ACES JOURNAL, Vol. 33, No. 2, February 2018

# UAV-Radar System for Vital Sign Monitoring

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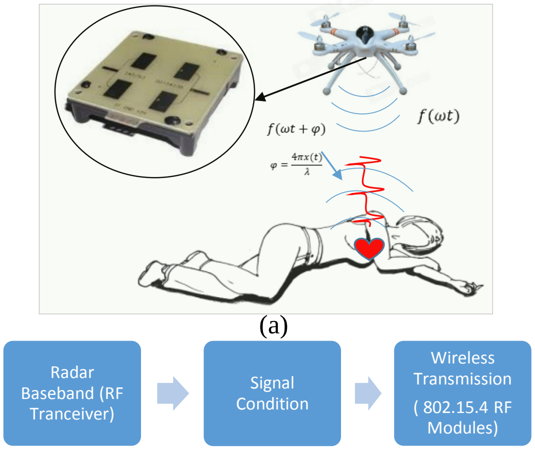
***Abstract*** ─ Feasibility and fabrication of components of a life-sign radar system on unmanned aerial vehicle (UAV) has been studied. A signal conditioning circuit has been simulated, fabricated, and tested for data preparation and acquisition. Application such as, vital-sign detection, using UAV in real-time requires wireless transmission of baseband data to the monitoring station. Methods have been devised to achieve this goal. A quadrature Doppler radar has been assembled using two single channel x-band MDU1020 radars. The united radars can avoid null point distortion in physiological monitoring. Examinations were performed with both mechanical targets.

***Index Terms*** ─ Amplifier, demodulation, Doppler radar, filter, microwave, phase, phase noise.

## I. INTRODUCTION

Short distance Doppler radars have been thoroughly studied and reported in RF based noninvasive measurements. Short distance radars can detect small motions (mm or submillimeter, based on frequency of operation) and hence can be used in vital sign measurements based on respiratory effort. In vital sign measurements continuous wave (CW) Doppler radar uses RF echo reflected from human torso. The phase of echo is proportional to the variable displacement across the body surface corresponding to the motion of heart and lungs. Due to the high sensitivity of short distance radar any motion artifact will distort the received RF signal bounced of any moving surface. Some potential application of vital sign measurements from a mobile platform can be very useful. For example, a UAV carrying a vital sign radar can be used as first responder in a battle field or a search and rescue robot during natural catastrophe. Such a system requires a portable vital-sign radar system, a data acquisition and processing system as shown in Fig. 1.

Single channel vital sign radar has major limitation since a null case may arise in numerous positions in front of the radar which gives inaccurate measurement [1]; hence, quadrature radar is preferred. Some manufacturers produce cheap single channel motion detector radars for specific purposes, i.e., MDU1020 motion detector by Microsemi. These radars are application specific and subject to null point distortions depending on the nominal distance of the target and the radar. However, two of these radars can be placed in a way to avoid the single channel radar's constraint providing a cost effective means of vital sign detection [2]. Commercial motion detection units (MDU) or vital sign radars have reasonably good power output; 13-dBm, for instance, in a MDU 2400 module mass-produced by Microwave Solutions Ltd.



(a)

(b)

Fig. 1. An illustration of life sign detection using shot distance radars reveals: (a) UAV mounted radar (MDU-1020) for vital sign detection, and (b) shows a block diagram of the system components [3].

However, the baseband signal output is only a small portion of 13-dBm, due to the fact that vital sign related motion is very small compared to the radar's full range of exposure ability. This imposes the fact that the radar signal needs to be enhanced prior to sending the output to a communication link. A feasible solution is to apply ZigBee based on the IEEE 802.15.4 protocol. ZigBee device's analog sampling is limited to the range of 0 to 1.2 volts. Testing several MDU's over a range of a meter, the MDU's voltage output swing was found to be -20 mV to 20 mV for respiration which may easily be buried in

*Submitted On: June 3, 2016*
*Accepted On: June 15, 2016*

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the noise during wireless transmission [3]. Moreover, since the ZigBee device cannot sample negative voltages, the radar output needs to be shifted, amplified and filtered. Integrating these functions requires a custom design of signal conditioning circuitry.

## II. SYSTEM ARCHITECTURE

Radar measurement from a mobile platform is modulated by the motion artifact introduced by the mobile platform. The combined motion may show phase distortion, and saturation problems in received backscattered signal. Additionally, the occurrence of null points in the received radar signal makes the extraction of life signs challenging [4], [5]. These issues stem from inconstant traveling distance seen by backscattered RF between the radar antenna and the target [5]. A motion compensation technique for mobile CW Doppler vital signs radar has been demonstrated using high precision cameras [5]. Another work included development of a new, field applicable, low-cost methodology for motion artifact compensation using only a small RF tag [5]. Some other techniques related to vital sign measurements were reported in [6]-[8]. However, these works either focused on body motion cancellation, whereas, our work focuses on vital sign detection from a UAV. Additional sensors can characterize UAV platform motion to filter out the noise introduced by vibration and drift. The output of these sensors also requires some conditioning (amplification and filtering) as shown in the detailed system architecture in Fig. 2.

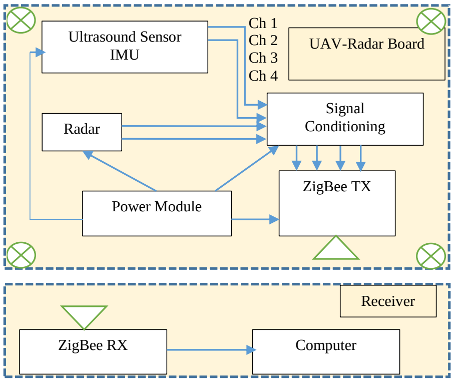


Fig. 2. A detail system diagram of UAV radar system for vital sign monitoring.

Application of ultrasound sensor can generate and approximate spatial map (in a confined space, or ground elevation for open space) of a moving object within the range of speed and sensitivity. This can help characterize platform motion, hence, useful data for radar signal processing in noise cancellation.

To test the concept by starting from the scratch, we needed low cost radars, able to perform demodulation of signal with greater quality. On the other hand, recorded signal needs to be cleaned up for further processing and filtering unwanted components. So, this worked focused on finding an engineering solution to a low cost radar also creation of custom signal conditioning circuit.

## III. LOW COST RADAR SENSOR

We proposed a low cost solution to an IQ radar system. The price is well under of exisitng solutions. A typical qudrature radar MDU-4200 from Microwave Solution Ltd. Costs about $120, whereas, a single-channel MDU 1020 can be found as low as $7. A theoritical explanation presentated below justifies the composition of two single channel radars for making an alternate solution to qudrature radar.

### A. Radar theory of vital sign detection

A typical coherent continuous wave vital sign Doppler radar system sends an RF signal towards human torso, the echo is phase modulated due to the positional variation of moving body parts. The echo is mixed and down converted to retrieve the target's displacement. The output of a single channel receiver is given by [1]:

$$\mathrm{B}(t) \approx A_B\, cos\left(\theta + \frac{4\pi x(t)}{\lambda} + \frac{4\pi y(t)}{\lambda} + \Delta\emptyset\left(t - \frac{2d_0}{c}\right)\right), \quad (1)$$

where $\theta$ is constant phase shift and $\Delta\emptyset$ is residual phase noise. $A_B, \lambda, x(t), y(t)$, and $d_0$ are baseband amplitude, wavelength, chest movement, heart movement and nominal distance between the radar and the target. Now, if somehow $\frac{\pi}{2}$ phase change is introduced, (1) will result in:

$$\mathrm{B}(t) \approx A_B\, sin\left(\theta + \frac{4\pi x(t)}{\lambda} + \frac{4\pi y(t)}{\lambda} + \Delta\emptyset\left(t - \frac{2d_0}{c}\right)\right). \quad (2)$$

Our work proves that physical offset between two single-channel radars can achieve proper phase shift for quadrature radar channels.

### B. Null and optimum demodulation

The constant phase shift in (1) is related to nominal distance and can be expressed as:

$$\theta = \frac{4\pi d_0}{\lambda} + \theta_0;\; d_0 = \frac{\lambda(\theta - \theta_0)}{4\pi};\; d_0 = \frac{\lambda\left(\frac{k\pi}{2} - \theta_0\right)}{4\pi}. \quad (3)$$

If $\theta$ is denoted as the k multiple of $\frac{\pi}{2}$, the baseband output $\mathrm{B}(t)$ will be either null or optimum for an integer value of $k$ when small signal approximation is applicable [1]. From (1) and (2) we see that null and optimum baseband output occurs for the nominal distances as:

$$d_{NULL} = \frac{\lambda(m\pi - \theta_0)}{4\pi};\; d_{OPT} = \frac{\lambda\left(m\pi + \frac{\pi}{2} - \theta_0\right)}{4\pi}, \quad (4)$$

where $m$ is an integer. (3) reveals that the adjacent null and optimum separation is:

$$|d_{NULL} - d_{OPT}| = \frac{\lambda}{8}. \quad (5)$$

This examination proves the fact that if two single channel radars are oriented in similar way with a separation of $\frac{\lambda}{8}$ in the plane of nominal distance between the target and the radar transceivers, one of the radars will be in optimum position given that the other is in null position and vice versa [2]. One fundamental assumption is that the difference of the residual phase noise of the radars is negligible.

### C. Fabrication and testing

Two MDU1020 radars were used for the experiment. MDU1020 has the operating frequency is 10.525 GHz. The theoretical distance between consecutive null and optimum points is 3.5629 mm; $\frac{\lambda}{8}$ in other words [2]. Now creating the physical separation of this length in traveling plane of the wave should ensure fail-safe design. In case the nominal distance between one of the radars is in null position, the other will be in optimum position. The two radars were physically separated approximately 3.5 mm, as shown in Fig. 3. A mechanical mover was programmed to move in 0.5 Hz sinusoidal motion. The nominal distance between the radar pair and target was varied in the range of [0.5 m (0.5+.0035) m]. Linear demodulation has been performed using the output (voltage proportional to displacement) of the two radars as shown in Fig. 4.

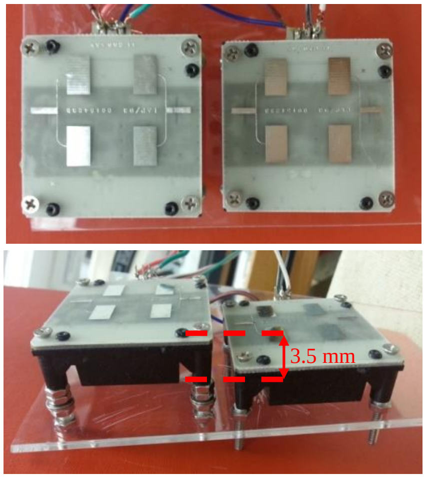


Fig. 3. Quadrature radar assembly is illustrated. A physical offset of approximately 3.5 mm has been kept between the two MDU1020 single channel k band radars [2].

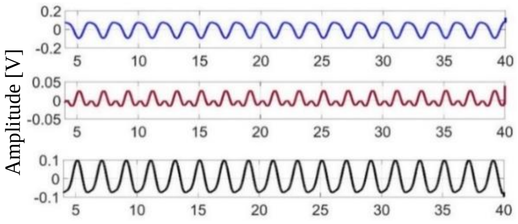


Fig. 4. Shows the two radar output and combined output when the nominal distance is gradually changed. It is evident that one radar suffers distortion, but the other radar helps demodulating the correct signal [2].

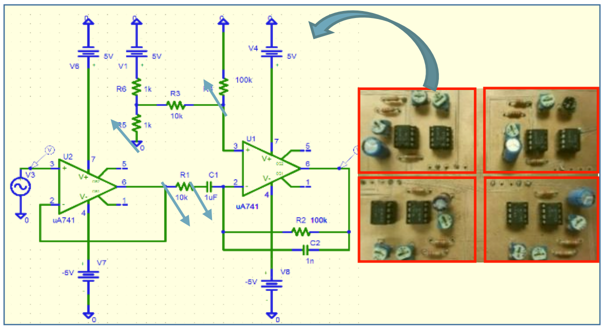
## IV. SIGNAL PROCESSING MODULE

### A. Design requirment

The design requirements of the signal conditioning circuit are amplification, filtering, light-weight, DC offsetting capability for level shifting.

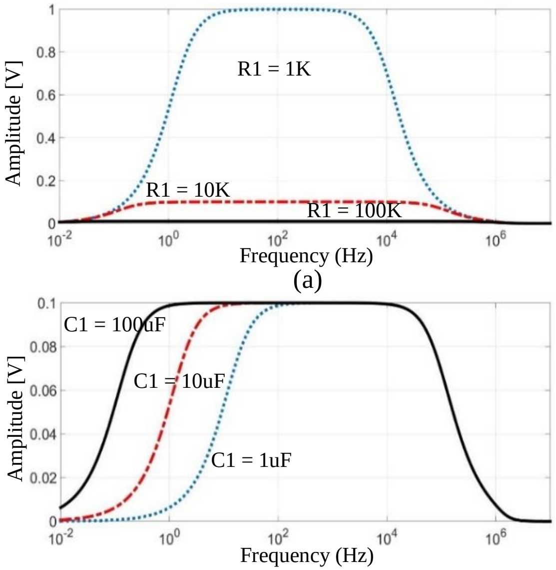
### B. Simulation

General purpose uA741 operational amplifiers were selected for design and fabrication of the quick prototype. The circuit has two stages as shown in Fig. 5. The first stage is a voltage follower while the second stage is a summing inverting amplifier. Passive components have been used for filtering, i.e., variable resistors along with capacitors were used to provide DC offset, tunable band and gain. Figure 6 shows some tuning simulation.



(a) (b)

Fig. 5. Software simulation and layout is shown: (a) depicts the circuit diagram of the single channel amplifier, and in (b) fabricated circuit containing four amplifier blocks [3].



(b)

Fig. 6. Bandwidth and gain variation by tuning resistance in (a), and capacitance in (b). R1 and C1 in Fig. 5 (a) were varied.

### C. Fabrication and testing

PCB layout was made using a LPKF mid-range PCB milling machine. A double sided FR-4 board was used to print the layout. A four-channel signal conditioning circuit was designed, so the circuit is capable of conditioning four channels.

## V. RESULTS

Experiments were to check the performance of signal conditioning, wireless data acquisition. Target's motion and a simple platform motions were simulated using mechanical moving stages, as demonstrated in Fig. 7. The radar sensor and signal conditinging circuitry was mounted on a linear stages. Figure 8 illustrates the presense of noise in radar signal due to motion artifact simulated using linear stage. The radar sensor data was recorded via ZigBee communication link.

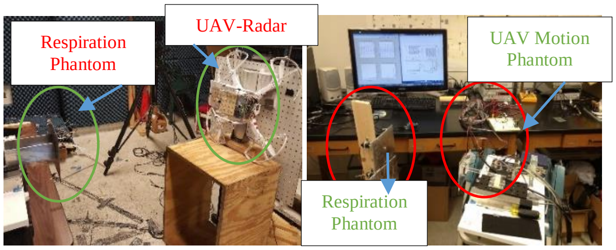


Fig. 7. (a) Shows experimental assembly, a DJI phantom quadcopter carrying the circuitry, and (b) shows experiments, simulating platform motion and target motion with two different linear stage.

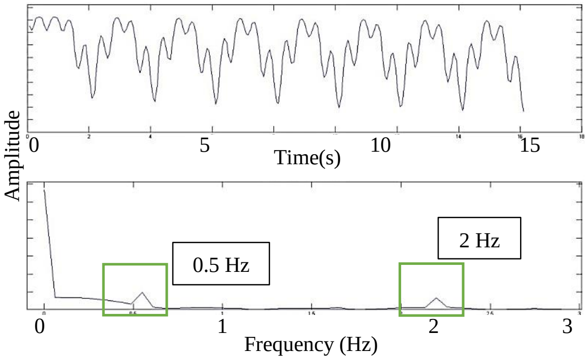


Fig. 8. Shows the time and frequency domain plots of radar data that contains two motion signature, platform motion was 2 Hz and target motion was 0.5 Hz simple periodic motion. Both platform motion and target's motion are in composite signal.

## VI. CEM APPLICATION

This work implemented off-the-shelf radar having vertical and horizontal polarization of 36 degree, and 72 degree respectively in patch antenna. For motion artifact compensation low-IF RF tags can be used. A computational EM (CEM) simulation will help making a robust system.

## VII. CONCLUSION

UAV-Life sign Radar system has been studied and system components were built to provide a low cost fabrication of the platform. A low noise lightweight four-channel amplifier with DC offsetting and frequency tuning capability was fabricated. A low cost solution for quick prototyping of distortion-less radars system has been proposed with practical implementation. Overall, our work opens up the potentials for using UAV for life sign monitoring.

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National Institute on Minority Health and Health Disparities (NIMHD), National Institutes of Health (NIH), National Science Foundation (NSF).