National Aeronautics and Space Administration

Optimized Bragg resonators for high performance W band oscillators

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Objectives

i) experimental implementation of a prototype of Ka-band Bragg resonator experimentally and development of a design a W-band Bragg resonator; ii) optimization of the coupling methods and achievement of critical coupling and low insertion loss; iii) implementation of a breadboard prototype and measurement of phase noise of Bragg resonator based Ka-band oscillator from discrete components in the lab, and iv) development of a layout of W-band oscillator with integrated package.

Background

Compact commercial W-band dielectric resonator oscillators (DRO) are capable of delivering W-band signals with frequency noise of -90 dBc/Hz at 10 kHz. We develop a concept of low phase noise purely electronics-based W-band oscillator on the basis of innovative microwave resonator with uniquely high Q-factor. Traditional microwave dielectric resonators have Q-factor that progressively decreases with frequency, rarely exceeding 10^4 in Ka band, limited by inverse loss tangent of dielectric. Class of distributed Bragg resonators (DBR) where dielectric elements act as mirrors, can maintain very high unloaded Q>150,000 in Ka band and Q>50,000 in W-band. Early X-band studies [1] have shown promise in DBR but suffered from SWaP limitations. In millimeter wave bands, dimensions of DBR cavities will become acceptable for compact packaging, while the high Q and emerging electronic components permit the implementation of DRO that will reach target phase noise values at small frequency offset, with compact (~1cu in) dimensions.

Approach and results

As a feasibility demonstration step, we have simulated, assembled and tested Ka-band DBR system. Dimensions are based on detailed Ansys simulations and optimizations using parameters of monocrystalline sapphire and target frequency of 36GHz.

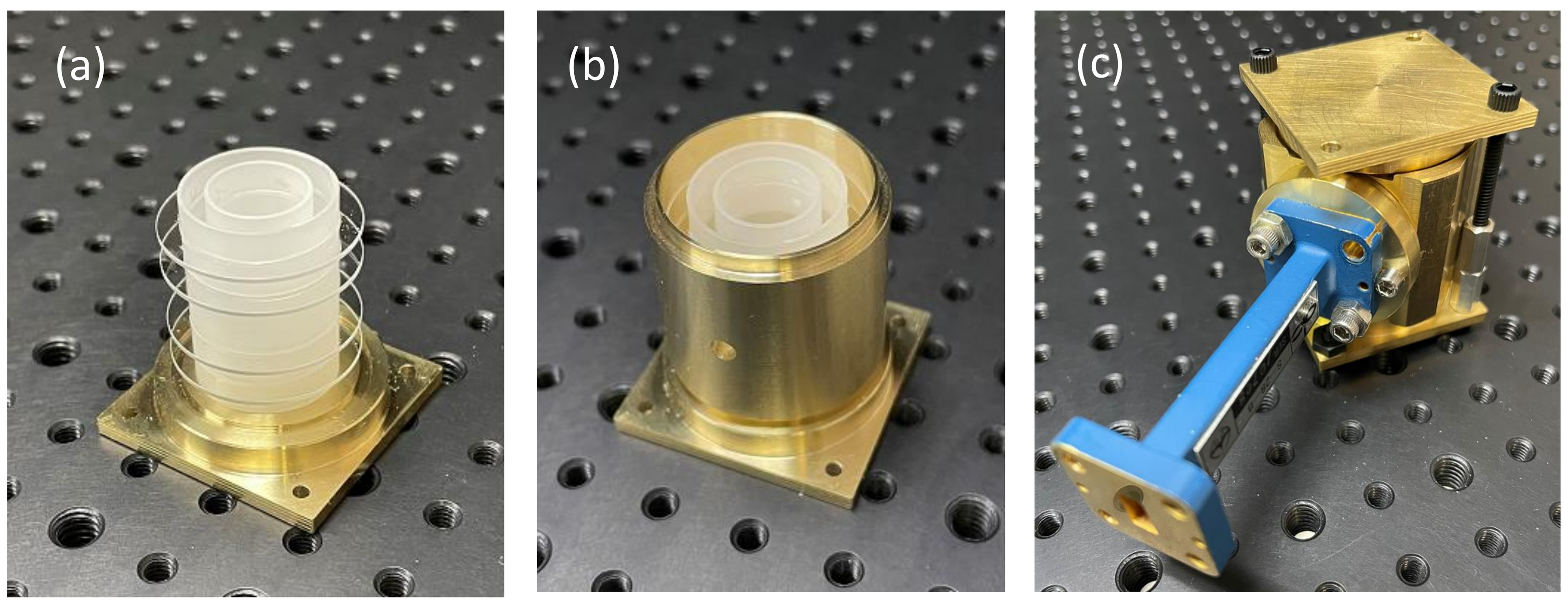

Fig.1. Ka band sapphire DBR resonator prototype. Open stack (a); in metal enclosure for low coupling tests (b); with single near critical coupler and WR28 waveguide

Cavity structure consists of a stack of monocrystalline sapphire elements enclosed in metallic housing with properly designed coupling apertures and WR28 waveguide(s). Low coupling measurements have yielded unloaded bandwidth of 185kHz at 35.95GHz indicating the intrinsic quality factor Q_0 = 195,000 that is 7.5 times higher than best Q_0 = 26,000 achievable in TE modes of Ka band dielectric sapphire resonators [2]. Early X-band studies indicated high modal density in simple structure with small inductive loop coupler. We have designed and prototyped aperture coupler that achieves selective near-critical DBR and further suppression of parasitic modes with inexpensive passband filters. Most of parasitic low-Q whispering-gallery modes in cylindrical shells are decoupled because of carefully chosen aperture better matched to TE_{02} Fabry-Perot modes in cylindrical sapphire shell.

Approach and results (contd)

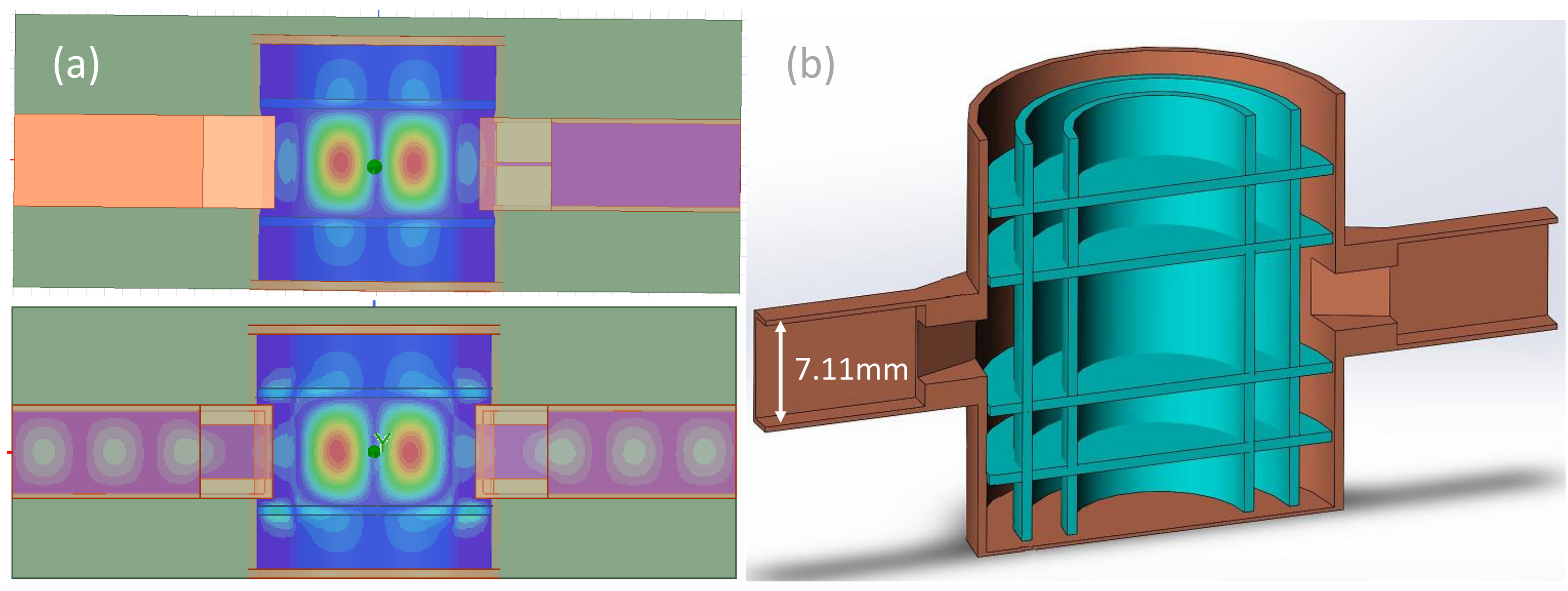

Fig.2. Aperture coupler simulation of "ultra-Q" TE_{02} DBR mode with critical coupling to TE_{10} mode of WR28 waveguide, simplified single layer stack (a). With two layer stack (b) and optimized dimensions, calculated S_{21}= 7dB with Q_L= 147,000.

Given limited budget and high cost of custom aperture mini-horn, we have tested a simplified single modular conical horn coupler (see Fig.1c), and were able to obtain mode selective near critical regime and substantial suppression of parasitic low-Q WGM modes compared to inductive loop results in [1].

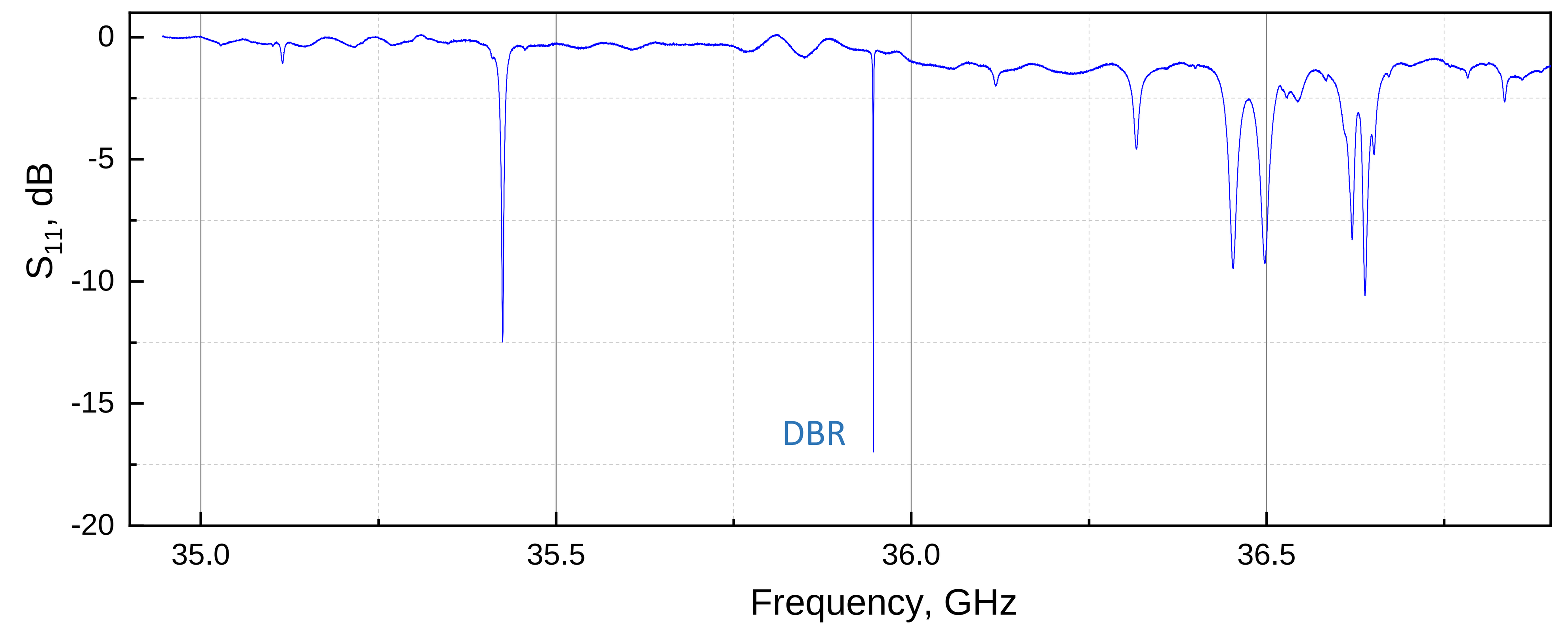

Fig.3. VNA scan of modal spectrum in 2GHz range around 36GHz. 35.95GHz DBR mode with S_{11}=-17dB and loaded bandwidth 450kHz.

Considering the Q-factor of the cavity and expected performance of the available electronic components we have estimated the phase noise of the oscillator based on the cavity (see schematic on Fig. 4a) not to exceed -120 dBc/Hz at 10 kHz offset (Fig. 4b). The Ka-band oscillator will allow achieving phase noise of < -130 dBc/Hz at 10 kHz offset. Hardware demo of oscillator requires purchase of the components not covered by the project budget. We calculated phase noise of the oscillator using Leeson model and the following parameters of available oscillator components: W-band Q-factor Q=50,000; carrier frequency f=100 GHz, amplifier noise figure NF=6 dB, and W-band signal power P=1 mW. In summary, based on the results of our analytical, numerical and experimental studies performed in this effort, we can conclude that it is technically feasible to general W-band signals with phase noise -120 dBc/Hz at 10 kHz offset using an ultra-high Q Bragg resonator of monocrystalline sapphire.

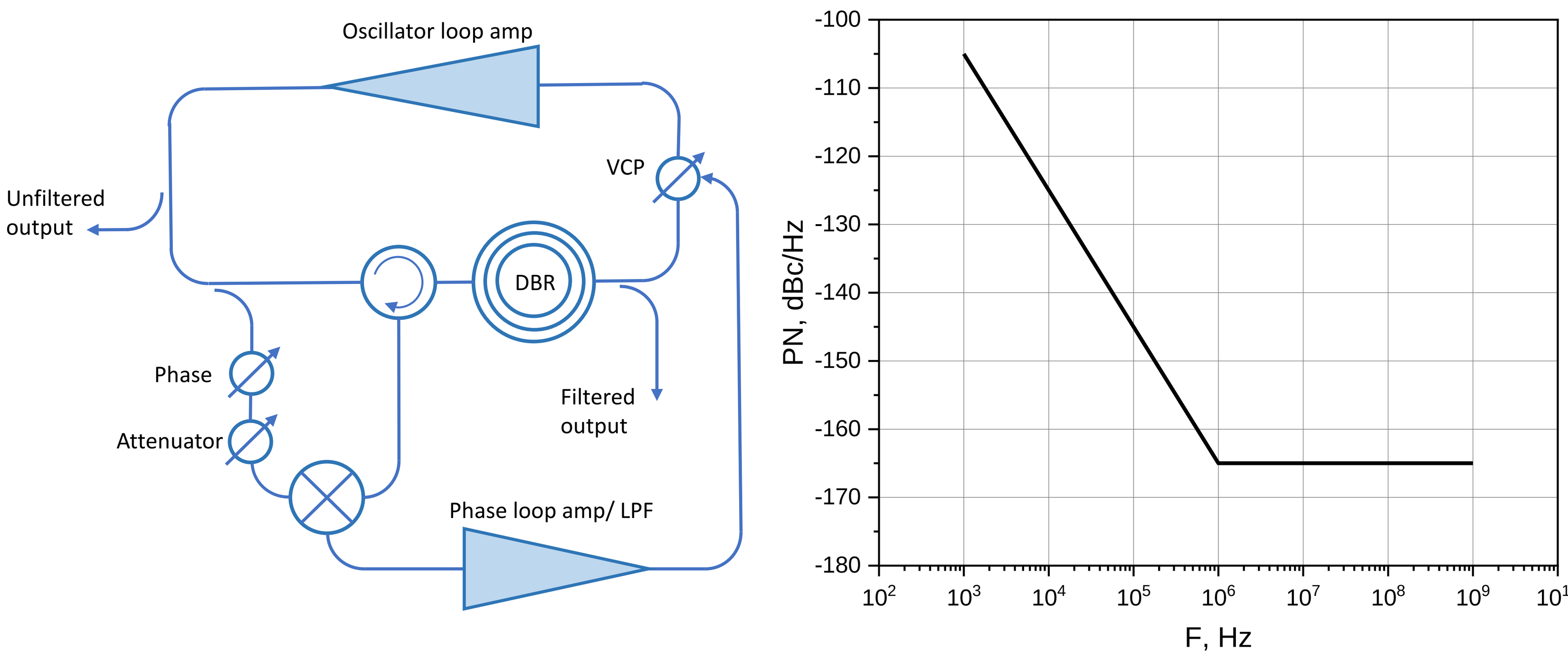

Fig.4. Suggested schematic (a) and Leeson model phase noise projection (b) of W-band DRO based on optimized sapphire DBR

Significance/Benefits to JPL and NASA:

High stability and low phase noise signal sources are needed for success of multiple NASA and JPL programs, including the DSN, GRACE-FO, DSACII, and NASA-ACES. They are also needed to support flying formations of spacecrafts. High spectral purity W-band (75-110 GHz) sources can be used in high resolution cloud and precipitation radars, radars used for detection of space dust, modern molecular clocks, very long baseline interferometry, planetary boundary layer observation, altimetry and surface scattering measurements, and other applications benefitting from improved directivity or small antenna size. Ultra-compact millimeter wave radars will benefit whole class of instruments on space constraint platforms (e.g. SmallSats and CubeSats).

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References:

[1] C. A. Flory and H. L. Ko, "Microwave oscillators incorporating high performance distributed Bragg reflector resonators," *IEEE Trans. Ultrason., Ferroelect., Freq. Contr.* ***45*** *(May 1998), pp. 824–829*

[2] J. G. Hartnett, M. E. Tobar, E. N. Ivanov and J. Krupka, "Room temperature measurement of the anisotropic loss tangent of sapphire using the whispering gallery mode technique," in *IEEE Trans. on Ultrason., Ferroelect., and Freq. Contr.* ***53****, (Jan. 2006), pp. 34-38*

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