Development the Concept of 340 GHz FMCW Single Channel Radar

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1. Introduction

Development new generation of FMCW radar operating in sub-mm band and provides an excellent frequency choice for improving overall radar performance operation in brownout and degraded visibility conditions and far superior to optical and infrared systems for penetration of smoke, fog, haze, dust, blowing sand, clouds, and other adverse conditions. It is particularly suited for short-range applications, because there is no minimum range. The 340 GHz frequency range allows miniaturization of antennas necessary to achieve the required azimuth resolution. Reduced weight is an additional advantage, particularly for homeland security applications. These systems are often peak-power limited due to available solid-state devices, and an FMCW radar implementation allows increased average power, compared to pulsed radar.

The FMCW waveform offers high average power and excellent short range performance. However, this waveform demands careful design of a highly linear frequency sweep for high range resolution requirements. Our partner ELTA has a valuable experience in design and fabrication highly linear X-band synthesizers. So, the Ariel's team is focused on development sub-mm wave parts of 340 GHz FMCW radar to be integrated with available now X-band synthesizers and processing systems.

2. General concept of FMCW radar

Frequency Modulated Continuous Wave (FMCW) Radar transmits a frequency sweep, often called a chirp. The signal is reflected from distant targets and detected by the receiver where the return signal is mixed with a copy of the transmitted signal to determine the range of the target.

The transmitted waveform has a time varying frequency f(t) given by

$$f(t) = f_0 + \alpha \cdot t \qquad \forall \quad t < T \qquad (2.1)$$

where f_0 is the initial frequency, α the Rate of Change of Frequency and T is the sweep time.

This is a linearly increasing frequency sweep as shown in Figure 2.1. The frequency is f_0 at the start of the sweep and increases to f_1 at the end of the sweep after a time T called the sweep period. The bandwidth B is the difference between f_1 and f_0.

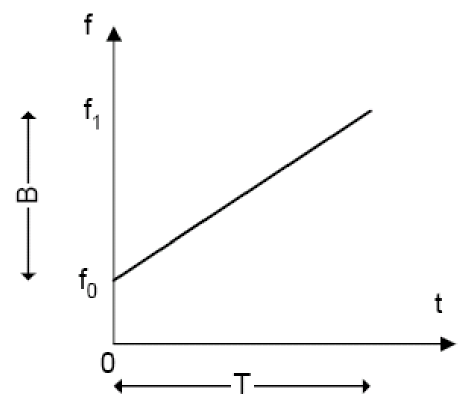

Figure 2.1 - FMCW Radar Sweep

The rate of change of frequency is then given by

$$\alpha = \frac{B}{T} \qquad (2.2)$$

The phase of the waveform is given by

$$\phi(t) = 2\pi \int f(t)dt = 2\pi \cdot (f_0 t + \frac{1}{2}\alpha \cdot t^2) \qquad (2.3)$$

The transmitted waveform travels to the target at distance R and returns after a time delay τ given by

$$\tau = \frac{2R}{c} \qquad (2.4)$$

where c is the velocity of light in the medium. The process of generating the beat frequency from the return signal can be visualized as shown in Figure 2.2.

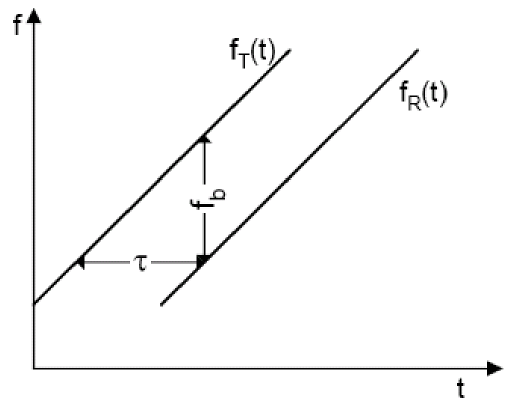

Figure 2.2 - Beat Frequency

Given that the transmit signal frequency f_T is

$$f_T(t) = f_0 + \alpha \cdot t \qquad \forall \quad 0 < t < T \qquad (2.5)$$

and assuming an ideal point target, the received signal frequency f_R is given by

$$f_R(t) = f_0 + \alpha \cdot (t - \tau) \qquad \forall \quad \tau < t < T \qquad (2.6)$$

Mixing of these two signals produces sum and difference frequencies, $f_T + f_R$ and $f_T - f_R$. The resultant signal is then low pass filtered to remove the $f_T + f_R$ term. The term that remains is the beat frequency term f_B. This process is modeled in Figure 2.3. The beat frequency term is directly related to the range by Equation 2.7.

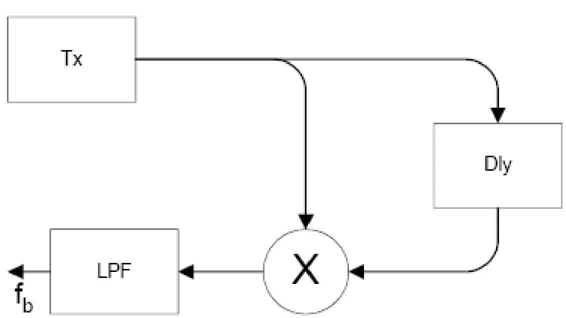

Figure 2.3 - Conceptual FMCW Radar Model

$$\begin{aligned} f_B &= f_T - f_R \\ &= \alpha \cdot \tau \\ &= \frac{B}{T} \cdot \frac{2R}{c} \\ &= \frac{2RB}{cT} \end{aligned} \qquad (2.7)$$

Thus knowing the beat frequency and the radar parameters of B and T, we can retrieve range information from the return signal. FMCW radars often store the beat frequency signal to allow for off-line processing using Fourier transform techniques. The Fast Fourier Transform (FFT) is the mathematical tool used to interpret the spectrum of the beat frequency signal in terms of radar range. The point target scenario can be extended to multiple targets also. For each target, there will be a return with a frequency corresponding to the distance. Each return will also have an amplitude corresponding to the round trip attenuation to its specific target. These can be seen as peaks in the frequency domain. This can be further extended to spread targets. In this case, the return will not consist of only individual peaks but will have spread peaks corresponding to returns from other scatterers.

3. Integration 340 GHz Rx-Tx module with ELTA equipment: basic concept.

The basic idea of integrating ELTA's equipment with 340 GHz Rx-Tx module is shown in Fig. 3.1. The yellow boxes are X-band ELTA synthesizer and processor. The blue boxes are newly designed Rx-Tx module. The W-band part of this circuit can be assemble from commercially available RF passive and active components like multipliers, amplifiers, up-converts, etc. However, there is very limited choice for 340 GHz at present. A few high-tech companies may offer some selected versions of these elements such as mixers, local oscillators, antennas etc. Another problem is to match 340 GHz components with available W-band parts. Due to different configurations and realizations of these components there is no universal solution of that problem.

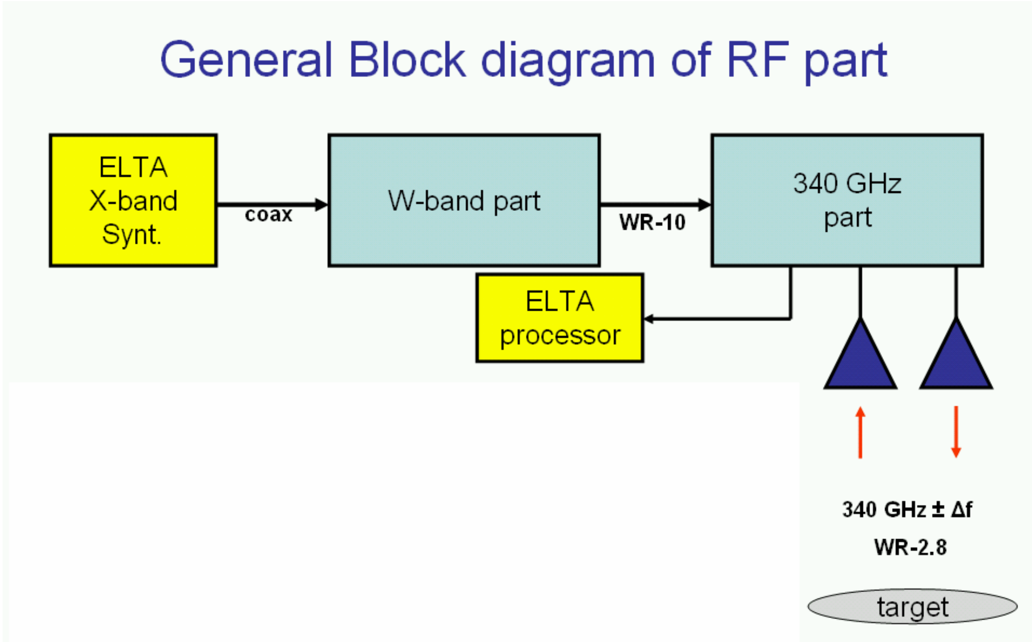

Fig. 3.1. Integration of the ELTA's equipment with Tx-Rx module operating at 340 GHz.

The only compromised solution is an implementation of the custom designed configuration of the Rx-Tx module depicted in Fig.3.2. It consists of the input driver-multiplier x4 excited by ELTA's ultra-linear synthesizer. Then the signal of frequency 42.5 GHz is splitting on Rx and Tx channels and goes to the two independent power amps (PA). The three multiplying stages x2x2x2 are used in the Tx channel to reach needed operation - 340 GHz . Horn Tx antenna is employ to transform the RF energy to plane wave radiating toward the target.

The signal reflected from target is converted by the horn Rx antenna (similar to Ts antenna) to the energy coming directly to the 2-nd harmonic mixer. The LO port of this mixer is feeding by Rx multiplying x2x2 stages resulting IF signal. This signal is processed by ELTA's processor to determine the required characteristics of the target under study.

The detailed link budget of the suggested configuration of Rx-Tx module has been calculated in the separated report. This custom-designed configuration has been matched with manufacturing facilities of Virginia Diodes Ltd and approve for ordering.

The preliminary experiments of the similar Rx-Tx configuration have been performed in Ariel Lab with participating representative of ELTA. They have proved basic concept suggested here for realization of 340 GHz single channel setup.

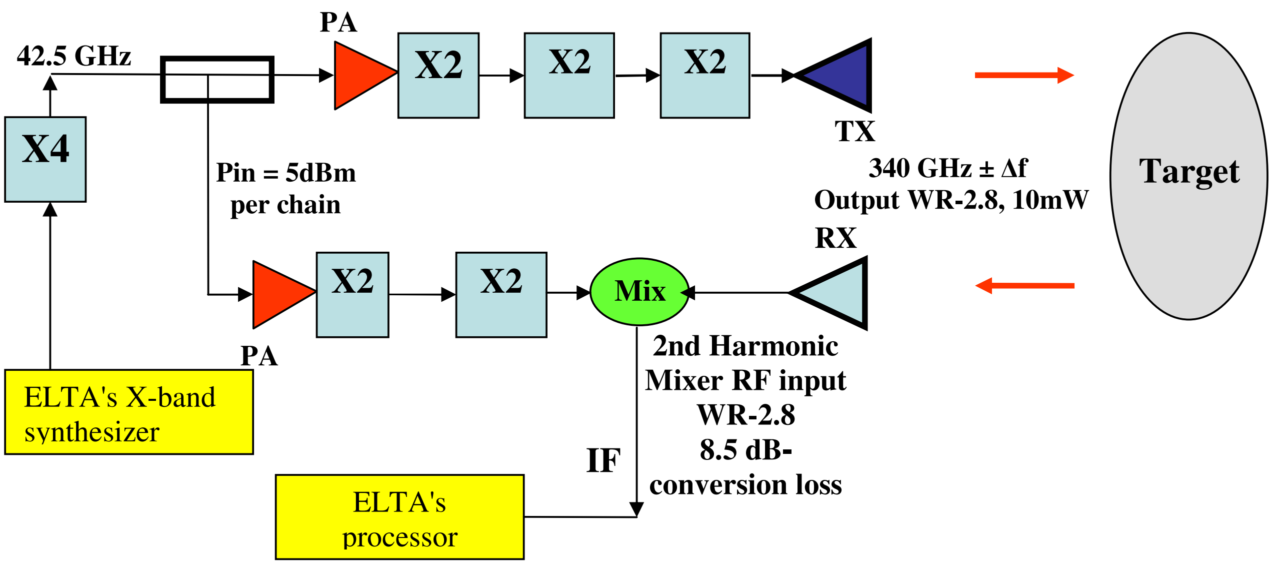

Fig. 3.2. The custom designed configuration of the Rx-Tx to be integrated with the ELTA's equipment.