# Miniature W-Band Phase Noise Test System

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## Objectives

Design, prototyping and testing of compact millimeter wave band phase noise measurement setup based on tunable dielectric resonator discriminator. Particular objectives are i)design of tunable resonator discriminator for W band; ii)fabricate prototype of discriminator in Ka-band with Q factor approaching 30,000; iii)validation of measurement system by measurement of phase noise at the level -130dBc/Hz at 10 kHz offset in a photonic Ka-band oscillator

## Background

Low phase noise signal sources are needed for success of multiple NASA and JPL programs intended for next generation of ultra-compact millimeter wave radars suitable for cloud and precipitation profiling similar to TRMM, CloudSat, RainCube, and GPM missions and support flying formations. High spectral purity is needed in radars for detection of space dust, modern molecular clocks, VLBI, planetary boundary layer, altimetry, surface scattering and other applications that need directivity or small antenna size. Various approaches are being pursued to create compact oscillators at frequencies beyond W-band with phase noise that is better than -120 dBc/Hz at 10kHz frequency offset, limit that enables number of new NASA applications. In the meantime, common measurement of phase noise at this level requires complex frequency conversion, or use of large expensive instruments based on precision internal reference and complex synthesis, or self-homodyning with use of long delay lines. Commercial phase noise systems are available only up to Ka band in 7U format at cost of ~$400k. We *here propose a simple tool for phase noise measurement using discriminator with miniature tunable dielectric resonator with Q more than 10x higher than conventional cavities*

## Approach and results

Our approach is based on use of split-disk, dielectric resonator with whispering gallery (WG) modes $TM_{ll1}$ of high azimuthal number $l$ = 20-100. Unlike metal cavity resonators, having fixed frequency and Q-factor in millimeter wave band ~1000, WG modes in low loss dielectric like sapphire can have Q-factor reaching 30,000-50,000 in Ka band and 10,000-20,000 in W-band.

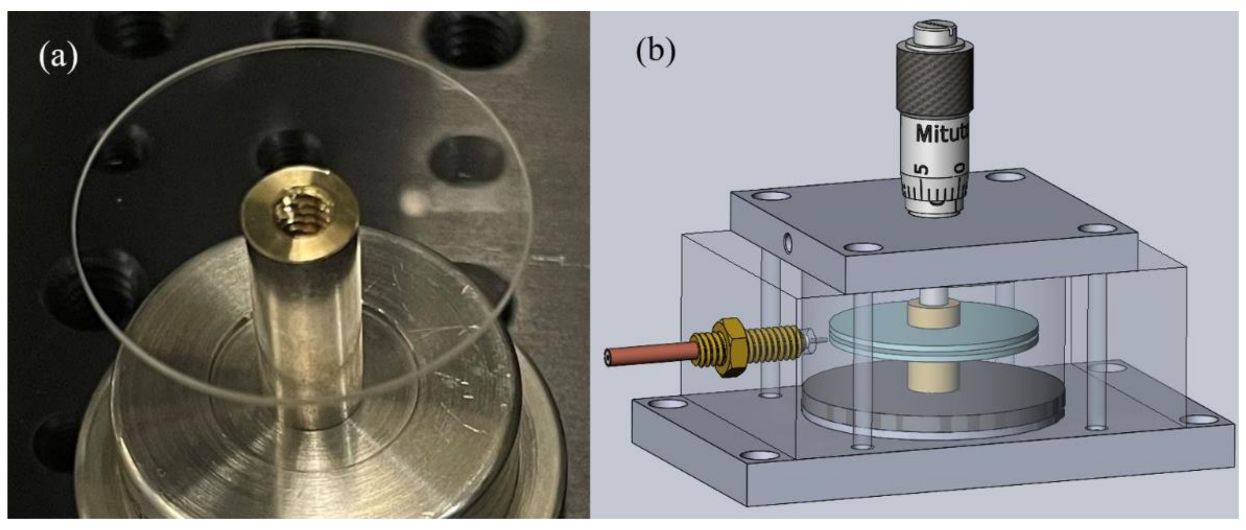


Fig.1. Individual sapphire disk resonator on test pin (a) and integrated package of tunable double disk resonator

Pair of slim disks acts as a single resonator in which effective dielectric constant can be adjusted by changing gap between the two parts.

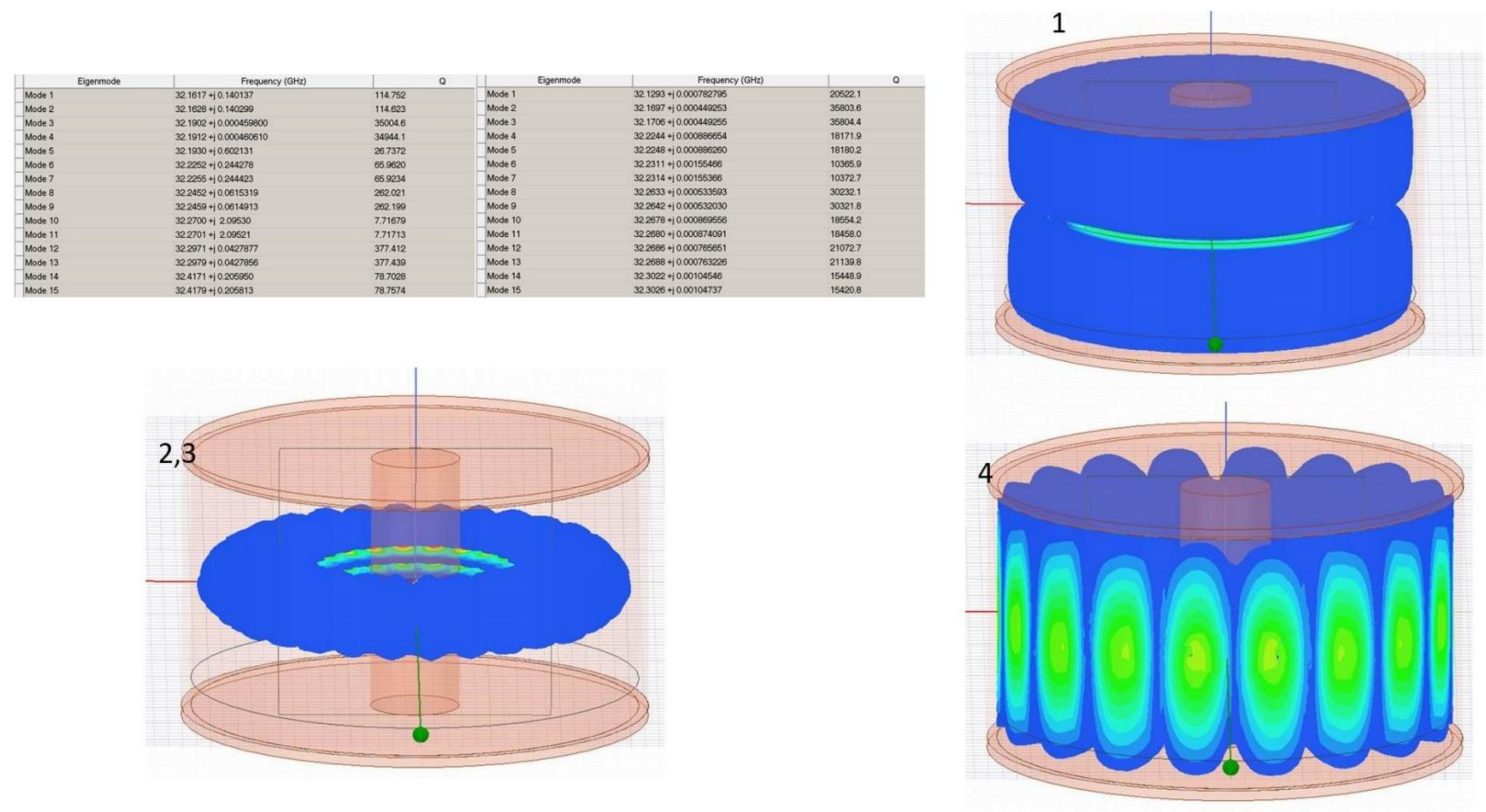


Fig.2. Simulated mode field of operational WGM (mode 2,3) and two parasitic modes (1,4), and also table 1 that illustrates strong ~100 fold suppression of Q-factor parasitic modes by absorbing disc element

Tuning range exceeds the free spectral range, and resonator can be tuned to match any oscillator under test (OUT).

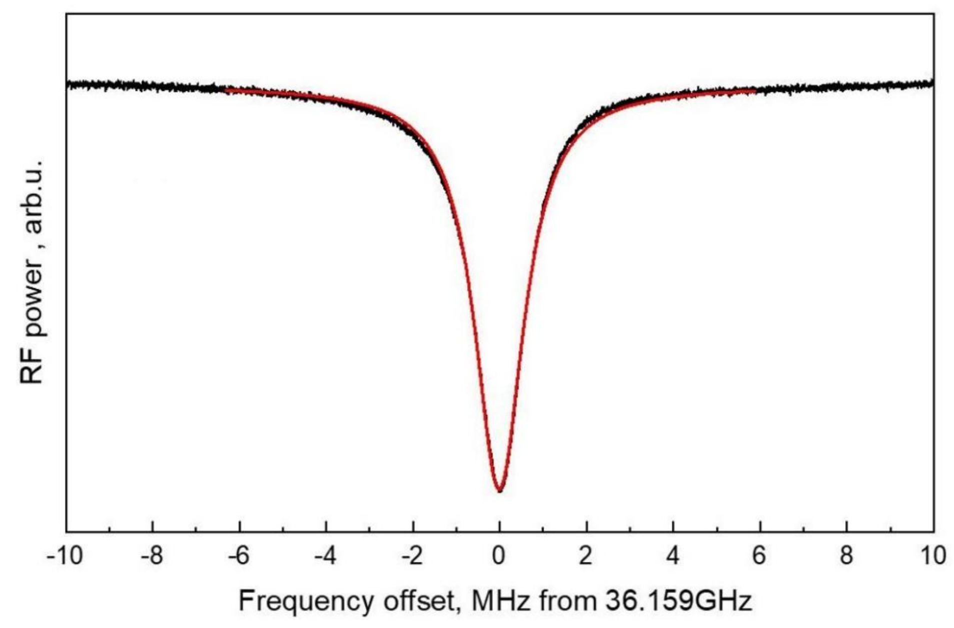


Fig.3. Measurement of quality factor of WGM mode in double disk resonator. Bandwidth 1.7MHz corresponds to Q of 21,000

We have designed frequency scalable tunable resonator for millimeter wave band (Fig.1), simulated (Fig.2), fabricated and tested (Fig.3) Ka-band prototype, achieved the Q value approaching 30,000 in the range 32-36 GHz and tuning that easily exceeds free spectral range (~1.4GHz)

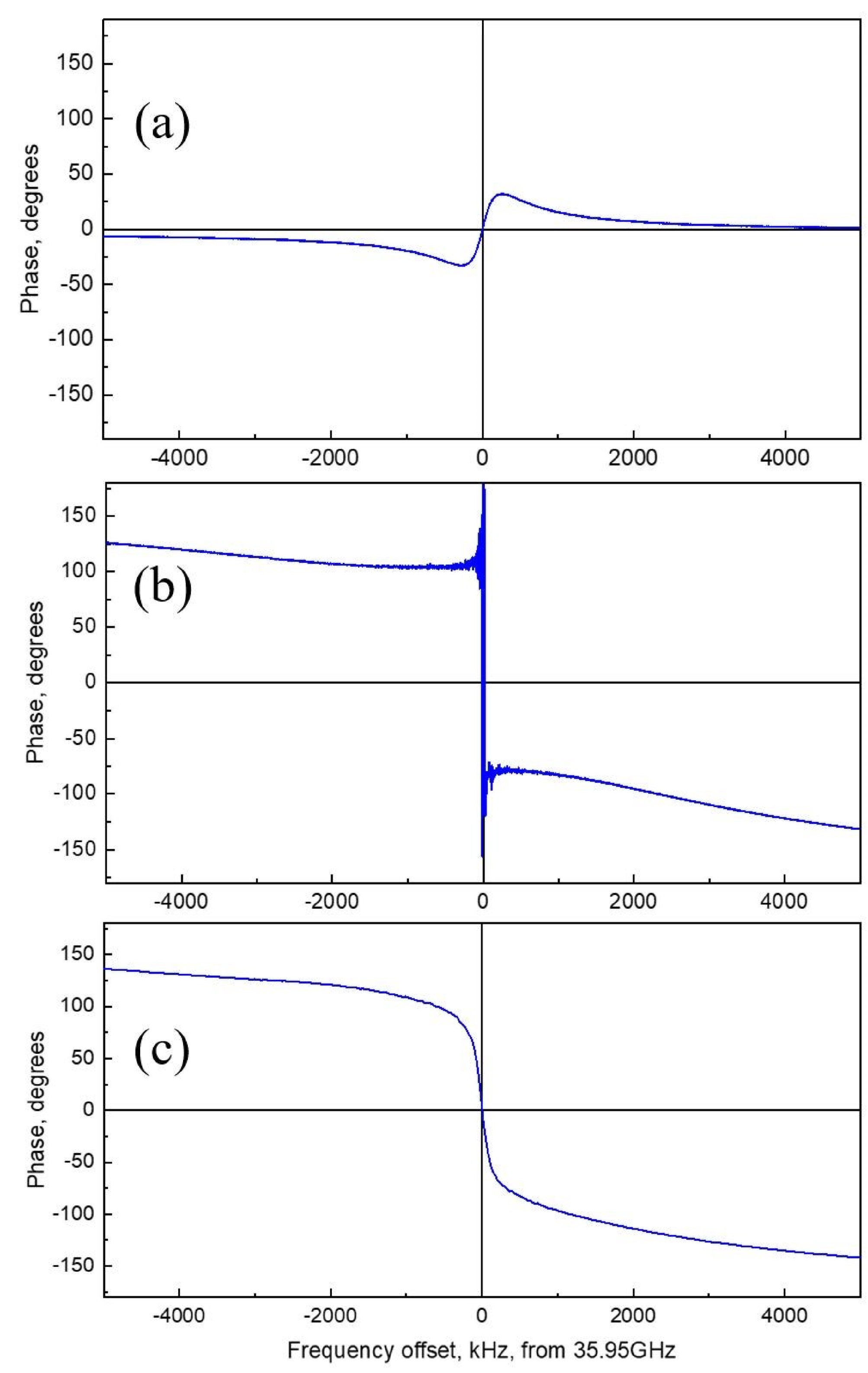


Fig.4. 4. Frequency to phase conversion by tunable dielectric resonator in sub-critical (a), near critical (b) and overloaded (c) regime

Fig.1 depicts the housing with two c-cut Hemex grade sapphire disks, 25.4mm diameter and 0.72mm thick, enclosed into 32mm diameter, 18mm high metallic cavity, with micrometer driven adjustment of gap. Fig.2 illustrates simulated field structure of operational WG mode, along with "parasitic" non-tunable modes of the box. We suggested and implemented method of suppression of non-tunable modes by addition of absorptive element included into design. Table 1 illustrates the negligible effect of this element on the Q of operational WG modes and ~100 fold reduction of Q in parasitic modes. We have built and tested reflective discriminator based on split-disk WGM resonator (Fig.4), and used it to test the phase noise of photonic oscillator, achieving the sensitivity at the level --130dBc/Hz at 10kHz offset. Fig.4 represents test results of frequency to phase conversion in discriminator based on critically coupled split-disk WGM resonator.

## Significance/Benefits to JPL and NASA:

We have demonstrated efficiency of proposed approach to facilitate simple measurement of low phase noise in millimeter-wave oscillators. Quality factor and tunability of simulated, fabricated and tested prototype resonator were sufficient to achieve the goals of measurement of phase noise in arbitrary frequency Ka-band oscillator using discriminator method. The Ka-band design can be scaled for implementation of W-band tunable WGM discriminator. Further integration can be achieved with compact motorized and PZT assisted precision tuning for remote and automatic implementations of in-situ onboard phase noise testers , and feedback loops for use in autonomous radar flight systems. Resulting millimeter wave band low phase noise signal sources will help success of multiple NASA and JPL programs intended for next generation ultra-compact millimeter wave radars suitable for cloud and precipitation profiling, TRMM, CloudSat, RainCube, and Global Precipitation Measurement (GPM) missions, support of flying formations of spacecrafts, altimetry, surface scattering measurements, and other applications benefitting from improved directivity in small antennas.

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### References:

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