Design and Test of New Millimeter Wave Notch Filter for Plasma Diagnostics

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Abstract— **A new design of millimeter wave notch filter was suggested and tested. Fundamental waveguide notch filter consists of a smooth TE301 resonator with a coupling cut-off hole and a frequency tuning plunger. Six resonator notch filter was manufactured and measured. A numerical control machining was used to mill two identical half of the filter. In the experiment the only one resonance was observed in the 53.6 – 78.3 GHz frequency band. Power transmission of -90 dB was measured at 68 GHz, the notch band at the level -60 dB is 600 MHz. Frequency tuning of 0.5 GHz was also demonstrated.**

I. INTRODUCTION

A notch filter is one of important components of some plasma diagnostics systems. For example it isolates sensitive detectors of a diagnostic system from a dangerous gyrotron stray radiation. There are a few filter designs – fundamental waveguide filters [1, 2], quasi-optical resonance filters [3] and microwave resonance gas absorption [4]. Here we present a new fundamental waveguide notch filter with simple design which can be used for rather high frequencies (e.g. 170 GHz).

II. FILTER DESIGN

The new design of notch filter uses a smooth extension of fundamental rectangular guide as a resonator. For smooth tapers the incident TE10 mode has a very weak coupling with any mode of the resonator. To provide optimal coupling of the traveling mode with resonant one we introduce the scatter – a small cut-off circular hole in the center of the resonator. As the result we obtain the following look of the notch filter (Fig.1).

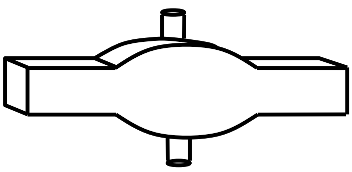

Fig.1. New notch filter schematic.

Let us consider the principal notch filter scheme to explain principles of rejection and derive general expressions (Fig.2). The one resonator notch filter includes two reflecting mirrors and translucent slab in between them.
The reflection coefficient of each mirror is denoted R, and the transmission coefficient of the slab is $r=\sqrt{1-t^2}$, respectively. The amplitude transmission T_s and reflection R_s coefficients of entire one resonator filter could be expressed in the following form

$$T_s = jt\cdot\left[1+\frac{r^2R^2\cdot\exp\left(j2kL\right)}{1+t^2R^2\cdot\exp\left(j2kL\right)}\right]$$

$$R_s = \frac{-r^2R\cdot\exp\left(jkL\right)}{1+R^2t^2\cdot\exp\left(j2kL\right)}.$$

Let us introduce additional notations which are Ohmic quality Q_o and coupling quality Q_c of the resonator. In these terms the transmission coefficient at the resonance frequency has a minimal value as

$$\left|T_s\right|^2 = t^2\left[1-\frac{r^2R^2}{1-t^2R^2}\right]^2 \approx \left(1+{Q_o}/{Q_c}\right)^{-2}.$$

Loss at the resonance frequency is

$$Loss = 1-\left|R_s\right|^2-\left|T_s\right|^2.$$

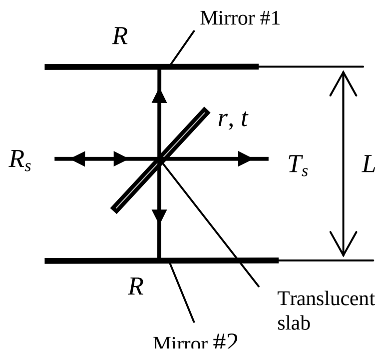

Fig. 2. Simple scheme of notch filter.

To increase the attenuation one has to diminish the coupling quality of the resonance $Q_c << Q_o$. As a result, the total quality of the filter resonance is determined by the coupling quality Q_c. To build a narrow band notch filter the high-quality open resonator is preferable, but it has too dense resonance spectrum [3]. The new filter has a single resonance in the fundamental guide operation band (53.6-78.3 GHz), because of selective excitation of the TE301 mode only. New six resonator 68 GHz notch filter was manufactured by numerical control milling machine. Filter dimensions are 28x42x140 mm. Plungers in the cut-off circular holes were used for notch frequency adjustment.

III. EXPERIMENTAL SET-UP

We use special devices with broad dynamic range to tune and measure frequency characteristics of the filter. There are also standard tools for amplitude-frequency characteristic measurements. For example, a standard vector network analyzer of Agilent Technology and Rohde & Schwartz has

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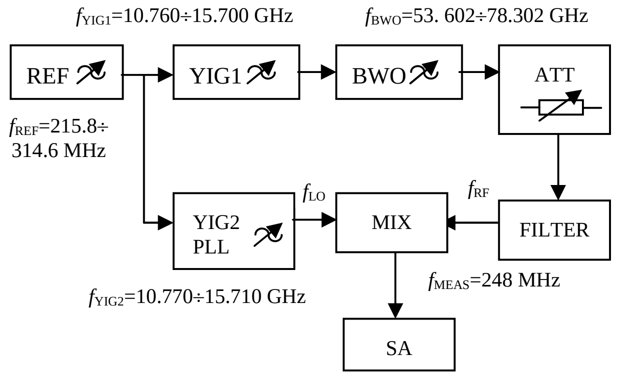
the dynamic range of 95 dB at millimeter waves. In some cases we need devices with bigger dynamic range at frequencies of interest.

Thus we have developed and tested a measuring device with dynamic range of 140 dB at 53.6-78.3 GHz (Fig.3). Similar device was previously reported in [5] with 130 dB dynamic range at 78.3-118.1 GHz.



REF – reference frequency generator,
YIG PLL – oscillator on yttrium-iron garnet resonator with phase locked loop,
BWO PLL – backward – wave oscillator with phase locked loop,
ATT – polarization attenuation 0÷70 dB,
FILTER – filter under test,
MIX – harmonic mixer,
SA – Spectrum analyzer E4402B.

Fig.3. Attenuation meter scheme.

The source of probing signal is a BWO with an output power level of P_{BWO} = 20 mW. The amplitude-frequency characteristic measured with the spectrum analyzer (SA) E4420B at intermediate frequency f_{MEAS}=248 MHz. Measuring signal is a mixture of the fifth harmonic of reference generator P_{LO} with operating frequency f_{LO} and BWO signal P_{RF} with f_{RF} frequency (pass through the filter). Schottky diodes are used as a mixer. The following expression can be used for frequency of the measuring signal calculation

$$f_{LO} - f_{RF} = f_{MEAS}$$

$$5\cdot(50\, f_{REF} \text{ -20MHz}) - 5\cdot(50\, f_{REF} \text{ -30MHz}) + 198\text{MHz} = 248 \text{ MHz}.$$

The frequency of measuring signal f_{MEAS}=248 MHz keeps the same in all frequency band 53.6 - 78.3 GHz. Polarizing attenuator (0 ÷ 70dB) provides the linear operation of harmonic mixer (incident power P_{RF} < 100 μW). Mixer incoming signals P_{LO} and P_{RF} are coherent in a PLL control, as synchronized with reference signal P_{REF}. Spectral powers of phase noise for P_{MEAS} and P_{REF} signals coincide in the frequency band of PLL control. Spectral width of the P_{REF} signal (half power level) is essentially less than 10 Hz (minimal frequency band of SA E4402B device). It means the minimal analysis frequency band of P_{MEAS} signal is 10 Hz. Respective sensitivity of the SA is -136 dBm.

As a result, the attenuation meter measuring signal sensitivity is 130 dBm in 10 Hz band. Dynamic range of the attenuation meter (we take into account the power level of the probing signal is P_{BWO}=13 dBm: N=13 dB +130 dB=143 dB.

Preliminary filter tuning with plungers was carried out with a modified measuring scheme. To observe filter characteristics in a 600MHz band the SA was replaced by a low-frequency INSTEK GSP-810 analyzer with dynamic range of 95 dB.

IV. Experimental results

The attenuation meter with dynamic range of 140 dB at 53.6-78.3 GHz was developed and used for the notch filter measurement. Measured attenuation in the notch band is shown by Fig.4. Power loss outside the notch band over entire frequency range is 0.5- 0.7 dB.

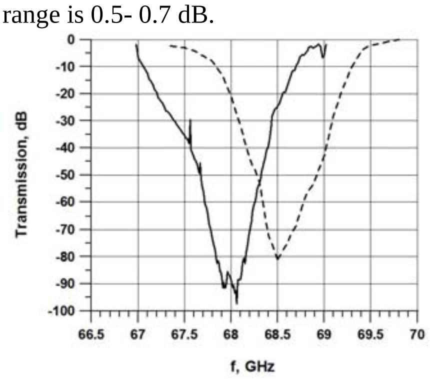


Fig.4. Measured transmission coefficient for two plunger positions.

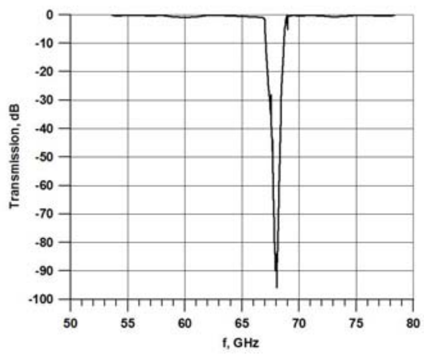


Fig. 5. Filter transmission over entire frequency band.

A 170 GHz filter of the new type for ITER plasma diagnostics has been fabricated and now is under test.

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