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Heterodyne Sweeping Radiometer Operation Manual

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1. GENERAL REMARKS

1.1. 52 – 85 GHz Heterodyne Sweeping Radiometer, hereinafter called Radiometer, is intended to be used for plasma temperature measurements on TCV BR Tokamak.
1.2. The Receiver may be used in laboratory conditions.

2. EXPLOITATION

Conditions:

operations temperature:	5°-40° C°
relative air humidity :	up to 95% at the temperature 30° C°
primary power:	AC(220±10)V/(50±0.5)Hz
atmospheric pressure:	84-112 kPa.

3. PARAMETERS

Operational Frequency range is 52-85 GHz. Device has a reserve more then 1% at the edges of the range.
LO output power is 10 – 30 mW.
LO frequency stability is better than $5*10^{-4}$.
Typical LO frequency sweep time from 52 to 85 GHz is 150 us.
Minimal time of one 30 % LO frequency step is 50 us.
Noise figure is better then 13 dB (better then 15 dB at frequency range edges ± 1 GHz).
IF band is 0.1 to 1 GHz.
Video Amplifier integration time (manually switched) is: 1 uSec, 10 uSec, 100 uSec and 0.5 mSec.
Harmonic Oscillator for LO calibration

Frequency Stability is better than 1 ppm;
Long Term Amplitude Stability is better than 5%.
Harmonics frequencies are 6*N GHz, where N = 9 – 14

Noise source model ISSN-15 for calibration of Noise Factor of the Radiometer

Typical ENR is 15 dB;
Typical Flatness is +/-1.5dB;
Long time stability is better than 0.01 dB/°C

Cryogenic matched load return loss is better then 20 dB.

4. RELIABILITY

4.1. Main time to failure, no less than 2000 h.
4.2. 90% life time, no less than 1 year.

5. CONSTRUCTIVE PARAMETERS

5.1. Dimensions 495x180x480 mm.
5.2. Weight, no more than 20 kg.

6. PRINCIPLE OF OPERATION

Block Diagram of the Radiometer is presented on fig. 1.

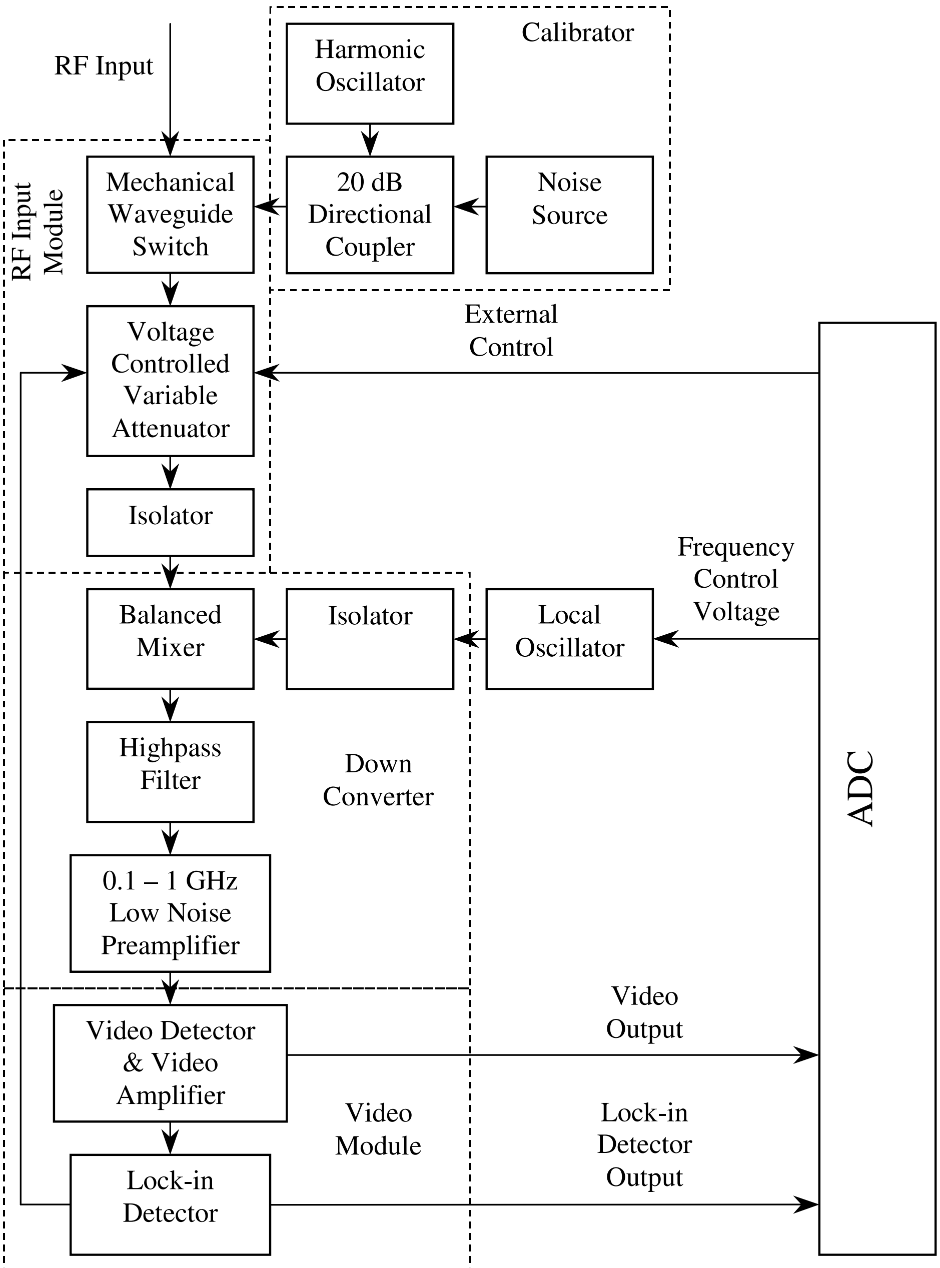

Fig. 1. Receiver Block Diagram.

The blocks depicted are:

1. Local Oscillator (MMW Generator G4-140, see operation manual).
2. MMW Receiver (see technical description) made of
   Calibrator
   RF input module
   Down-converter
   Video module
3. ICP A-812 ADC card needed for the LO external frequency control, VCVA attenuation control, acquiring data from the Lock-in Detector and video Outputs.

Principles of the plasma temperature measurements are presented on fig. 2.

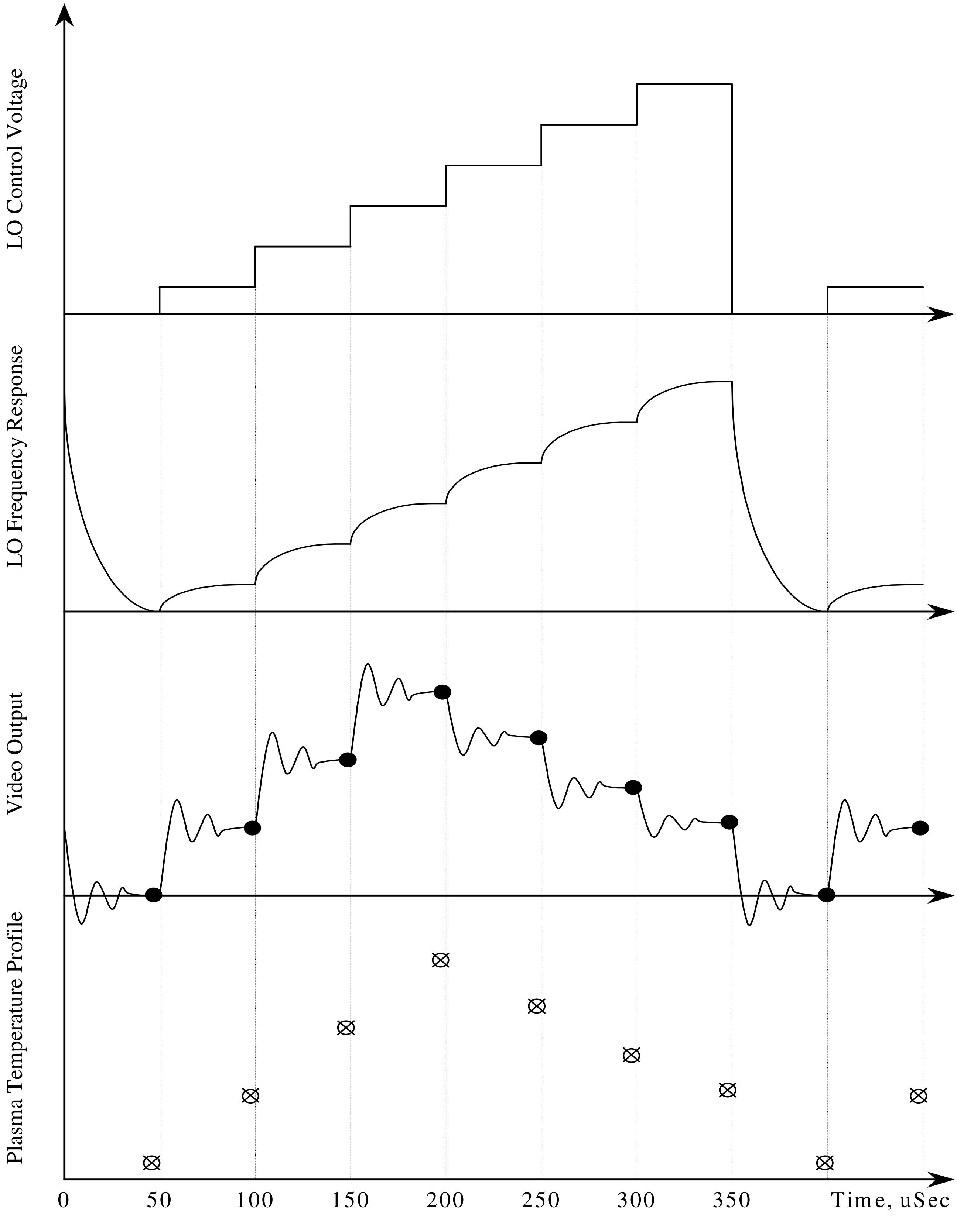

Fig. 2. Basic principles of the plasma temperature measurements.

The basic fact that in the magnetized plasma electrons emit electromagnetic energy at electron cyclotron frequencies with intensity proportional to the plasma temperature. As there is toroidal magnetic field gradient in the tokamak plasma, electrons at different points along the major radius of the torus radiate at different frequencies. So the radial electron temperature distribution can be measured by changing the frequency received by the radiometer.

The fact is that in used scheme of the heterodyne radiometer LO frequency defines the input radiometer frequency but IF bandwidth – frequency resolution along the major tokamak radius. So changing of the LO frequency allows measuring of the major radius temperature distribution.

Step controlling voltage like presented on fig. 2 is applied via digital-to-analog converter to the external control input of the Local Oscillator. LO frequency setting time (50 uSec) defines the maximum available Radiometer sampling rate because one have to wait until the LO output frequency become stable after the control voltage changing. Maximum available sampling rate of the Radiometer is 20 kHz.

To achieve the maximum available speed of the temperature measurement one has to do the following:

1. Set the desired LO frequency
2. Wait 50 uSec until the LO frequency become stable
3. Acquire the data from the Video Output of the Radiometer
4. Set the next LO Frequency.

7. PRINCIPLES OF THE RADIOMETER CALIBRATION.

Integrated calibrator (see fig. 1) is specially designed for the LO frequency and the Radiometer sensitivity calibrating. It includes:

1. The Harmonic oscillator made of the master 6 GHz DRO and frequency multiplier. At the output they produce a signal consisting of 7 harmonic components, 48, 54, …, 78, 84 GHz. The fact that the harmonic Oscillator provides better than 1 ppm long time frequency stability can be used for the day to day LO frequency calibrating.
2. The Noise Source that provides white noise signal within the 52 – 85 GHz frequency band with stable output power density. The fact that the Noise Source provides better than 0.01 dB/°C long time amplitude stability allows using of the device for the Radiometer sensitivity calibrating.
3. Cryogenic Matched Load especially for the measurements connected to the RF input of the Radiometer instead of the signal from plasma.

LO Frequency calibration.

The LO frequency calibration is performed for the checking of the frequency step values generated by the Local oscillator. Calibration signal from the Harmonic Oscillator comes to the input of the Down Converter via the coupled channel of the 20 dB Directional Coupler and Mechanical Waveguide Switch. As the calibration signal is much more powerful than signal from plasma additional attenuation should be set by the Voltage Controlled Variable Attenuator via the VCVO External Control input. To make a calibration one have to change step-by-step the LO frequency from the lowest to the highest and acquire output video signal. Signal from the Harmonic Oscillator should provide response at 54, 60, 66, 72, 78, 86 GHz. Getting the data from the Harmonic oscillator and comparing the results with the previous measurements allows to check the LO frequency stability.

The Radiometer Sensitivity calibration.

The fact that the integrated Noise Source provides white noise signal with stable output power density can be used for day-to-day Radiometer sensitivity calibration. Calibration signal from the Noise Source comes to the input of the Down Converter via the direct channel of the 20 dB Directional Coupler and Mechanical Waveguide Switch. To make a calibration one have to change step-by-step the LO frequency from the lowest to the highest and acquire output video signal. As the signal from Noise Source is very stable signal at the Video Detector Output also should be stable. Comparing the new acquired data with the previous allows day-to-day checking of the radiometer sensitivity and gain.

Noise Source calibration.

Stability of the ENR of the Noise Source can be checked using the Cryogenic Matched Load (CML). CML presents a standard black body noise source stabilised at liquid nitrogen boiling temperature, 77.4 °K. So at any time CML can be used as a precision source of the white noise. The only problem is that signal level from CML is very low, much smaller than the Radiometer noise. So Lock-in Detector is intended for measurements using CML. While calibrating CML is connected to the Radiometer RF input. Signal from the CML comes to the input of the Down Converter via the VCVA which is modulated with the 1 kHz oscillator of the Lock-in Detector. Being controlled with the same 1 kHz oscillator as VCVA, the Lock-in Detector measures difference between the signal at the closed VCVA, that is noise of the Radiometer itself and the signal at the opened VCVA, that is the radiation from the CML. Comparing data acquired from the CML and than from the Noise Source using the scheme with the Lock-in Detector one can check the Noise Source ENR stability.

8. OPERATION MANUAL.

Plasma temperature measurements.

Block diagram of the plasma temperature measurements is presented on fig. 3.

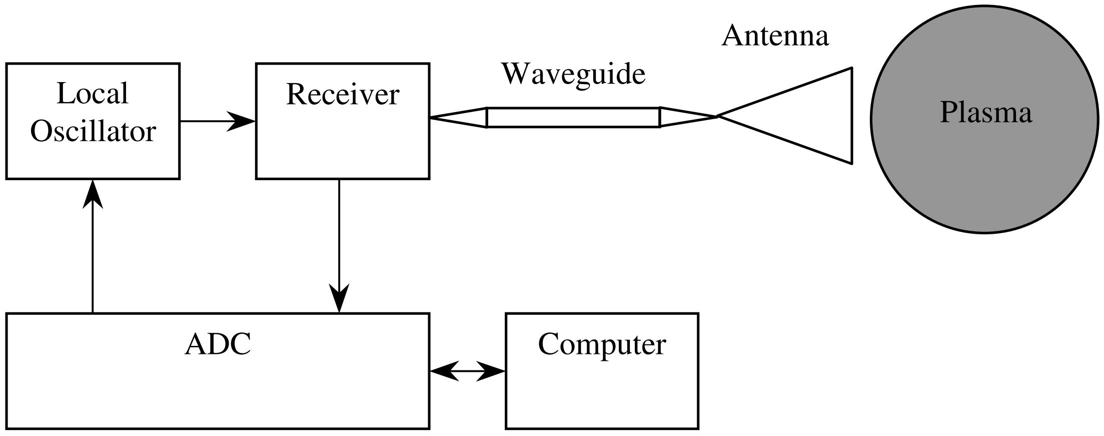

Fig. 3. Block Digaram of the Plasma Temperature measurements.

To prepare the Radiometer for measurements:

1. Install the Local Oscillator into the rack or on the table
2. Install the Receiver on the Local Oscillator
3. Connect the LO output to the Receiver LO input
4. Install the Antenna near the tokamak vacuum window. Distance between the Antenna and window should be 0 – 5 cm.
5. Connect the Antenna and RF input Of the Receiver with set of the oversized waveguides.
6. Connect DA1 output of the ADC Card (see manual for the A-812 ADC card) to the External Broadband Frequency Control Input (input 5, G4-140 manual).
7. Connect Video Output of the Receiver (output 13, see the Receiver Technical Description) to the AD 11 input of the ADC.
8. Turn on the Local Oscillator in the external frequency control mode (see G4-14- manual).
9. Turn on the Receiver as mentioned below:
    - Set the Calibrator switch in "OFF" position
    - Set Mechanical waveguide switch in "SGN" position
    - Choose the needed Video bandwidth using the Integration time switch
    - Turn off the amplitude modulation of the RF signal by means of Modulation switch. Modulation Indicator should mot glow.
    - Turn on the Receiver and warm up it during 30 min.

To measure the one temperature point evaluation set fixed LO frequency and acquire data from the Receiver Video output during the tokamak pulse. LO frequency defines the position of the temperature point on the torus major radius .

To measure the temperature profile sent sequentially to the LO frequency control input series of the voltage steps as mentioned in fig 2. One step length should not be less than 50 uSec (the LO frequency setting time). Changing of the LO Frequency allows to scan the plasma temperature along the torus major radius.

Calibration of the Local Oscillator output frequency using the Harmonic oscillator.

Block Diagram of the calibration is presented on fig. 4.

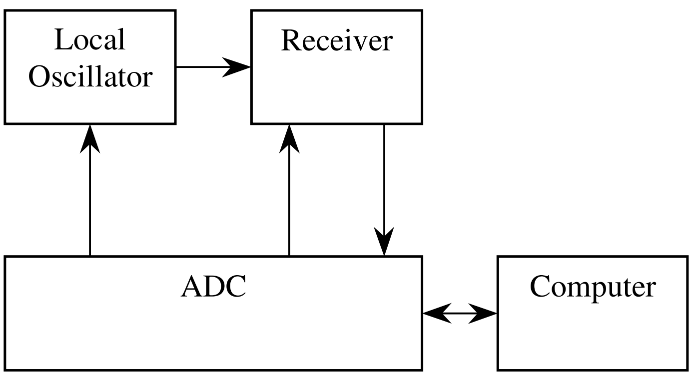

Fig. 4. Block Diagram of the LO frequency calibration.

To prepare the Radiometer for measurements:

1. Install the Local Oscillator into the rack or on the table

2. Install the Receiver on the Local Oscillator
3. Connect the LO output to the Receiver LO input
4. Connect DA1 output of the ADC Card (see manual for the A-812 ADC card) to the External Broadband Frequency Control Input (input 5, G4-140 manual).
5. Connect DA2 output of the ADC Card to the External Attenuator Control Input of the Receiver (input 11, receiver technical description).
6. Connect Video Output of the Receiver (output 13, see the Receiver Technical Description) to the AD 11 input of the ADC.
7. Turn on the Local Oscillator in the external frequency control mode (see G4-14- manual).
8. Turn on the Receiver as mentioned below:
   - Set the Calibrator switch in "HRM" position
   - Set Mechanical waveguide switch in "CAL" position
   - Set the Integration time switch in "1 MHz" position.
   - Turn off the amplitude modulation of the RF signal by means of Modulation switch. Modulation Indicator should mot glow.
   - Turn on the Receiver and warm up it during 30 min.
9. Insert the initial attenuation in VCVA by means of applying the 7.8 VDC voltage to the External Attenuator Control Voltage Input of the Receiver via DA2 output of the ADC card.
10. Start measurements

To provide calibration one have to change step-by-step LO frequency from the lowest to the highest value and acquire signal from the Video output of the Receiver. Signal from the Harmonic Oscillator should provide response at 54, 60, 66, 72, 78, 86 GHz like presented on fig. 5. Day-to-day getting the data from the Harmonic oscillator and comparing the results with the previous measurements allows to check the LO frequency stability.

Calibration of Receiver sensitivity using the Noise Source.

Block Diagram of the calibration is presented on fig. 6.

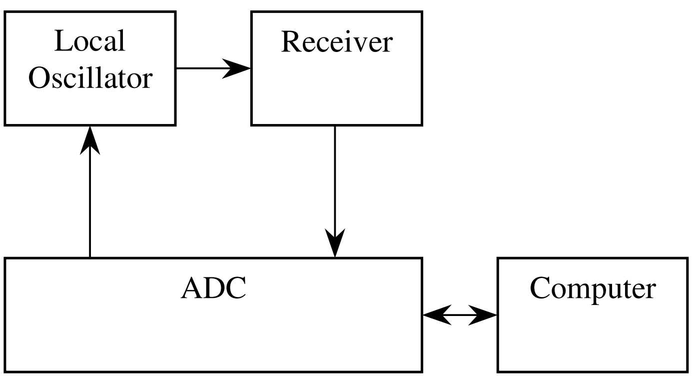

Fig. 6. Block Diagram of the Receiver sensitivity calibration.

To prepare the Radiometer for measurements:

1. Install the Local Oscillator into the rack or on the table
2. Install the Receiver on the Local Oscillator
3. Connect the LO output to the Receiver LO input
4. Connect DA1 output of the ADC Card (see manual for the A-812 ADC card) to the External Broadband Frequency Control Input (input 5, G4-140 manual).
5. Connect Video Output of the Receiver (output 13, see the Receiver Technical Description) to the AD 11 input of the ADC.
6. Turn on the Local Oscillator in the external frequency control mode (see G4-14- manual).
7. Turn on the Receiver as mentioned below:
   - Set the Calibrator switch in “NS” position
   - Set Mechanical waveguide switch in “CAL” position
   - Set the Integration time switch in “2 kHz” position.
   - Turn off the amplitude modulation of the RF signal by means of Modulation switch. Modulation Indicator should mot glow.
   - Turn on the Receiver and warm up it during 30 min.
8. Start measurements

To provide calibration one have to change step-by-step LO frequency from the lowest to the highest value and acquire signal from the Video output of the Receiver. Day-to-day getting the data from the Noise Source and comparing the results with the previous measurements allows to check the Receiver sensitivity stability.

8. MEASUREMENTS MADE IN ELVA-1 LABORATORY.

The next tree figures present the radiometer sensitivity measurements provided in ELVA-1 laboratory. Data presented on the first plot (fig. 7) were obtained using the Cryogenic Matched load connected directly to the Radiometer RF input.

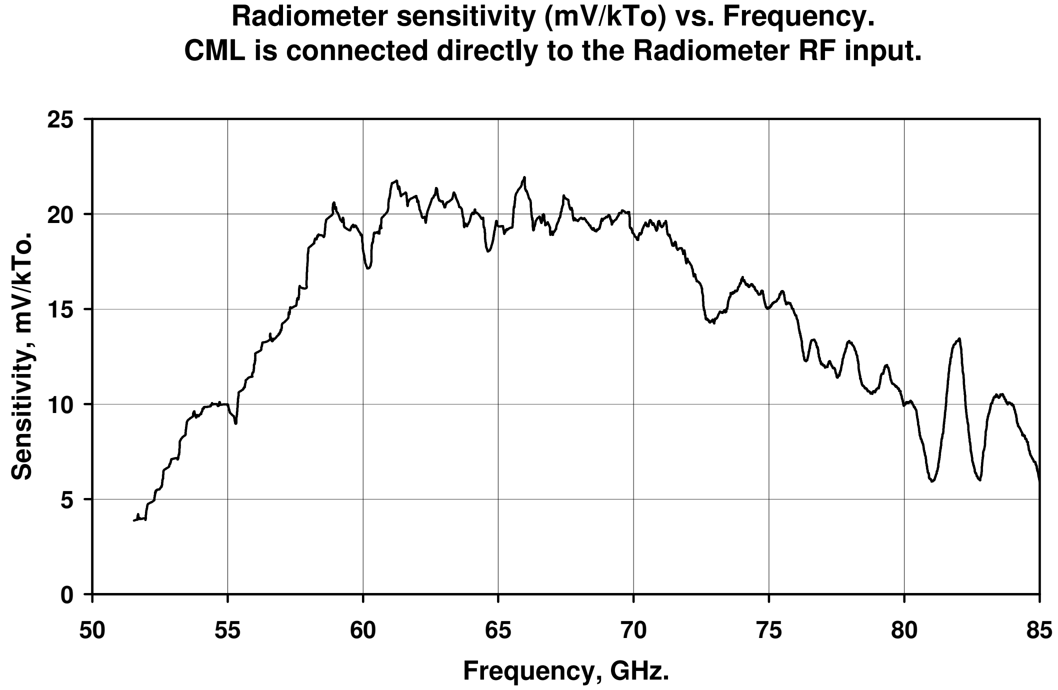

Fig. 7. Radiometer sensitivity.

Losses in 1.5 m one section of the oversized waveguide are taken into account in the next plot (see fig. 9). In this case CML was connected to the Radiometer RF input via the oversized waveguide (see diagram on fig 8).

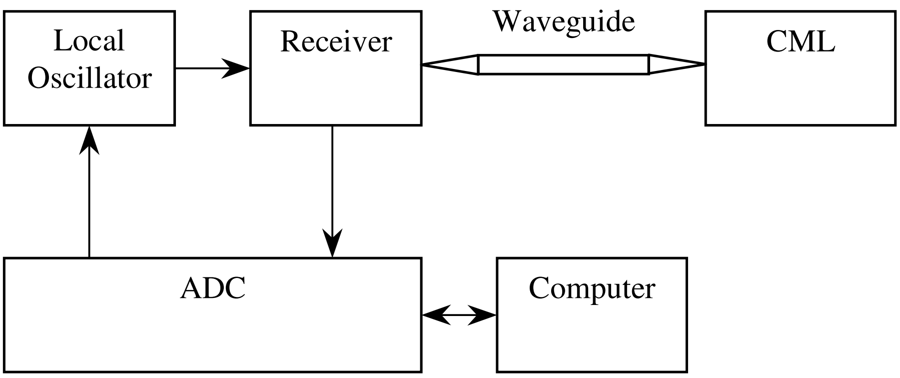

Fig. 8. Block Diagram of the radiometer sensitivity calibration using the CML. Experiment No. 2.

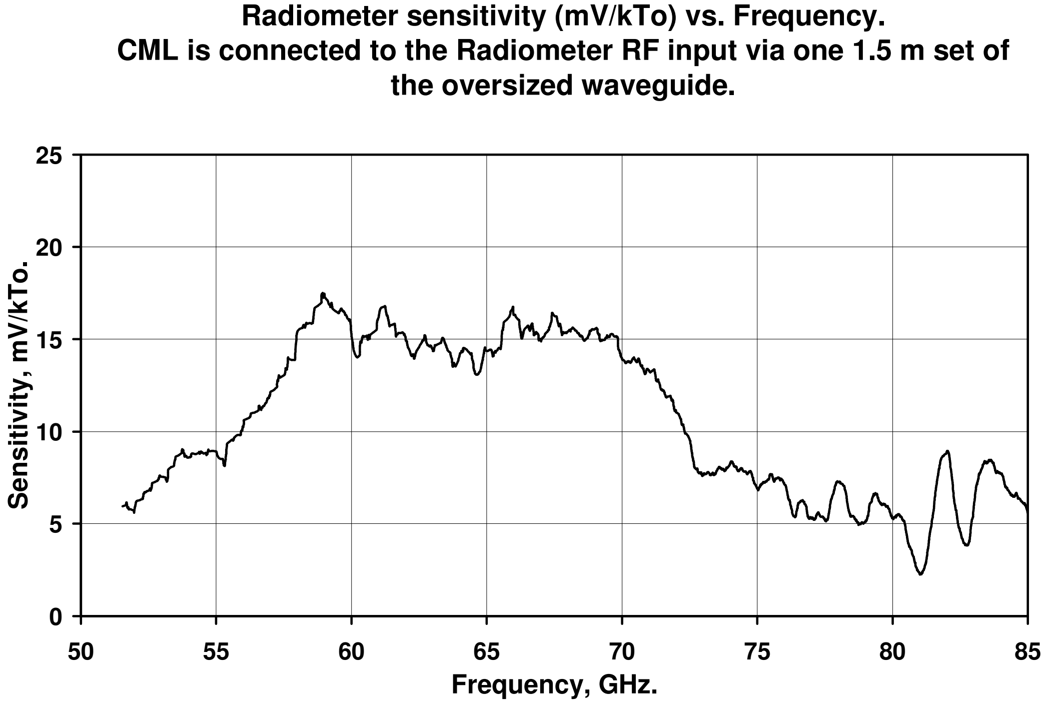

Fig. 9. Radiometer sensitivity. Experiment No. 2.

Block diagram of the third experiment is presented on fig. 10. Antenna of the Radiometer war directed to the container filled with liquid nitrogen. So the next plot presents final radiometer sensitivity including losses in the oversized waveguide and antenna.

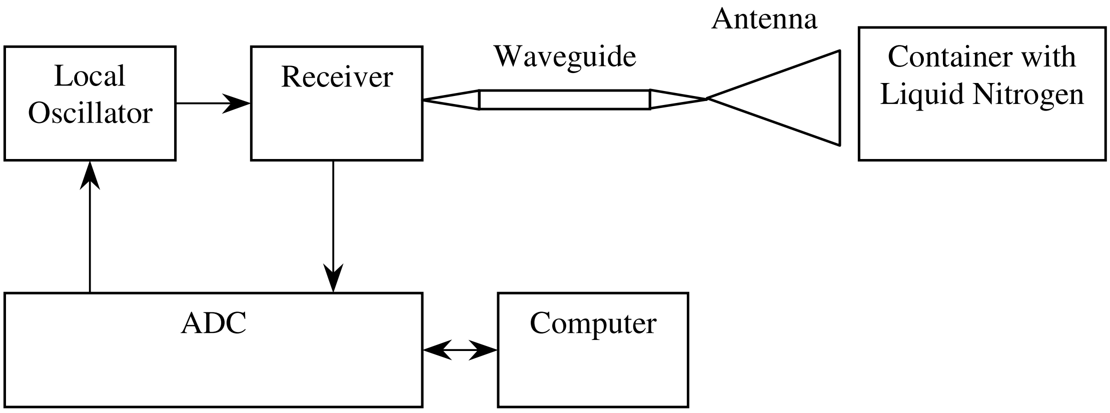

Fig. 10. Block diagram of the final radiometer sensitivity measurements.

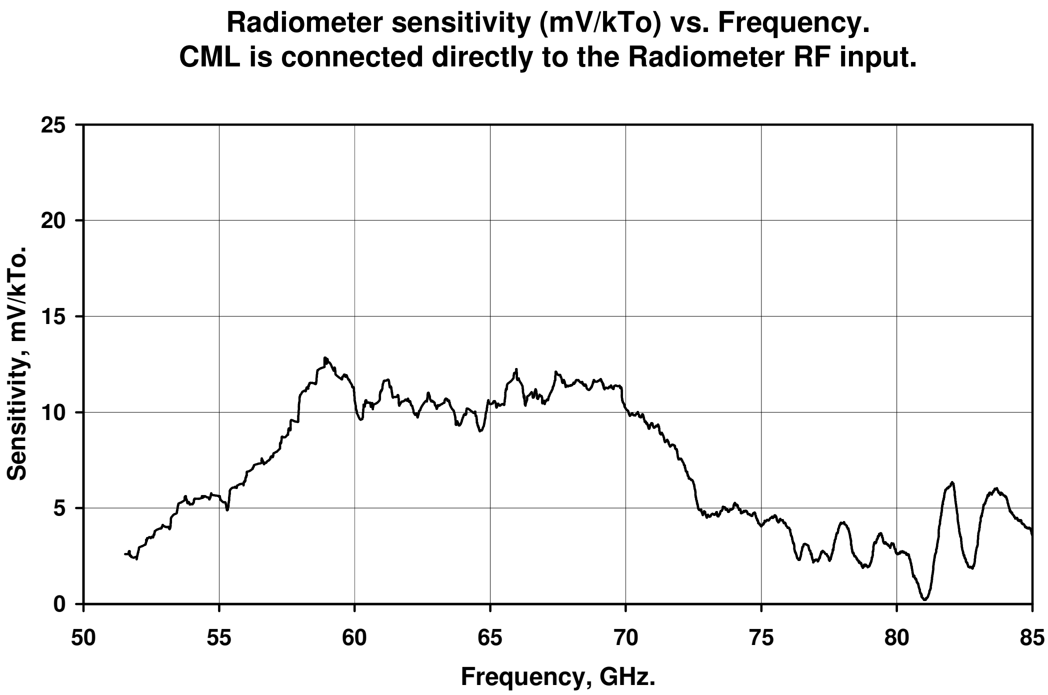

Fig. 11. Radiometer sensitivity. Experiment No. 3.