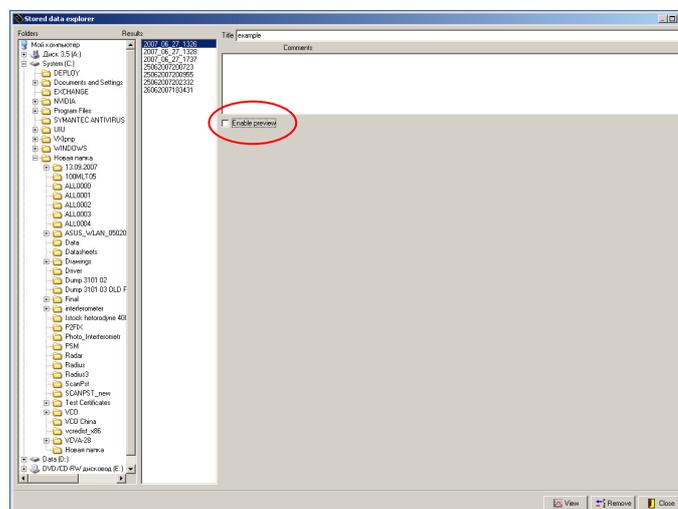
For detail looking data through press button 'View' and window with software tools will be activated.
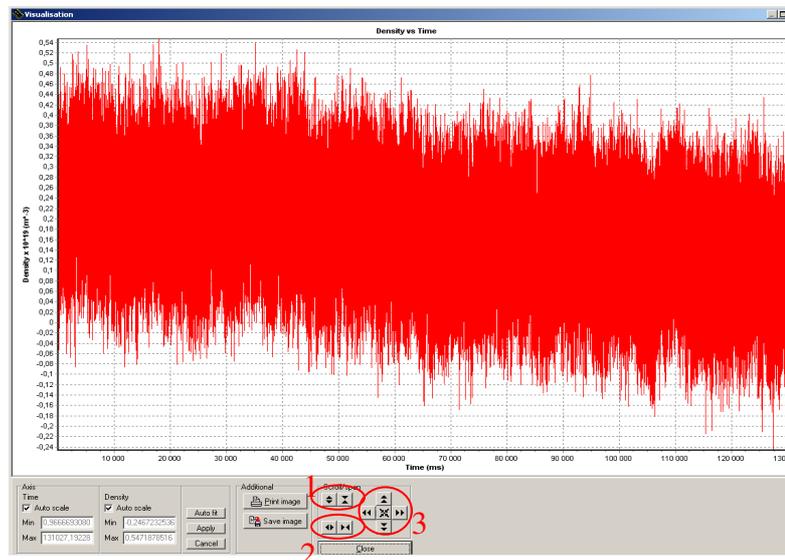
In initial stage auto scale regime is installed for X and Y scales. To unlock auto scale remove markers from Auto scale windows and pres 'Apply'. After that, the user can use Scroll / Span buttons group.

'1' – zoom in / out for Y axis (density);
'2' – zoom in / out for X axis (time);
'3' – joystick for shifting and compressing;

For selection observed field the customer also can use the PC mouse. For that press left mouse's knob and select desired field.
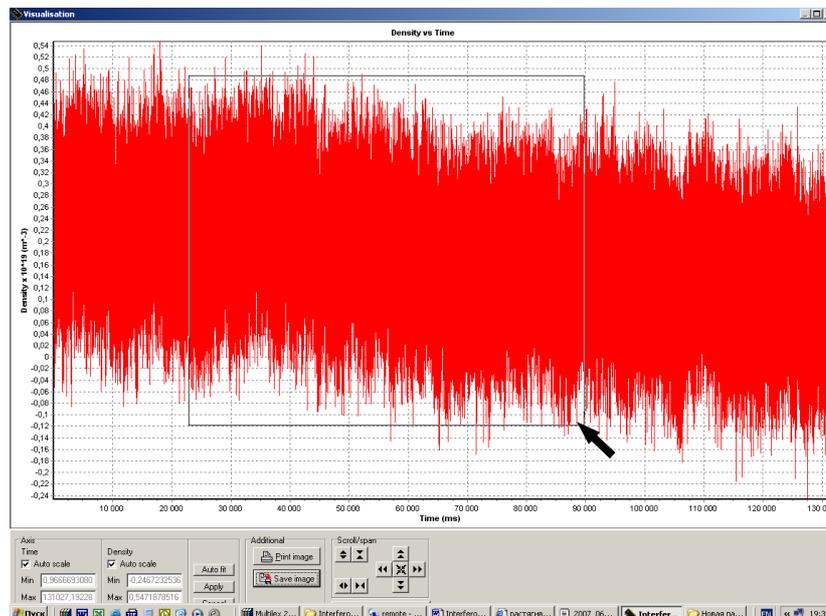
Print or save picture in bmp format use buttons accordingly.
Return in auto scale regime set markers into windows and press 'Apply'
Return in preview press 'Close' and another saved data can be chosen for viewing.