A 75-110GHz Micro Machined High-Q Tunable Filter

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***Abstract*—A 75-110GHz (W band) high-Q tunable band pass filter is demonstrated. The band pass filter has low insertion loss, a Q of approximately 200 and can be tuned across the entire W waveguide band. This filter has a variety of uses including rejecting spurious signals generated from non-linear frequency multiplication and improving signal to noise ratio at the front end of a receiver. The tuning is achieved by actuating a resonant cavity by using a sub-micron resolution stepper motor.**

Keywords-Sub millimeter wave filters, Band pass filters, passive circuits, microelectromechanical devices, millimeter wave circuits.

I. INTRODUCTION

Millimeter wave frequency applications are seeing a lot of development in collision avoidance, imaging systems, chemical spectroscopy and recently, communications [1-2]. However, there remains a gap in technology in millimeter wave devices due to higher atmospheric attenuation, high circuit losses, parasitic reactance in passive circuits and carrier mobility limitation in active devices. Due to the lack of high power millimeter wave sources, a common method of generating millimeter waves is by cascading frequency multipliers on a lower frequency source. These frequency multipliers are non-linear elements which inherently generate spurious signals when they are cascaded. Often, these spurious signals reside within the designed frequency band of a system and are difficult to filter out. Among other applications, test and measurement equipment, radiometer receivers, spectrometers and communications devices have strict requirements on spurious interference. High-Q tunable filters can be used to reduce the spurious interference in a broadband system. However, such technology has not been adequately developed at millimeter wave frequencies; Tunable YIG filters are limited to 40GHz and varactor diode circuit filters are lossy and have inherently low Q. We present the design, fabrication, test and measurement of a high Q resonator filter with low insertion loss which can be tuned across the entire W band (75-110GHz). The resonator is designed to remove spurious interference from broad band millimeter wave sources. It can also be used at the front end of a receiver to improve signal to noise ratio or as a high Q tank circuit for developing millimeter wave tunable oscillators.

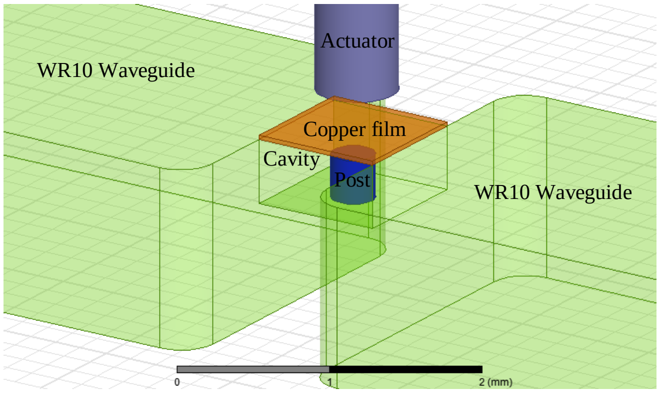


Fig. 1 ANSYS HFSS 3-D model of the WR10 tunable filter. Power is coupled to a resonant cavity through standard rectangular waveguide. The resonant frequency is tuned by changing the distance between the copper film cavity ceiling and the capacitively loaded post (blue). This is achieved by actuating the copper film ceiling above the post with a sub-micron resolution actuator.

II. DESIGN AND FABRICATION

It is difficult to design high power and broad band sources at millimeter wave frequencies. Frequency multipliers have low conversion efficiency and compress or get damaged when driven at high input power. Existing broadband power amplifiers at millimeter wave frequencies are costly and difficult to design at high frequencies. Therefore, it is essential that passive filter components have low insertion loss. To achieve this, it is essential that we avoid using lossy transmission lines at millimeter wave frequencies [3]. Rather, in this work, we couple power to a resonant cavity with low-loss rectangular waveguide. A model of the filter is shown in figure 1. In order to reject non-resonant frequencies, the cavity width is designed to be sufficiently narrow so that the upper edge of the W band (110GHz) is well below cut-off of the resonant cavity in TE_{10}. Power at the resonant frequency may enter cavity in an evanescent mode, couple to the post and similarly couple to the output waveguide. Crucially, the cavity length has to be sufficiently short so that the evanescent fields reach the resonator circuit and exit back to the output waveguide with minimum attenuation.

Similarly to previous work at lower frequency, the resonator consists of a cavity with a conductive post in the center [4]. A gap between the post and the ceiling of the cavity capactively loads the post. This design achieves an average Q on the order of 200. The capacitance of the resonator is dependent on the top surface area of the post and the gap distance between the cavity ceiling and the post. Therefore, the resonance frequency of the cavity is proportional to the square root of the gap distance.

A 3D model of the filter was drawn and simulated in ANSYS HFSS. From figure 2, the S_{21} performance of the filter shows an average passband insertion loss of approximately 1dB and Q of approximately 200. The model was simulated with aluminum boundaries on the waveguide and cavity walls with conductivity of $38*10^6$S/m and 1µm surface roughness. In order to tune the filter, the ceiling of the cavity was designed with a flexible thin copper film which can be actuated. As shown in the cartoon in figure 2, an M3-L stepper motor from New Scale Technology which can push and pull at 0.5µm resolution was affixed to the thin film.

The resonator cavity and waveguides were machined in an H-plane split aluminum block using a CNC mill. A 1mil thin copper film was laser cut to form the ceiling of the waveguides and the cavity. A precision actuator was 3D printed and integrated with the stepper motor.

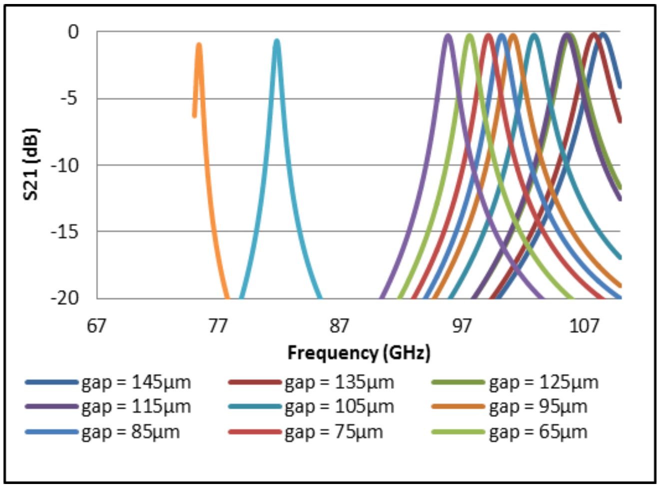


Fig. 2 ANSYS HFSS simulation of the resonator filter with varying gap distances between the cavity ceiling and the capacitively loaded post. As shown, the resonant frequency is tuned across the W band.

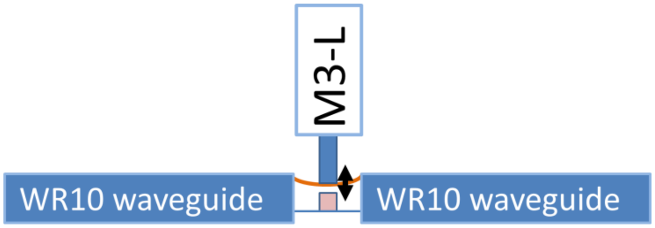


Fig. 3 Cartoon cross section of the cavity thin film ceiling being actuated by the M3-L stepper motor.

III. RESULTS AND MEASUREMENTS

The filter was machined in 60-61 aluminum using a CNC milling machine. Unfortunately, the CNC machining of the cavity had inaccuracies in critical dimensions. Vibrations on the milling tool enlarged the cut dimensions which resulted in a larger cavity with a narrower capacitive post. The cavity dimensions were measured using an optical microscope and were compared with the designed parameters as shown in table 1. These critical parameters were quite far off from the designed model. The HFSS model was re-simulated with the actual machined cavity dimensions. As predicted, the filter Q was lowered and the insertion loss was slightly higher than expected. The machined filter was assembled and tested using Agilent W-band extension modules and an Agilent PNAX vector network analyzer. The extension modules were calibrated using an SOLT calibration kit. As shown in figure 5a and 5b, the measured results were compared with the new simulation results. The resonant frequencies of the new model were in close agreement with the measured data. However, there was some discrepancy in the Q factor and insertion loss of the filter. The measured insertion loss of the machined filter was approximately 1dB lower than the simulated results and the measured Q factor of the filter is slightly lower as well.

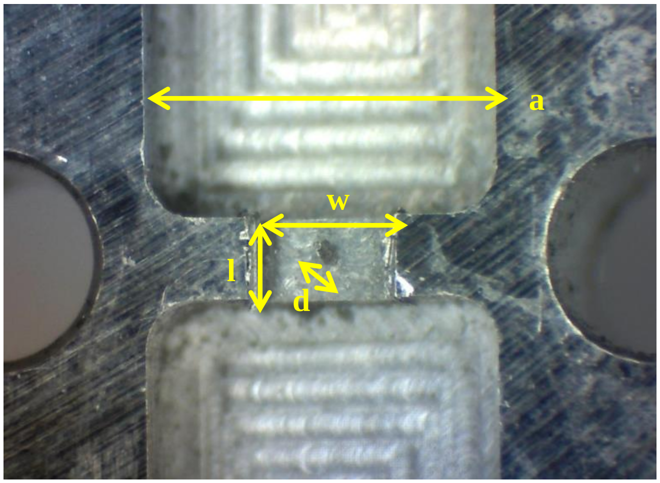
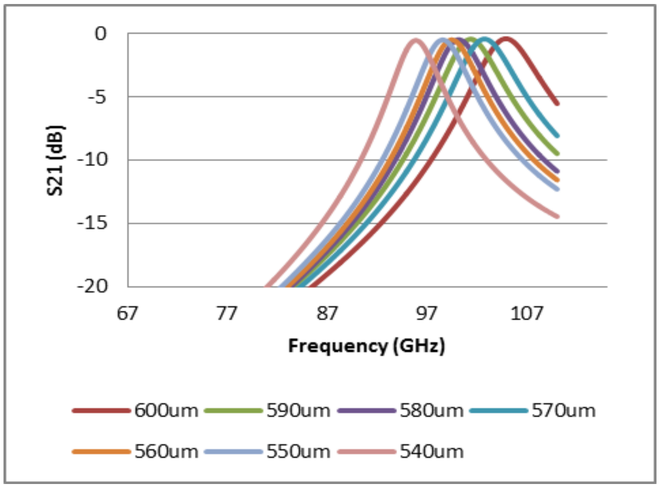


Fig. 4 Top down photo of the machined resonator cavity. ‘a’ is the waveguide width, ‘l’ is the cavity length, ‘w’ is the cavity width and ‘d’ is the post diameter.

TABLE I. MACHINED DIMENSION COMPARISON

Cavity	Design Parameters			
	a(µm)	w(µm)	l(µm)	d(µm)
Designed	2540	900	900	300
Machined	2552	1024	602	140



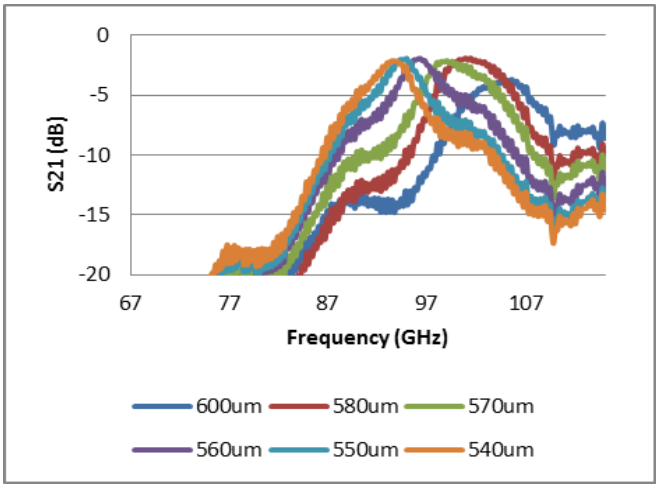


Fig. 5a (top) HFSS simulation of the filter redrawn with machined dimensions and losses due to the conductivity of aluminum and 1µm surface roughness included.

Fig. 5b (bottom) Measured S21 of the filter. Measurements were taken using an Agilent PNAX and W band extension modules.

IV. CONCLUSION

As described in this paper, we have demonstrated a tunable band pass filter at W band. Although the measured results differed from the initially designed filter, there was close agreement in performance between the measured results and the re-simulated S_{21} data from the updated model.

To achieve the initial intended design performance of the filter, there are several steps we can take. The discrepancy in insertion loss from the measured results and design performance can be attributed to two causes; The electrical discontinuity in the H-plane split waveguide and the conductive losses from the machined aluminum block [5]. To alleviate these losses, we intend to gold plate the aluminum block. This will increase the conductance of the block as well as improve the continuity from the H-plane block split. Secondly, the discrepancy in the Q of the resonator was caused by inaccuracies in machining the filter cavity. To improve the Q of the filter, we intend to re-machine the cavity using higher precision tools [6]. With these improvements, we believe that we can achieve the intended performance for this W band filter as well as filters at higher frequencies.

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