Research on Data Acquisition Front End of Millimeter Wave Imaging

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Abstract

In recent years, with the increase of the threat of terrorism and the increase in casualties caused by personnel carrying improvised explosive devices, it is urgent to establish an imaging system to detect such threats and ensure personal safety. Millimeter waves can be transmitted in the atmosphere and clothing with little attenuation, and are widely used in security imaging, battlefield detection and other fields. Combined with these advantages of millimeter wave, millimeter wave imaging technology has been widely used in many fields such as human security inspection and military reconnaissance. This article is mainly for the safety inspection of airports, docks, etc., the need to carry out millimeter imaging of the target and then check the presence or absence of carrying dangerous materials. This paper mainly studies the design of the millimeter wave acquisition front end and the millimeter wave raw data.

Keywords

Millimeter wave imaging, data acquisition, raw data.

1. Introduction

Object detection based on millimeter wave radiation or reflection can be divided into two modes: active imaging and passive imaging. Both imaging methods have a unique set of requirements for the millimeter wave imaging receiver or detector circuit and its supporting circuit components, as shown in the Fig.1 is shown.

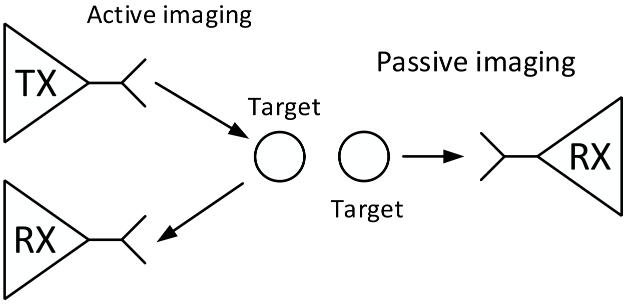

Fig 1. Simple diagram of active imaging and passive imaging

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The effectiveness of any imaging device depends on its ability to capture radiation emitted from the target scene. Passive and active imaging differ in the manner in which such radiation is produced, the former utilizing the thermal radiation of the object and the latter measuring the reflected radiation of the relatively high power source. In each case, the magnitude of the available power varies greatly, depending on the spectral region to be measured, especially for passive imaging.

Passive imaging: Imaging is constructed by detecting the subject's own blackbody radiation, without the need to use a millimeter wave source. This simplifies the system and facilitates its wide range of applications[1-3].

Active millimeter wave imaging is a process of modulating, amplifying, etc. at the transmitting end and then transmitting the required millimeter wave signal. The millimeter wave signal is reflected by the target and the background and received by the receiving end, and finally a series of processing is performed on the reflected echo signal for imaging. . Compared with passive imaging, active imaging has low impact on external environmental factors, and more useful information is obtained from it, and imaging quality is also randomly improved. This paper mainly discusses and studies millimeter wave active imaging[4-7].

2. System Structure

The data acquisition front-end based on millimeter wave imaging is mainly composed of four parts: transmitting module, receiving module, data processing module and target positioning module. The system architecture is shown in Fig.2. The core control of the hardware system is Cortex-R4F. The Cortex-R4F can control the sampling data to be buffered in the ADC Buffer and then processed by the DSP or through the LVDS and CSI2 serial interfaces to transmit the sampled data, the associated clock and the frame synchronization signal. Other processing modules (such as: FPGA) complete the positioning. The clock is composed of a 40 and 50MHz crystal oscillator, which is increased to the required frequency by the PLL and frequency multiplier, and finally distributed to each module through the clock management circuit; the target positioning module is directly imaged on the PC.

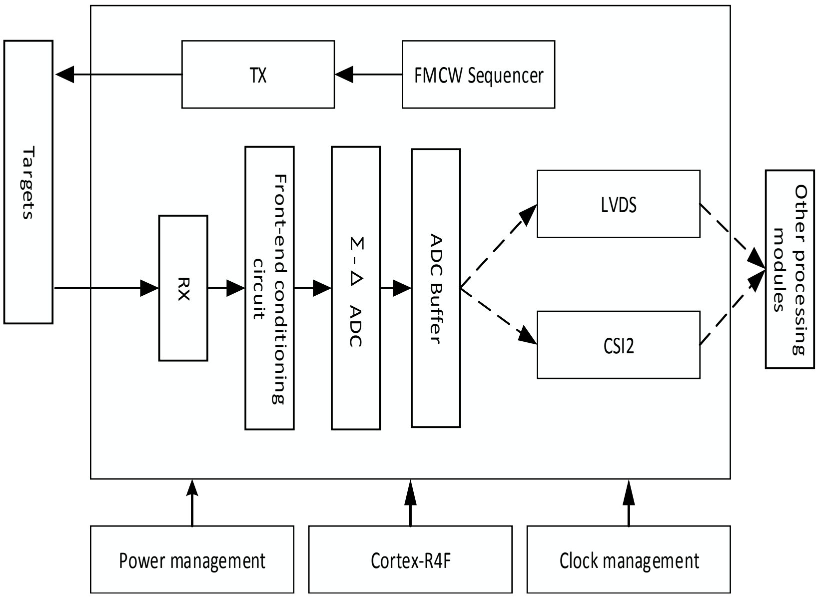

Fig 2. System Architecture

Cortex-R4F is the core function device of this module. The core software tasks are: (1) use ARM-R4F to control the transmit FMCW of the transmit module, and set the FMCW properties (FMCW slope, duration, TX power, etc.); (2) Set the working mode of the module to MIMO, and the flow of data; (3) Control the algorithm related to the DSP to complete the positioning. This example is designed with the Cortex-R4F, which features an architecture for safety-critical applications, floating point functionality, advanced connectivity options, flexible real-time control peripherals, and a powerful communications interface.

3. Submodule Introduction

The system includes analog components including transmit (TX) and receive (RX) radio frequency (RF) components, as well as analog components such as clocks, as well as digital components such as analog-to-digital converters (ADCs), microcontrollers (MCUs), and digital signal processors.(DSP).

3.1. Transmitter Module

The transmitter module, shown in Fig.3, consists of two parallel transmission chains, each with independent phase and amplitude control. This module supports binary phase modulation and interference suppression for millimeter wave imaging.

Each transmit channel can provide up to 12 dBm of power at the antenna port. The transmit channel also supports programmable for system optimization. As shown in Fig.4, the transmit channel can be programmed to meet the needs. For example: set start frequency, transmit frequency slope, ADC sampling time, ADC effective start time, and so on.

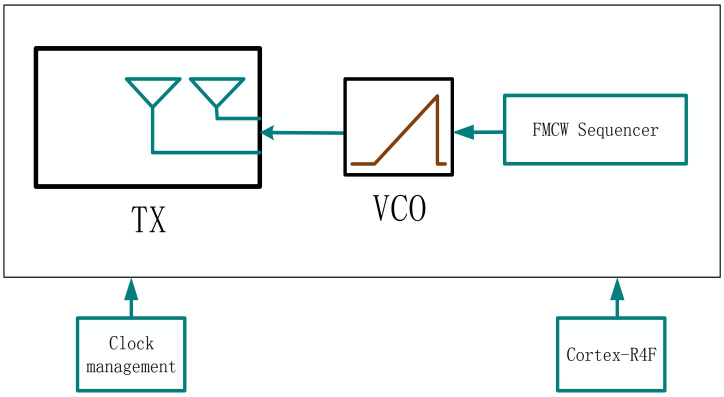

Fig 3. Transmitter module

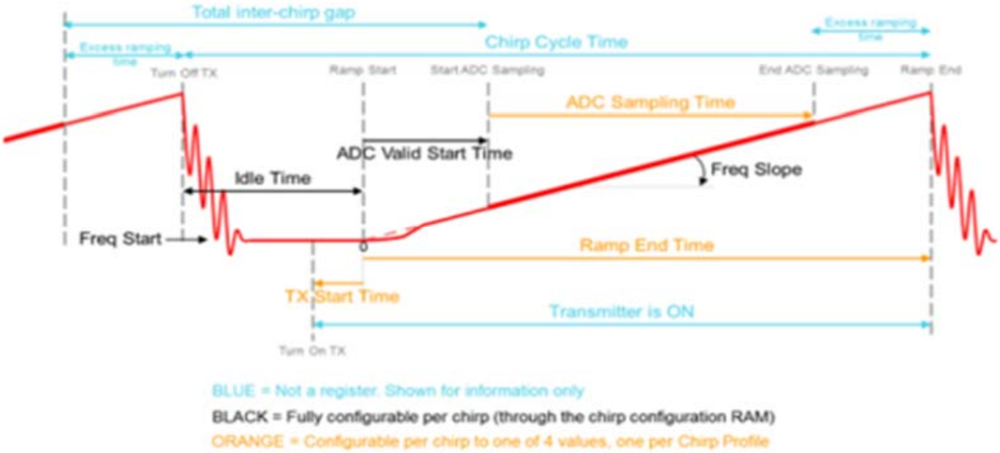

Fig 4. Programming the transmit channel

3.1.1. Sub-section Headings

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3.2. Receive Module

The receiving module consists of four parallel channels. A single receive channel consists of LNA, mixer, IF filter, and ADC, as shown in Fig.5. All four receive channels can operate simultaneously, and separate shutdown options are also available for system optimization. The clock management provides the baseband signal for the receiving module, and the Cortex-R4F programs the module to complete the IF filtering and data flow, so that the subsequent processing module can process the data more quickly and conveniently. The module supports a complex baseband architecture and provides complex I and Q outputs for each receiver channel using quadrature mixers and dual IF and ADC links. The bandpass IF chain has a configurable low cutoff frequency of 175 kHz or higher and supports bandwidths up to 5 MHz.

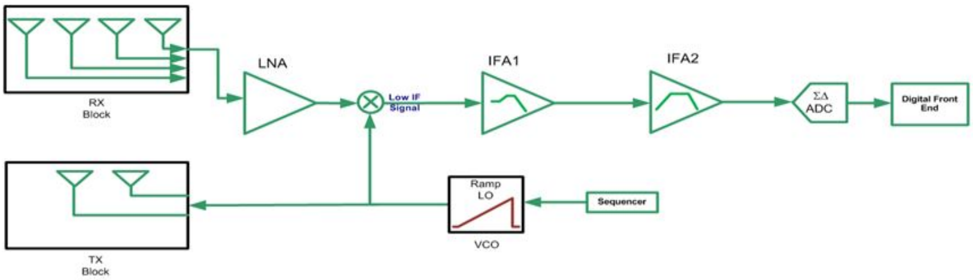


Fig 5. Receive Module

3.3. Data Processing Module

The module controls the flow of acquired data through Cortex-R4F programming. The data is processed by setting the selection DSP and then the target positioning display is performed by the PC. The specific processing algorithm is as follows:

The FMCW is transmitted through the transmitting module and captures the signal reflected by the object in its transmit path. Fig.6 shows a simplified block diagram of the main RF component of the acquisition front end.

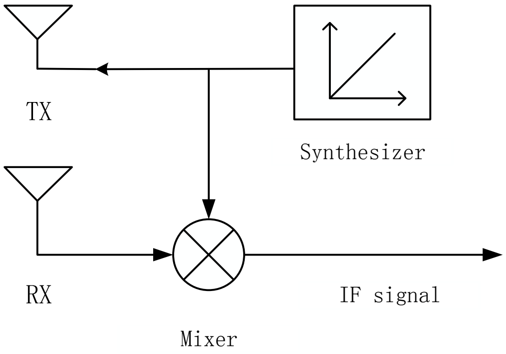


Fig 6. Acquisition front-end block diagram

A mixer is an electronic component that combines two signals together to produce a new signal with a new frequency.

For two sinusoidal inputs x_1 and x_2:

$$x_1 = \sin(\omega_1 t + \phi_1) \tag{1}$$

$$x_2 = \sin(\omega_2 t + \phi_2) \tag{2}$$

The output x_{out} has an instantaneous frequency equal to the difference between the instantaneous frequencies of the two input sinusoidal functions. The phase of the output is equal to the difference between the phases of the two input signals:

$$x_{out} = \sin[(\omega_1 - \omega_2)t + (\phi_1 - \phi_2)] \tag{3}$$

The mode of operation of the mixer can also be understood graphically by observing the TX and RX chirp frequency representations as a function of time.

The upper graph in Figure 6 is a plot of TX and RX chirp for a single object detected as a function of time. Note that this RX chirp is a delayed version of the TX chirp.

The delay (τ) can be derived mathematically:

$$\tau = \frac{2d}{c} \tag{4}$$

Where d is the distance from the object being detected and c is the speed of light.

To obtain the frequency representation of the mixer output as a function of the IF signal time, simply remove the two lines shown in the upper half of Figure 7. The distance between the two lines is fixed, which means that the IF signal contains a single tone signal with a constant frequency. Figure 6 shows that the frequency is St. The IF signal is only valid during the period in which the TX chirp and the RX chirp overlap (i.e., the period between the vertical dashed lines in Fig.7).

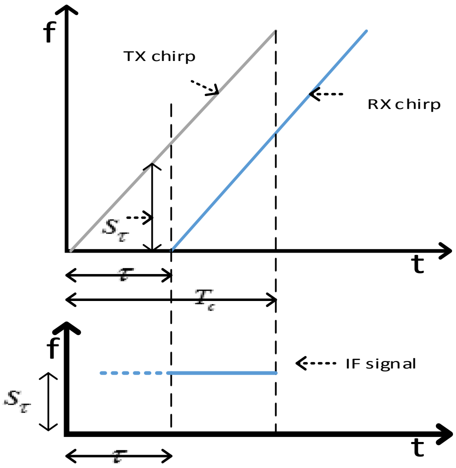


Fig 7. IF frequency is constant

The mixer output signal is a sine wave as a function of the amplitude of time because it has a constant frequency.

The initial phase (ϕ_0) of the IF signal is the difference between the phase of the TX chirp pulse and the phase of the RX chirp pulse at the time point corresponding to the start of the IF signal (i.e., the time point indicated by the vertical dotted line in the left side of Fig.7).

$$\phi_0 = 2\pi f_c \tau \tag{5}$$

Through mathematical methods, it can be further imported into the equation:

$$\phi_0 = \frac{4\pi d}{\lambda} \tag{6}$$

This equation is an approximate equation that is valid only when the slope and distance are small enough. However, the phase of the IF signal is linear with a small distance change (i.e. $\Delta\phi = 4\pi\Delta d/\lambda$) is still correct.

In short, for an object with a distance d from the acquisition front end, the IF signal will be a sine wave, so:

$$A\sin(2\pi f_0 t + \phi_0) \tag{7}$$

Where $f_0 = \dfrac{s2d}{c}$ and $\phi_0 = \dfrac{4\pi d}{\lambda}$.

4. Data results and Analysis

The Data path module has interface for Enabling and controlling high speed data interface such as LVDS. Configures the data format, data rate, lane parameters. Fig.8 shows the data transfer for different data formats and lanes on high speed interface.

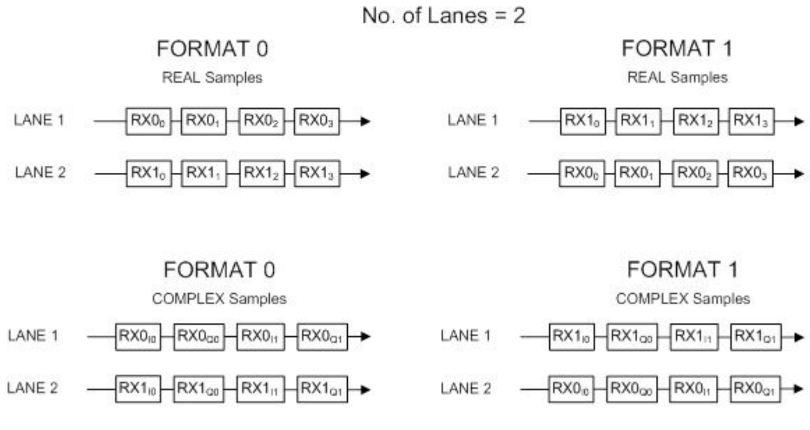
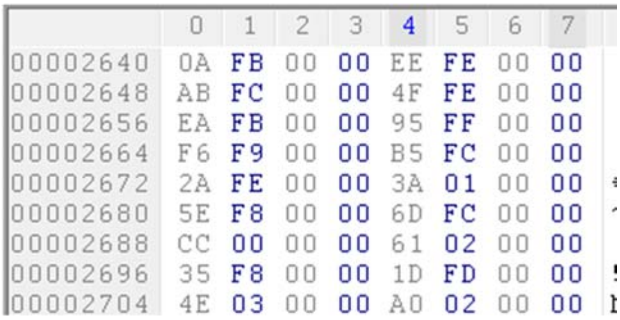


Fig 8. data format

As shown in Fig.9 is the data collected by the actual acquisition front end.



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          0  1  2  3  4  5  6  7
00002640  0A FB 00 00 EE FE 00 00
00002648  AB FC 00 00 4F FE 00 00
00002656  EA FB 00 00 95 FF 00 00
00002664  F6 F9 00 00 B5 FC 00 00
00002672  2A FE 00 00 3A 01 00 00
00002680  5E F8 00 00 6D FC 00 00
00002688  CC 00 00 00 61 02 00 00
00002696  35 F8 00 00 1D FD 00 00
00002704  4E 03 00 00 A0 02 00 00
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Fig 9. Actual data collection

It can be seen from the figure that the system design scheme can accurately collect data of the target and realize the transmission of the high-speed interface, and the collected result is the same as the analysis.

5. Conclusion

Combined with the millimeter wave active imaging principle, the front-end acquisition part of millimeter wave active imaging was researched and designed. The design model and the effect of each part of the acquisition front end are introduced.

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