

# Development of Millimeter-wave FMCW Vertical-looking Entomological Radar System

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**Abstract**— This work presents a frequency modulated continuous wave (FMCW) millimeter-wave vertical-looking radar (VLR) system. The proposed system operates at 34.5 GHz and can continuously detect targets flying at a maximum of 200m above the ground. In field tests, it measures the target’s displacement direction, moving speed, mass and body shape. An Altera Stratix IV FPGA is utilized for signal processing of the FMCW radar signal. A cosecant squared pattern leaky wave antenna is suggested to detect the targets with constant power and reduce the data processing load in real time system.

**Key words**— Vertical-looking radar (VLR), millimeter-wave, FMCW, entomological radar, FPGA.

## I. INTRODUCTION

Entomological radar systems have been used successfully for many years to study insect migration. Many insect species fly within a few hundred meters height and rely on wind-borne migration [1]. Long-term direct monitoring is difficult for traditional radar due to the equipment complexity and labor-intensive operational characteristics. In 1995, a vertically-orientated centimeter-wave radar system was developed for monitoring insect migration continuously and autonomously, but with limited target identification capabilities as it cannot derive more information from the returned signals [2]. In this work, a millimeter-wave vertical-looking radar (VLR) has been designed to monitor the migration of small insect crop pests such as aphids and beetles at different heights.

Frequency-modulated continuous-wave (FMCW) radar is a special type of radar sensor, the amplitude of the transmitted signal increases or decreases with frequency periodically. Once the echo signal is reflected back, there is a delay,  $\Delta t$ , corresponding to the change of frequency. The range measurement is accomplished by comparing the differences in frequency or phase between the transmitted and the received signals. The period of the transmitted signal is substantially longer than the receiving time for the distance measured. FMCW radar can detect and measure targets with high range accuracy and can measure target range and relative velocity simultaneously [3].

An X-band VLR was deployed and tested previously with detection range from 150m to 1200m above the ground. Signals captured are divided into 15 range gates within the detection range. This VLR employed a 9.4GHz marine pulse radar with

pulse width 60MHz. It is now being used to investigate the insect’s migration features.

The proposed compact millimeter-wave FMCW VLR is designed to detect insects flying up to 200 m above the ground. The VLR emits a vertical-looking beam which is continuously rotated at a speed of 6 turns per second. The vertical looking beam emits upwards with the center axis offset by  $0.18^\circ$ , making a conical shaped scan area. Targets flying through the beam are simultaneously detected and the returned signal is interpreted to determine the target’s size, shape, position and speed. The VLR system works 24 hours a day on a 15-minute period basis with 5-minute data capturing and 10-minute data processing. After processing, the results show the target’s displacement direction, body alignment, speed, correlation coefficient and radar reflectivity.

## II. THE RADAR SYSTEM

The block diagram of the prototype millimeter-wave FMCW VLR system is shown in Fig. 1. In this radar, the voltage control oscillator (VCO) is set as 34.5GHz with bias voltage  $\pm 5V$ . Input signal employed here is 1.5 kHz triangular wave with 0.7V peak-to-peak value. Isolator and circulator are designed for regulating the signal. DC and components above 30MHz are filtered out by the band-pass filter.

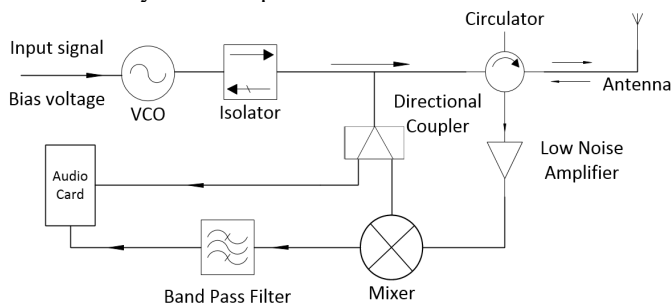


Fig. 1. Simplified block diagram of FMCW VLR

This radar emits a vertical-looking and circular symmetric beam by mechanically rotating the waveguide with 6 turns per second. This rotation frequency is controlled by a 3-phase motor. A heading marker is employed to record the reference direction of radar and from this the displacement orientation of the targets can be calculated. The vertical-looking beam is offset by  $0.18^\circ$  around the vertical axis by aligning the upward pointing waveguide.

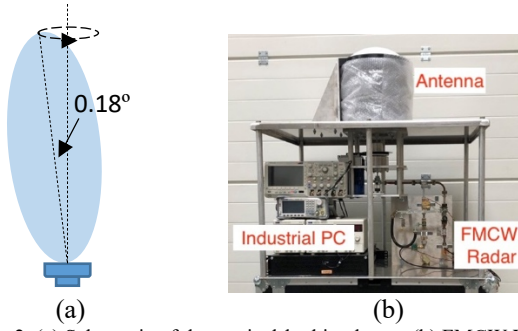


Fig. 2. (a) Schematic of the vertical-looking beam, (b) FMCW VLR

For a triangular frequency changing signal, the distance from the target can be determined from both the rising and falling edge. In equation (1),  $f_R$ , as a measure of distance determination, can be used in equation (2) to calculate the exact distance (R).

$$f_R = \frac{\Delta f_1 + \Delta f_2}{2} \quad (1)$$

$$R = \frac{c \cdot |\Delta t|}{2} = \frac{c \cdot |f_R|}{2 \cdot (df/dt)} \quad (2)$$

where  $\Delta f_1$  and  $\Delta f_2$  are frequency difference at the rising and falling edge respectively,  $c$  is speed of light in vacuum and  $df/dt$  is frequency shift per unit of time.

The signal processing is implemented on an Altera Stratix IV FPGA board with ADS4249 analog digital converter (ADC). The ADC takes 30MHz analogue signal in, which corresponds to the upper frequency limit of the band-pass filter employed in a practical system. After conversion, it passes the 14-bit digitized data to the FPGA where data enters a FIFO and is then processed by FFT. The FFT result is sent to a 16-bit digital analogue converter DAC3482, which can be easily monitored by oscilloscope.

### III. X-BAND RADAR RESULTS

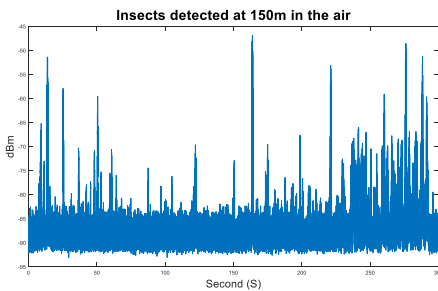


Fig. 3. Sampled result of the insects detected at 150m height in the air

Fig. 3 shows the X-band signals from the first gate (150m above the ground) overflying insects in a 5-minute interval. Spikes show the different mass and size of the insect targets. This visualization shows if there are targets detected and indicates their size. The detailed information about the detected insects including flying orientation, velocity and body shape are processed by a PC every 15 minutes. From these data, entomologists can determine the species of the insects and their migration characteristics (direction, height, velocity). It also serve as a reference for the development of the proposed mmW FMCW VLR system.

## IV. DISCUSSION

In VLR system, the upward pointing beam is offset by  $0.18^\circ$  to get a wider coverage. The adjustment needs to be very accurate and is complex to perform. Cosecant squared pattern antennas could offer improvements to the design. They enable an adapted distribution of the radiation in the beam pattern and result in a better space scanning. This radiation pattern can achieve a uniform signal strength as a target moves with a constant height within the beam. Normally, it is implemented in air-surveillance radar systems to detect an approaching target at a constant height with constant power [4].

The antenna could therefore be replaced by a leaky wave antenna with cosecant squared radiation pattern to make the practical adjustment easier. Furthermore, a leaky wave antenna enables frequency beam scanning, which makes the VLR data processing easier. As shown in Fig. 4, insects fly within the different beam area reflect different signal and thus the position can be obtained directly. Due to the cosecant squared pattern, insects flying in constant height reflect constant power. Once the height changes, the received power changes as well and computer will record the altitude changing directly. The leaky wave antenna will be employed in a later stage of the project.

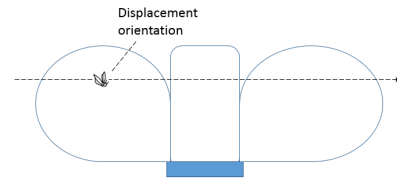


Fig. 4. Ideal radiation pattern of leaky wave antenna

## V. CONCLUSION

A frequency modulation continuous wave millimeter-wave vertical-looking radar is operational as a prototype. The design offers an innovative approach to the continuous monitoring of the migration of small insect crop pests such as aphids and beetles. The leaky wave antenna with cosecant squared pattern will be employed in the future work.

## VI. ACKNOWLEDGEMENTS

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