Alfvén and Helicon Wave Resonances Measured with Demodulator Circuit in TCABR

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Abstract.

The measurements of the RF driven magnetic field oscillations with the analog demodulator circuitry in the TCABR tokamak are presented. This circuitry works as the synchronous detector that is used to multiply the signal from magnetic probes by the reference signal, and then to filter out the low frequency signal. The output signal carries the information about the amplitude and the phase of the RF driven plasma oscillations, and can be acquired by the TCABR data acquisition system during all RF pulse.

The experiments were carried out in the regimes with the low-density plasma \( n = 1 \times 9 \times 10^{16}/m^3 \) and magnetic field 0.04T when helicon wave resonances can be excited. The antennae were fed by the RF generators whose frequency was varied in the range 2–5 MHz with variable time \( \Delta t = 1–5 \text{ms} \). The signals acquired with the analog demodulator circuitry were compared with the results obtained after numerical simulations of the data acquired directly with the high frequency oscilloscope. The very good agreement was demonstrated that makes possible to use the demodulator circuit measurements with long RF pulse duration in future experiments.

1. Introduction

The measurements of the externally induced Alfvén like waves in tokamak plasmas are very important for fusion plasma diagnostics. They can permit to measure the isotope composition of the fusion plasmas and \( q(r) \) profile in tokamaks [see Elfimov et. al. [1]]. Now this diagnostic technique is intensively developing at the TCABR tokamak. The experimental equipment consists of the RF generator with variable frequency, Alfvén wave antennae, magnetic probes [2] for wave detection, and a demodulator circuit [3].

The frequency of the excited Alfvén waves is in the range of approximately 4-5 MHz. The frequency of the data acquisition system of the TCABR is limited up to 3 MHz. That is why an analogous demodulator circuit has been developed in order to ensure the possibility to measure higher frequencies directly. Only one antenna module was used in these experiments but we are going to operate with two antenna module in order to separate toroidal mode numbers \( N = 1 \) and 2 in the future.

Usually, in order to increase the efficiency the RF power generators, they work with the resonant load, and the Alfvén antenna constitutes part of the resonant circuit that operate at fixed frequency. In the case of the sweeping frequency, it is difficult to ensure the impedance matching of the generator output and the resonant load in a large frequency range. In order to overcome this difficulty, the RF amplifiers with wide frequency band were developed using fast RF power MOSFETs in the switching regime. They can supply RF power up to 1kW in the
frequency bandwidth of $f = 0.05 - 5 MHz$. In this case, the frequency and the phase of the current in the RF antennae is controlled by the functional generator.

2. Demodulator Circuit

![Demodulator Circuit Schematics](image)

Figure 1. Schematics of the demodulator circuit.

A demodulator circuit shown in Fig.1 was developed [3] to solve the problem to measure the high frequency magnetic field oscillations. This circuit multiplies the signals from the magnetic censors [2] and the RF antenna current measured by a Rogowski coil, which is used as the reference signal. This multiplication gives rise to components of sum and subtraction of the frequencies from the antenna current and from the magnetic censors. As a result, a low frequency component $2kHz$ appears, which can be filtered out and acquired by the data acquisition system. This signal carry the information about amplitude and the phase of the magnetic field oscillations.
Filters and differential amplifiers were used to diminish noise from the input signal and a low-pass filter was used in the output stage because we have interest in the low frequency signal. There are four input channels, to use in conjunction with the four magnetic coils installed in the TCABR, of which two are positioned to measure the toroidal and the other two the poloidal magnetic field.

Characteristic curves of the demodulator circuit are presented in Fig.2. In Fig.2(a), we show the selectivity of the demodulator to the signals at the frequency of the reference signal and workable linear part of the characteristic curve is demonstrated in Fig.2(b).

![Figure 2](image-url)

**Figure 2.** Characteristic curves of the demodulator circuit.

### 3. Data Analysis

![Figure 3](image-url)

**Figure 3.** Spectrogram of (a) antenna and of (b) magnetic coil, (c) digital multiplication of (a) and (b). (d) Signal from demodulator circuit, for Shot 1.
The equipment was tested in the TCABR tokamak in regimes of the vacuum chamber cleaning by RF discharges with the frequency of 5kHz. The plasma density was \( n = 1 - 9 \times 10^{16}/m^3 \) and the magnetic field of 0.04T, both much lower than the normal regime of the TCABR. Temperature was estimated as 25eV. In the plasma with these parameters, we could not excite Alfvén waves but it is possible to excite helicon waves. To find helicon resonances, the frequency scan of the generator was fulfilled during 8ms in the desired frequency range 2 − 5MHz.

As an alternative to the circuit, a high sampling frequency oscilloscope is used to acquire data directly from the magnetic coils, as well as the signal of the antennas current. Then, both signals are digitally multiplied and the result is compared with the output of the demodulator circuit. We note that the multiplication of the signals permits to find the cross-correlation between them. When the correlation is high, it can indicate the excitation of the plasma eigenmodes. The cross-correlation signal and the analogical product at the output of demodulator circuit both depend on the phase shift between the input signals. We adjust the length of the signal cable that comes from the antenna to the demodulator circuit in order to compensate the instrumental phase errors and to maximize the signal. As the output signal from the circuit presents the cross-correlation, it is higher if the two input signals are in phase. To simulate this experiment digitally, we have introduced variable phase differences, and thus we could get good coincidence with the experimental data.

Here we present the results from two different shots in Figs.3 and 4 where Fourier analysis of the antenna current (a) and of the data from the magnetic coil (b) are shown. We can observe that both stay in a good agreement, it means that the magnetic field oscillation propagates from the antenna through the plasma with time delay due to the distance about 1m from the magnetic coil to the antenna. The signal is very small in the plasma absence. The other figure represent the signal from the demodulator circuit acquired from the magnetic coil (d) and the corresponding digital simulations, so that we can compare both signals. We note that the resonance frequency \( f \sim 4MHz \) is found in the shot No1 (Fig.3) at \( t \approx 0.005s \). This resonance

![Figure 4. The same values as in Figure 3 for Shot 2.](image)
is identified as the helicon wave after comparison with numerical calculations.

4. Numerical Calculations

![Figure 5](image_url)

**Figure 5.** Simulation of helicon waves (a) for parabolic density profile $2 - 9 \times 10^{10}/cm^3$ in the center, and temperature $25eV$. (b) shot that show better agreement with helicon wave simulation, (c) spectrogram of same shot. Synch ampl is similar to the cross-correlation before mentioned, but in this case is calculated between the magnetic probe signal and density fluctuations, measured with a Langmuir probe.

To simulate the helicon waves we used a numerical code which was previously developed for Alfvén waves studies, where parameters were changed for the cleaning discharge mode in TCABR. The simulation was done using k-spectrum related to one antenna module in the frequency range from $1-6MHz$. We choose the lowest toroidal and poloidal modes ($M = \pm 1, \pm 2$ and $N = \pm 1$) for simulations and the results are presented in the Fig.5(a). The density variation measured with a Langmuir probe, which is used in calculations, is presented in upper frame of Fig.5(b), the cross-correlation signal synch ampl is shown in the medium. Finally, the magnetic probe signal is presented in the low frame. As we can see there are resonances for some frequencies, one of them, in particular, is near the frequency $4MHz$ that is close to the frequency shown in Fig.3. The simulation is in agreement with analytical expression for helicon waves $\omega = c^2 k \omega_{ce}/\omega_p^2$. The good agreement with the simulation can be seen in the spectrogram of the magnetic probe signal in Fig.5(c) for the same shot. Unfortunately the demodulator circuit did not capture this shot.
5. Conclusion
The experiments have shown a good agreement between the measurements made by the
demodulator circuit and by the calculations of the cross correlation between the magnetic probe
and the reference signals, which simulate the circuit behavior. The demodulator circuit is
successfully tested, and ready for measurements of Alfvén wave resonances in tokamak plasmas,
as soon as TCABR is operational. It is especially suitable for fast findings of the plasma
resonances, which can be calculated more accurately later by the digital technique with some
high sampling frequency equipment.

It is demonstrated that magnetic probe measurements of sweeping frequency launched by
antenna are confirmed by numerical calculation that gives possibility to identify the plasma
density. In the future we will make measurements with two antenna modules in more dense
plasmas.

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