Trade Study for a 95GHz Ultra Low Noise Photonic Radar Front End

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Program: Spontaneous

Objective: Implementation of a photonic transducer is based on several concepts that allow for multiple alternative solutions, each with its own set of advantages and disadvantages. Choosing the optimal transducer configuration for a given application is a multi-dimensional problem which requires a serious trade study. The proposed task will undertake such a trade study and outline candidate architectures for resource constrained W-band radars

Introduction: Most modern radar electronics consist of RF components such as low noise amplifiers (LNA), mixers, filters etc., usually in a heterodyne configuration to amplify, filter and down-convert the received RF signal. For a well designed radar, the noise power, and consequently SNR is determined primarily by LNA noise figure and ambient temperature. As radars scale in frequency to W- band (95GHz) and beyond, typical LNA noise figures of +6dB or higher result in poor SNR performance. High Q photonic transducers such as Whispering Gallery Mode (WGM) resonators offer an attractive alternative to typical RF radar front ends with realistically achievable noise figures of -3dB (effective system temperature of approximately 150K), possibly even better.

Benefits to NASA and JPL (or significance of results):

As JPL continues to build radars at higher frequencies (V, W-band) taking advantage of reduced instrument size and power requirements to deploy on resource constrained platforms such as Cloudcube (RainCube follow-on) and ODCR on CubeSats, W-band landing sensors for smaller landing vehicles etc, such low-noise, low SWaP detectors could prove crucial

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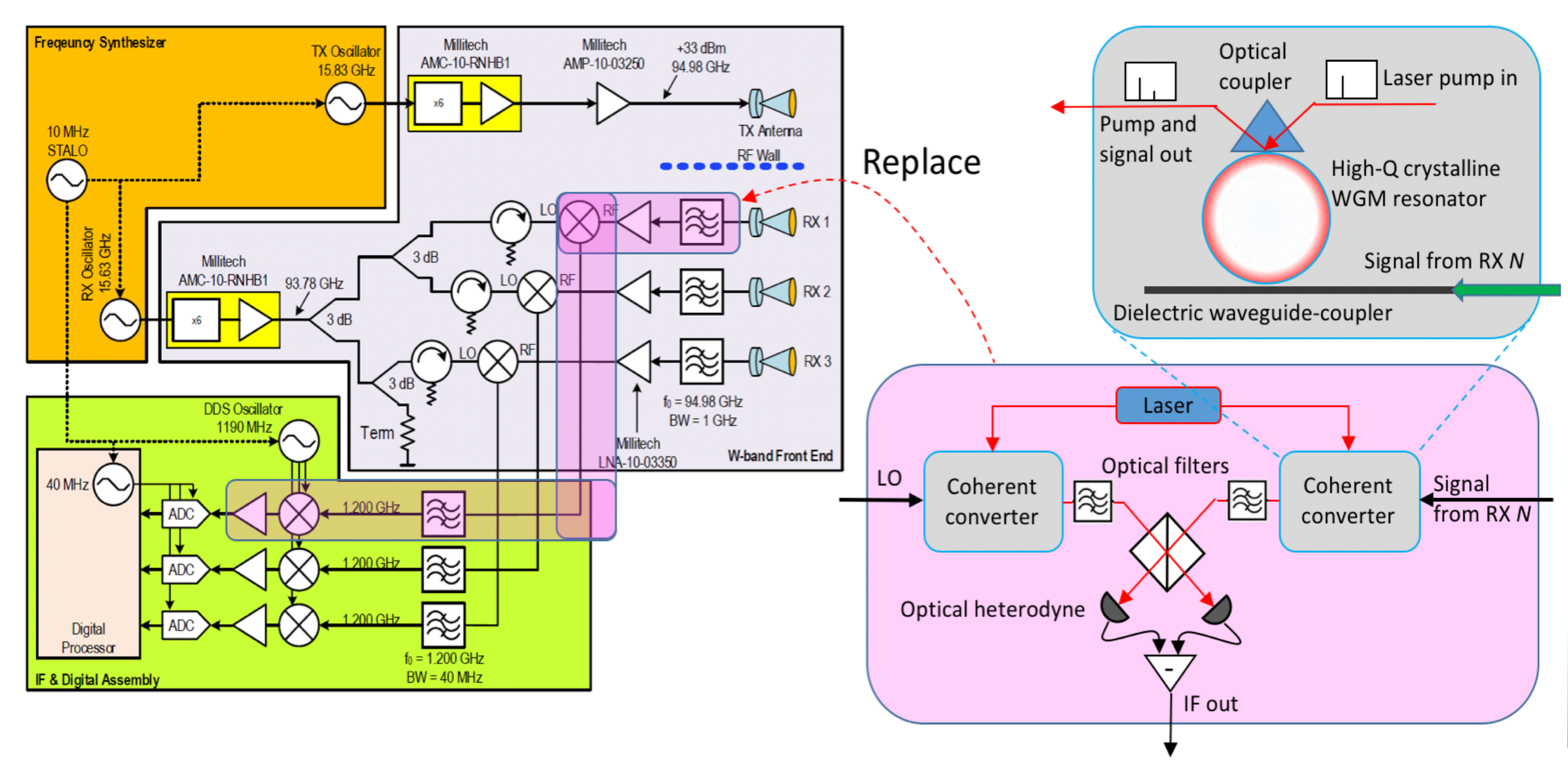
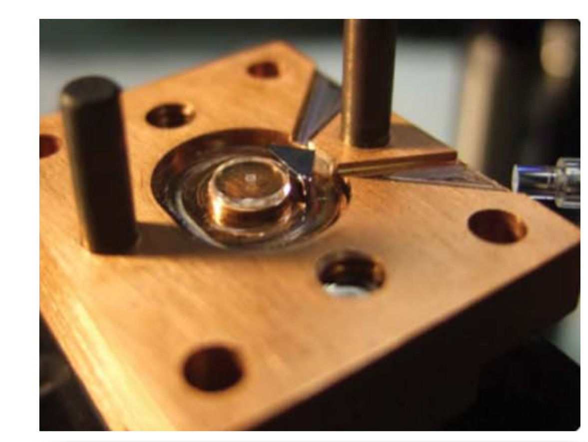
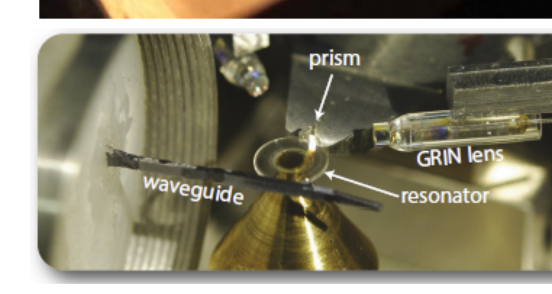
Approach and trade space

Photonic transducer can replace entire front-end down conversion chains for high frequency (W-band) radars with low noise, low SWaP components.



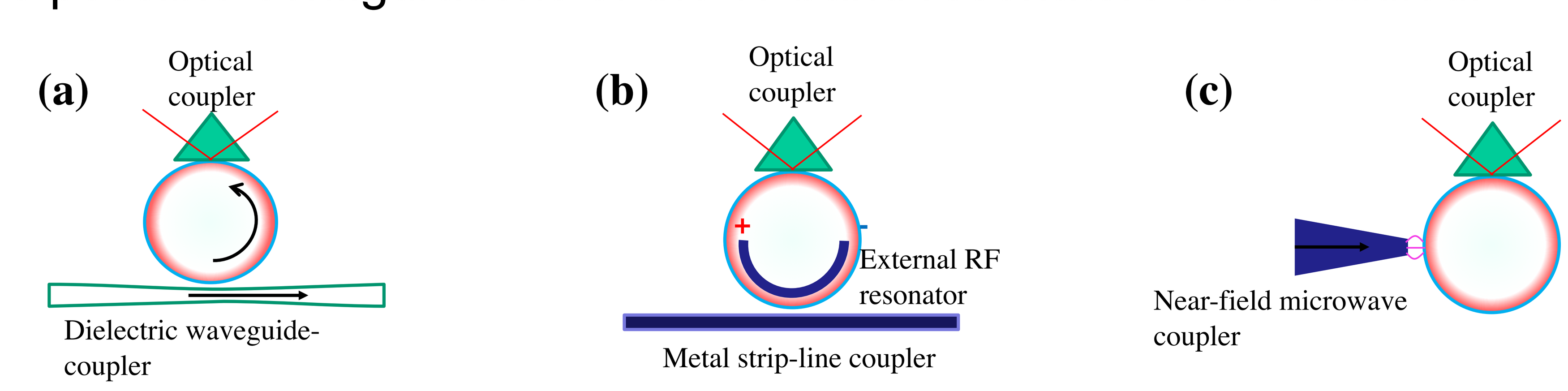
Proof-of-principle demonstrations of various receivers designs advancing the state-of-art by orders of magnitude are available



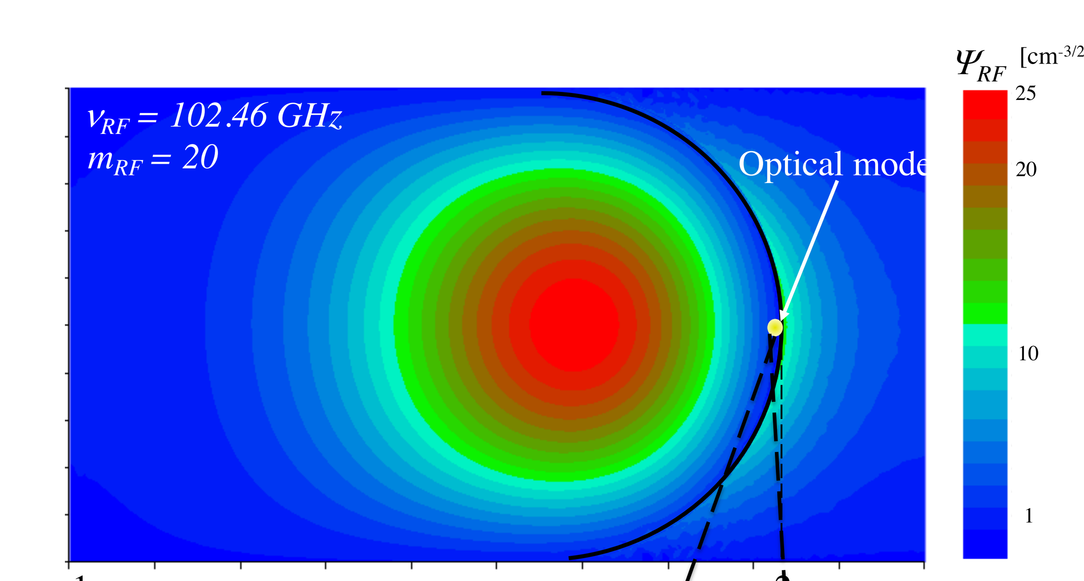


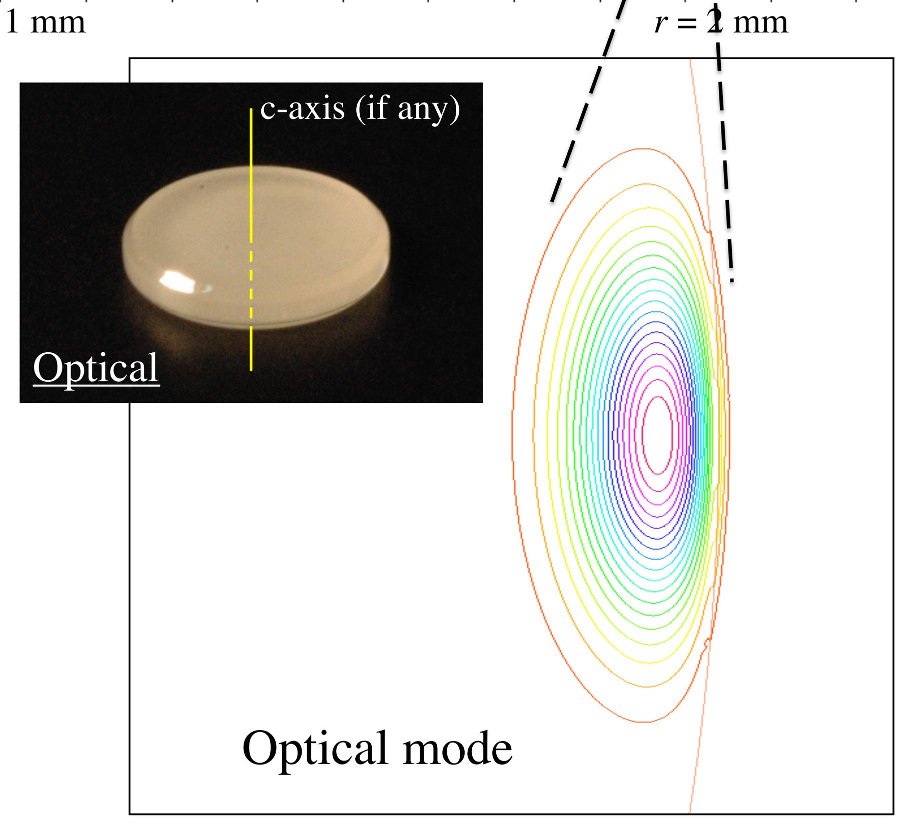
FY18/19 Results:

- Resonator material selection is reduced to a single candidate, $LiTaO_3$, based on a variety of criteria
- Microwave up-conversion configuration is selected as the “Type-II”, with TE and TM optical pump/signal fields and TM W-band signal field, leveraging electro-optical coefficient r_{51}.
- Three possible configurations of the W-band resonators were studied:



The study involved a FEM simulation of the microwave field and determination of its frequency spectra as well as the overlap with the optical fields. This lead to determining the resonator’s geometrical parameters, mode numbers, and the nonlinear conversion rate





$$g = \omega_0 \xi_1 \frac{n_a n_b}{n_c}\sqrt{\frac{\pi\hbar\omega_c}{2}}\int_V dV \Psi_a^* \Psi_b \Psi_{RF}$$

This rate for configuration (c) exceeded that for configuration (a) by a factor of 1000, while configuration (b) was shown unsuitable.

The conversion rate g is directly related to the photon-number conversion efficiency

$$\eta = \frac{\langle N_+ \rangle}{\langle N_M \rangle} \approx 64\frac{g^2}{\hbar}\frac{Q^2 Q_M}{\omega_{opt}^3 \omega_M} P_{opt}$$

The noise temperature of the microwave photonic receiver is lower than the ambient temperature by an order of magnitude because of the low attenuation of the system and low temperature of the space. Noise figure better than -3dB is feasible.

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Poster No. RPC-265