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Development and calibration of high-frequency 3D B-dot probe

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ABSTRACT: The system of the 3-axis magnetic probe to measure magnetic fluctuations and waves in the plasma was developed. Calibration of 3-axis magnetic probe with Helmholtz coils was made. The amplitude frequency response characteristics of the 3-axis magnetic probe and connection cables were measured. The electrical shield for such type of 3D probes was developed. The first measurements were made in the experimental plant IShTAR.

KEYWORDS: 3-axis magnetic probe, B-dot, electrical shield.

Contents

1. Introduction

The magnetic probes are widely used to research wave processes in plasma. Experiments with magnetic probes allow us to know the magnetic field value, type of waves in plasma, amplitude ratio and phase shift between different components of wave, wave number, etc. To study wave processes in the same point and in the same time for different wave components 3-axis magnetic probes are required [1].

In this work the development and calibration of 3-axis magnetic probe (3D B-dot probe) and also electrical shield to improve the signal-to-noise ratio are described. The amplitude frequency response characteristics for each probe in different planes are presented.

The 3D B-dot was developed to research high frequency electromagnetic oscillations in plasma in frequency range 1–25 MHz. Such magnetic probes are installed in Uragan-3M torsatron [2] and in linear experimental plant IShTAR (Max Planck Institute of Plasma Physics, Garching). The first test results were received in the IShTAR. Experiments are also planned on Uragan-2M torsatron.

2. Ion Sheath Test Arrangement (IShTAR)

IShTAR has been developed to investigate experimentally the plasma parameters near the antenna and measure the rectified electric field in the surrounding of the antenna including the sheath, which is suspected to be the main driver of the ICRF/plasma interactions. The test bed consists of a main vessel where the ICRF antenna is located and where conditions representative of a tokamak's edge are recreated: two main coils build a static magnetic field up to 0.2 T and an external RF plasma source creates a plasma with a density around 10^{18} m^{-3} for argon and 10^{17} m^{-3} for helium and a temperature between 5 and 10 eV. This plasma source is designed to reach helicon discharge mode with a helical antenna and five small 0.1 T coils to get high densities and uniform radial profiles along the crossection (Fig.1).

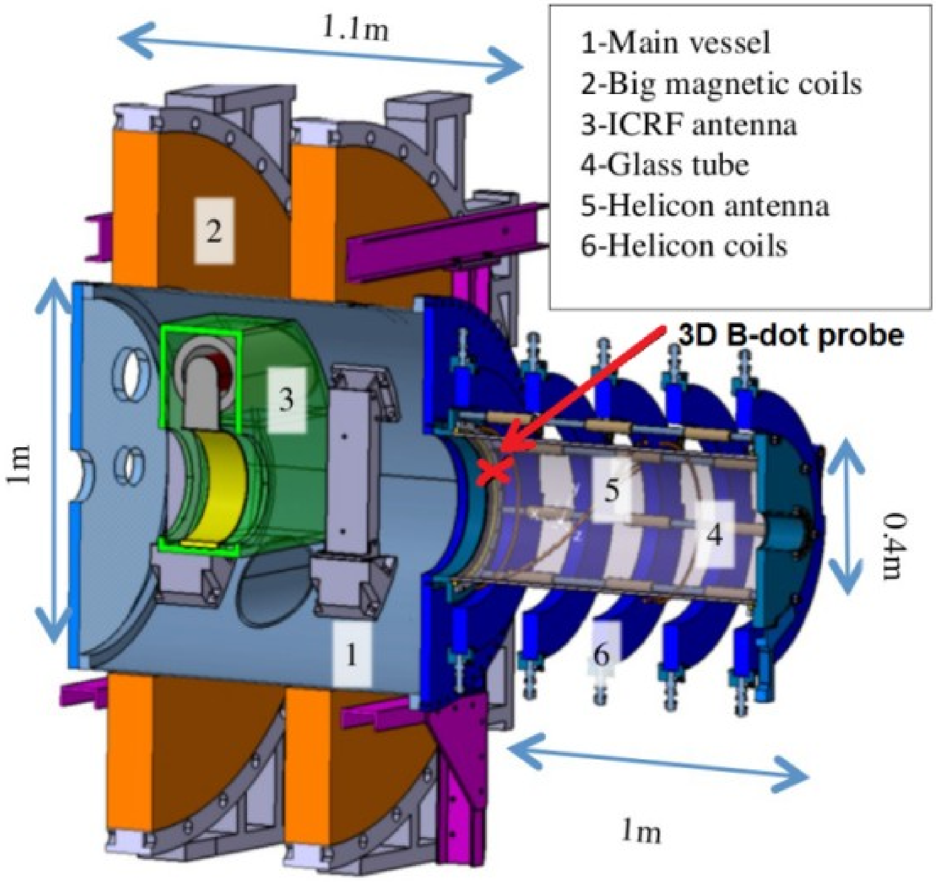

Figure 1. IShTAR view and 3D B-dot place

3. Calibration of 3D B-dot probe

Helmholtz coils are used for calibration of each coil in 3D B-dot probe [3]. The Helmholtz coils own resonance is above of top border of work frequency range (in our case 1-25 MHz). Each component of the 3D B-dot probe was calibrated separately. Each coil signal in 3D B-dot is transmitted to oscilloscope through coaxial cable with impedance of 50 Ohm. The distance between the Helmholtz coils and the oscilloscope is chosen to exclude the appearance of parasitic oscillation on the oscilloscope from high-frequency generator and Helmholtz coils. All signals from coils are observed simultaneously. It is done to define an influence of coils on each other. The scheme of calibration is shown on figure 2.

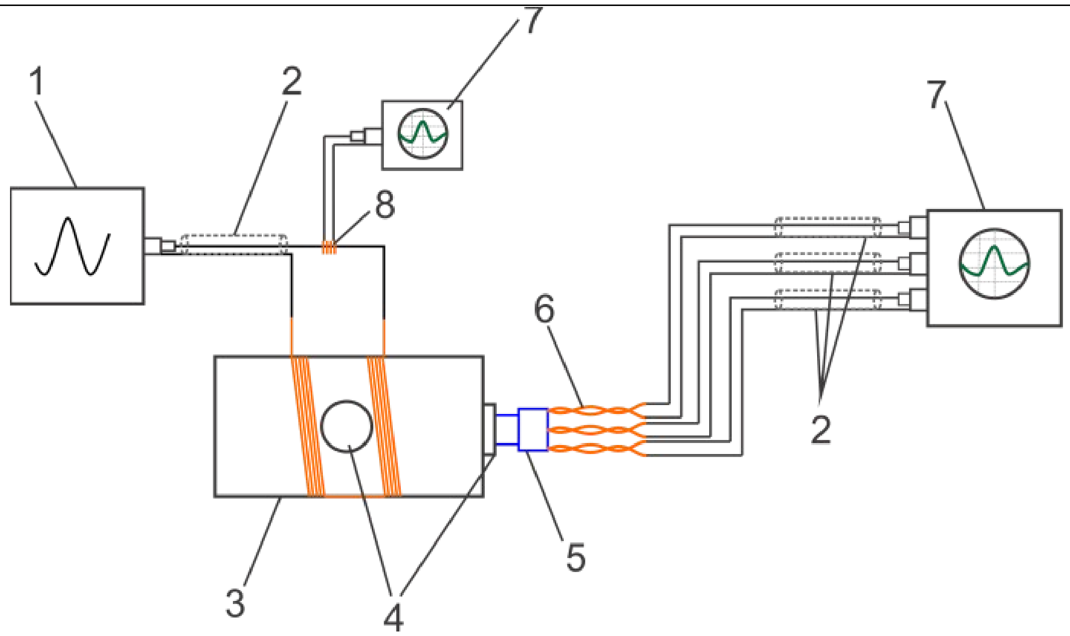

Figure 2. Scheme of 3D B-dot calibration.
1 – generator (1 – 30 MHz), 2 – coaxial cable (impedance 50 Ohm), 3 – Helmholtz coils, 4 – holes for calibration of coils in different directions, 5 – 3D B-dot probe, 6 – twisted leads, 7 – oscilloscope (3 input with 50 Ohm impedance), 8 – coil for current measurement

4. Scheme and view

The scheme of the 3D B-dot is shown on figure 3. 3D B-dot probe is made on a fluoroplastic tube as a support with 4 mm diameter. The tube length is 20 mm. A wire for coils is used with varnish insulation and diameter 0.2mm (the maximum temperature of the varnish insulation is about 170 degrees Celsius). The tails of each coil are made as twisted pair and each tail has different length (Fig. 4). Also axis direction is shown on figure 4.

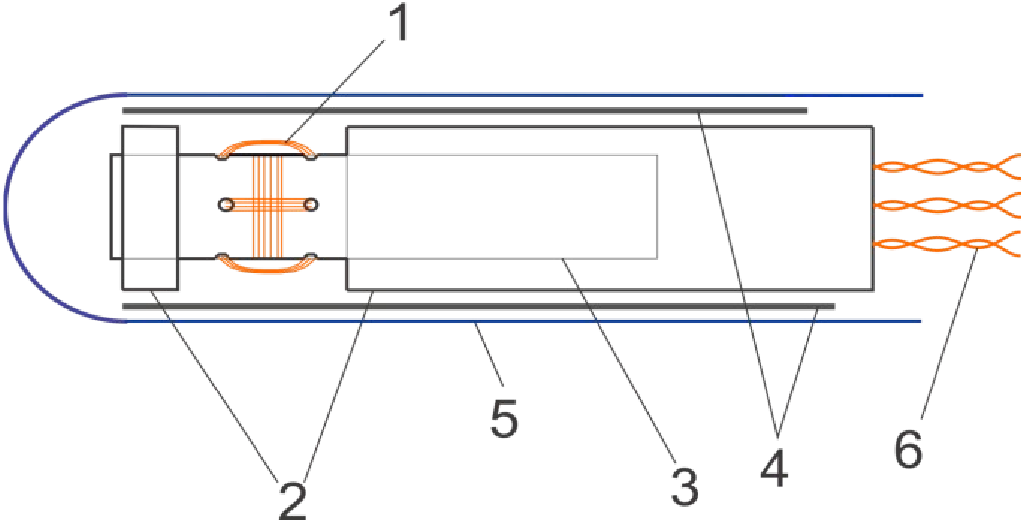

Figure 3. 3D B-dot scheme.
1 – Probe coils (wire with varnish insulation and diameter 0.2mm), 2 – fluoroplastic (teflon) tubes are used as a support for electrical shield (external diameter is 6mm and inner diameter is 4mm), 3 – fluoroplastic tube is used as a support for coils in different planes (external diameter 4mm), 4 – electrical

shield (copper foil 0.05mm thick), 5 – quartz or ceramic tube to defense magnetic probes from plasma, 6 – twisted leads from each coil

The length of the longest tail is less than 5 cm. The different length of the coil tails allows to connect coaxial cable with coils more conveniently and not use of insulation for each contact. All signals from 3D B-dot probe are transmitted using of coaxial cables with impedance 50 Ohm. The length of coaxial cable is equal or more than wave length that we want to research. In this case, whole transmission line is well matched and reflection of waves doesn’t appear in the line and the signal in whole work frequency range is reliable.

We tried to use a twisted pair cable but, in this case, we observed the reflection of waves in the cable. It is necessary to do the additional research before using the twisted pair cable as transmission line.

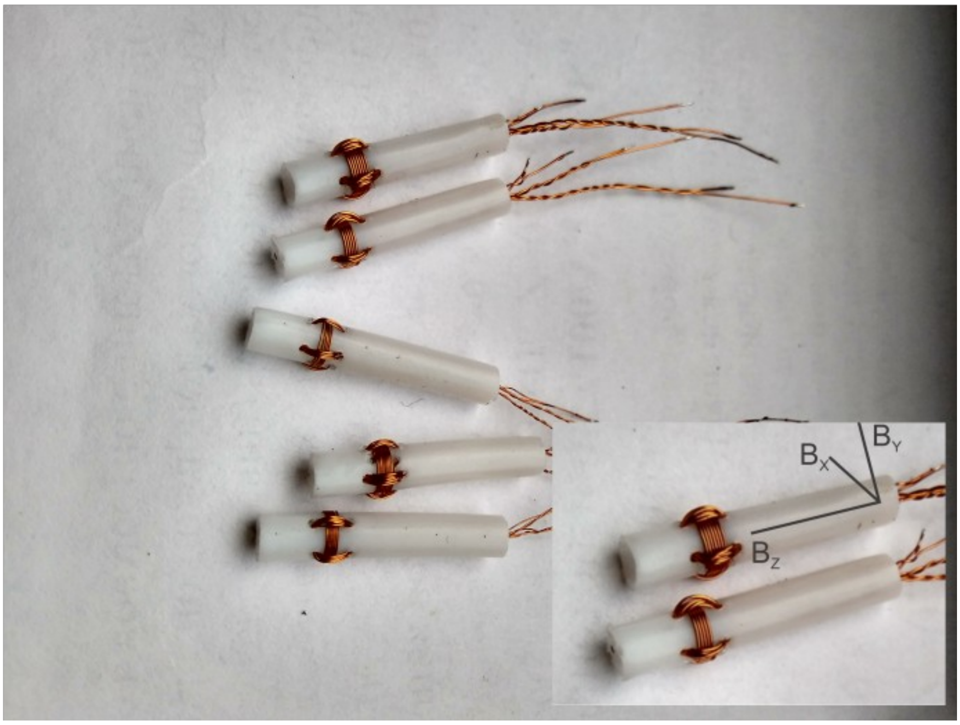

Figure 4. 3D B-dot photo and magnetic axes location

5. Development of electrical shield

To avoid electrostatic noise we use electrical shield for the 3D B-dot probe. This shield is made from copper foil with 0.05 mm thick. The shield for 3D B-dot has a view of strips (Fig.5). Such form of shield allows passing the appropriate wave component. From this plate it is necessary to make a cylinder. The magnetic probe is located inside of the cylinder. Each strip of shield shouldn’t have a contact with the nearest strips near the probe coils. These strips are arranged along the fluoroplastic tube with coils. The width of each strip has to be as thin as possible to the shield work correctly. At the same time, the less distance between strips in such shield the bigger the attenuation of the signal. Also, if the distance between the strips is too large the shield won’t work correctly because the noise will pass between the strips. In our case, the width of strips is about 1.5 mm, the length of strips is 17 mm and the distance between the strips is about half of the strip width.

The signal from the probe decreases on 20% when the probe is in the shield. But the signal-to-noise ratio improves significantly.

Figure 5. View of electrical shield

6. Amplitude frequency response characteristics

6.1 3D B-dot in frequency range 1-30 MHz

The magnetic probe was located in Helmholtz coils when the amplitude frequency response (AFR) characteristics were measured. Probe location was respectively changed for each component of 3D B-dot probe (Fig.6). Each coil has 7 turns and the diameter 4mm. Also the coils with 10 and 5 turns were tested.

From Maxwell equation

$$\oint E\,d\,l=\frac{-d}{dt}\int B\,d\,s$$

Considering that $\frac{d}{dt}\int B\,d\,s=NS\frac{d\,B}{dt}$ and $U=\oint E\,d\,l$.

We get that $U \quad N$.

So the number of turns influences on the signal level [4,5], but at the same time the coil inductance increases and work frequency range becomes less.

The frequency limit for each coils in 3D B-dot probe are defined from equation ωL = R [4,5], where R – 50 Ohm load; L – coil inductance. So for coils with 7 turns the inductance is 250nH and frequency limit is about 32 MHz.

The inductance and resonance for different coils: B_Z – this coil is wound in one layer. The inductance of the coil is 220 nH and the own capacitance is 2.75 pF. The resonance is on 205 MHz; B_X , B_Y – these coils are wound in several layers. The inductance of the coil is 250 nH and the own capacitance is 3.5 pF. The resonance is on 180 MHz.

Coils with 10 turns could work only till about 20 MHz and signal level from coils with 5 turns may be too small. For each experiment it is necessary to select the parameters of the coils individually. In our experiments coils only with 7 turns were used.

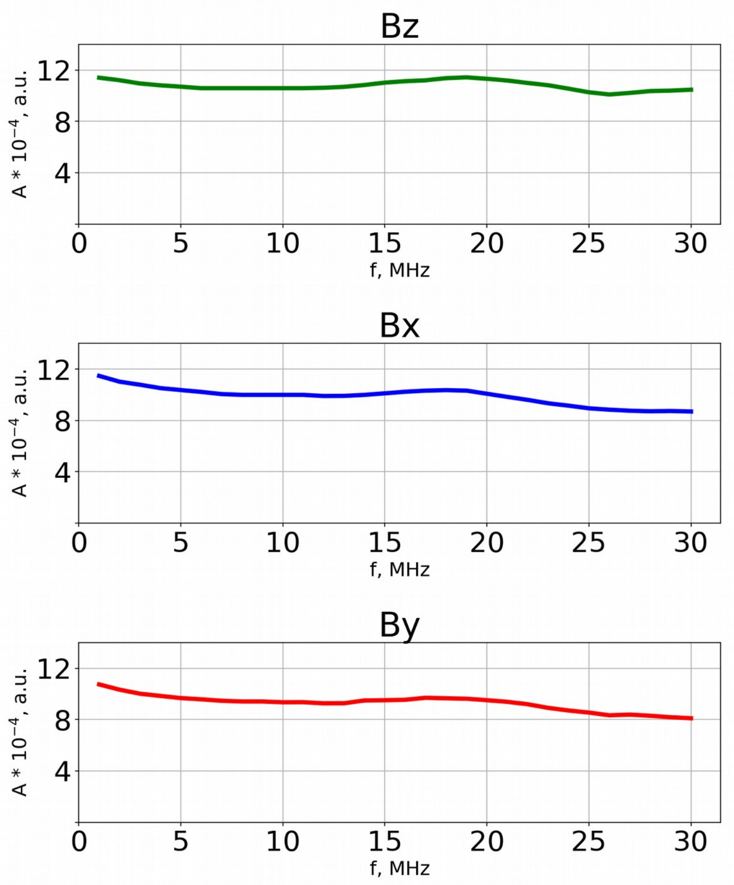

Figure 6. AFR characteristics each coils in 3D B-dot in frequency range 1-30 MHz

6.2 One coil of 3D B-dot in frequency range 10-200 MHz

The characteristic in this range was measured with Ronde&Schwarz ZVL3 Vector Network Analyser. The coil tails were connected to input of the Network Analyzer without any cables. Such view of characteristic has two components of magnetic probe (B_X and B_Y, Fig.7). The component of B_Z has the resonance on 205 MHz.

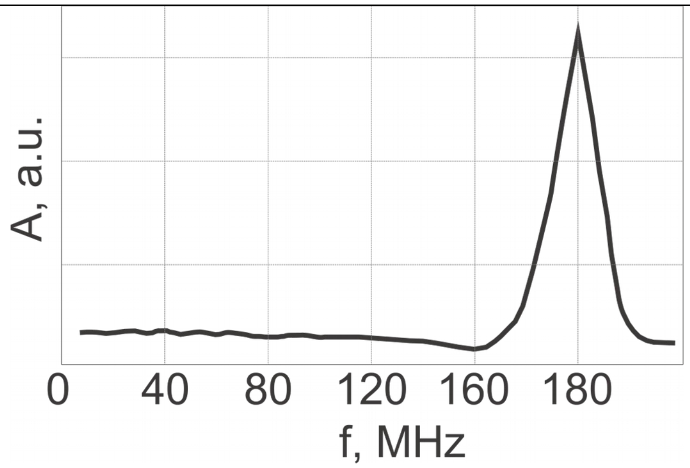

Figure 7. AFR characteristic in frequency range 10-200 MHz

7. First measurements in the IShTAR

3D B-dot was installed in the IShTAR to research the waves in the plasma that is created by the helicon type antenna. The plasma is created by high-frequency discharge with frequency 12.5 MHz. The signals from magnetic probes were recorded using 4-beam oscilloscope that allowed receiving signals with the frequency up to 300 MHz.

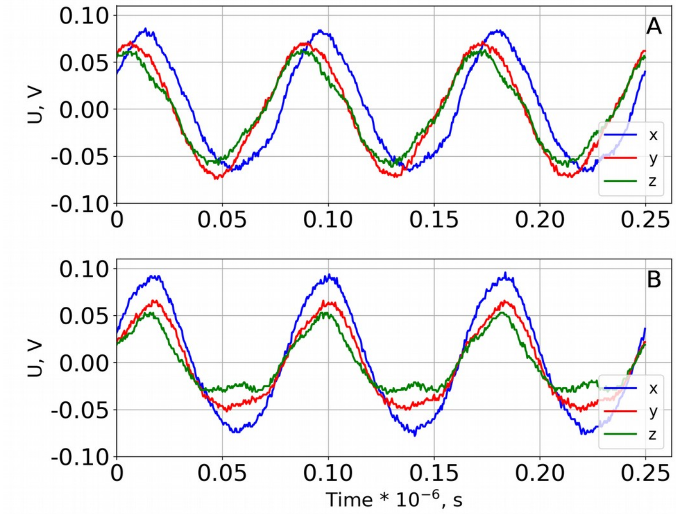

Figure 8. Compare signals from 3D B-dot for different pressures. A – 4 mBar, B – 0.8 mBar.

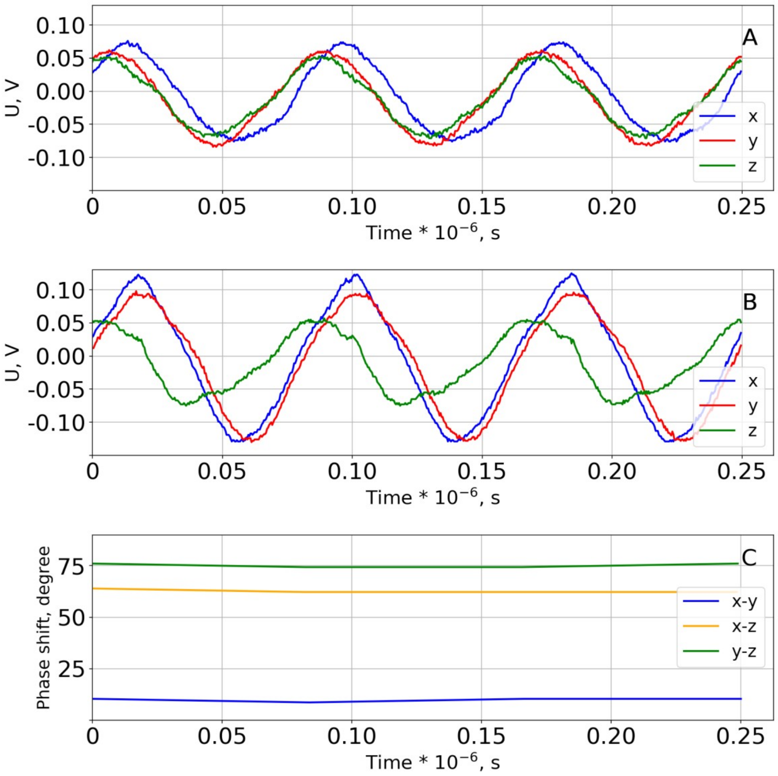

Figure 9. Compare signals from 3D B-dot for different currents in the magnetic confining coils. A - 1000 A, B – 200 A, C – shift phase between different components for signals on (B).

The first measurements were got from 3D B-dot probe. A change of amplitudes and phase shifts between signals from different coils in the 3D B-dot for different pressures (Fig.8) and different currents in the coils of magnetic field (Fig.9) were observed. Absolute values of the phase shifts between signals from different coils in the probe were calculated (Fig.9, C).

The typical frequency spectrum of signal is given on figure 10 (x-component from figure 9, B).

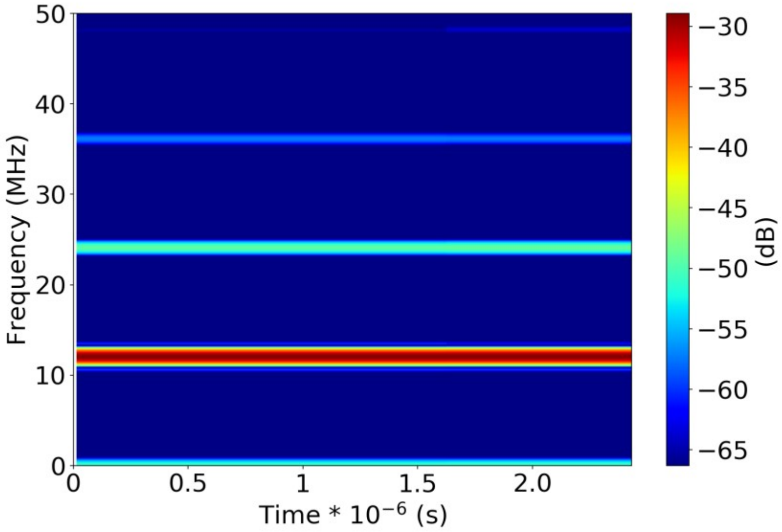

Figure 10. Frequency spectrum of x component (p = 4 mBar, I = 1000 A)

8. Summary

A construction of compact high-frequency 3D B-dot probe for studying wave processes in plasma (25 MHz) in the Uragan-3M, Uragan-2M and IShTAR was developed. The calibration of the magnetic probes was made. The Helmholtz coils were used for calibration B-dot. A construction of electrical shield for 3D B-dot probe was developed. The shield improves the signal-noise ratio significantly.

Each coil of 3D B-dot probe has a little effect on the other. But in the worst case this effect is less than 10% for B_X and B_Y coils.

Measurements of the amplitude-frequency characteristics with different cables as a transmission line (twisted pair and coaxial cables) were made. Using twisted pair cable requires additional research.

The first test results were got in the experimental plant IShTAR. A change of the signal (amplitude and phase shift) was observed depending on the pressure and current in the coils of magnetic field.

Acknowledgments

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