Intermodulation FMCW (IM-FMCW) Radar for Non-Linear Wearable Targets Detection

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***Abstract*—An intermodulation frequency-modulated continuous-wave (IM-FMCW) radar for non-linear wearable target detection is proposed in this paper. The non-linearity of a wearable target is utilized to generate third-order intermodulation from the transmitted single tone and chirp signal of the radar. On the receiver chain, another chirp signal with inverted ramp is used to de-ramp the third-order intermodulation product from the non-linear target. Thus, the range of the non-linear wearable target can be obtained. Moreover, clutters from other targets without non-linearity are automatically rejected due to the absence of intermodulation products. System-level model of the proposed IM-FMCW radar was created and simulated. The simulation results prove that the proposed IM-FMCW radar has the capability to detect the range of a non-linear wearable target as well as rejecting the clutters from other linear targets.**

I. INTRODUCTION

Harmonic radars can be used to identify some artificial targets by detecting unintended harmonic returns caused by the inherent non-linear properties of circuit elements in many RF and microwave devices [1]-[3]. Since naturally occurring objects do not exhibit significant non-linear characteristics, it provides a useful solution to detect man-made targets of interest. Harmonic radar can also be used for secure personal authentication. For example, the authorized person wears a specifically designed non-linear tag, which has some special non-linear properties for identification. However, the harmonic radars suffer from several major drawbacks. The first issue comes from the high requirements of the filters in both the transmitter and receiver to block fundamental reflections from targets, as well as minimizing the harmonics generated by the radar system itself [4]. In addition, for a harmonic radar, the radar system should be designed to operate at both the fundamental frequency band and the harmonic frequency band, which dramatically increases the hardware complexity.

It is known that a non-linear device not only generates harmonics, but also intermodulation if more than one tones are fed into the device. Different from the harmonics, the third-order intermodulation products are located very close to the fundamental tones. Intermodulation effect has been utilized to detect two human subjects at the same time shown in baseband with a conventional continuous-wave Doppler radar [5].

In this paper, an intermodulation frequency-modulated continuous-wave (IM-FMCW) radar architecture is proposed for non-linear wearable targets detection. Third-order intermodulation products of non-linear targets are utilized in the proposed system to detect non-linear target. Since all the components in the proposed work in one frequency band, the hardware complexity of the proposed IM-FMCW radar can be significantly reduced compared with a harmonic radar. A system-level simulation validates the proposed IM-FMCW radar can detect the range of the wearable non-linear target, as well as rejecting the clutters from linear targets.

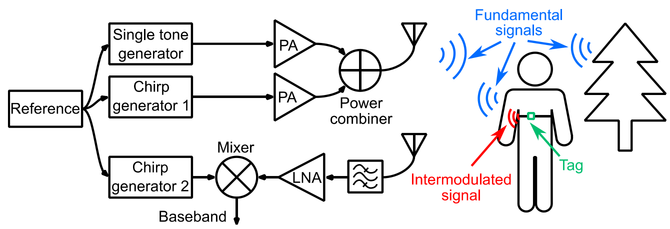

Fig. 1. Top level block diagram of the IM-FMCW radar.

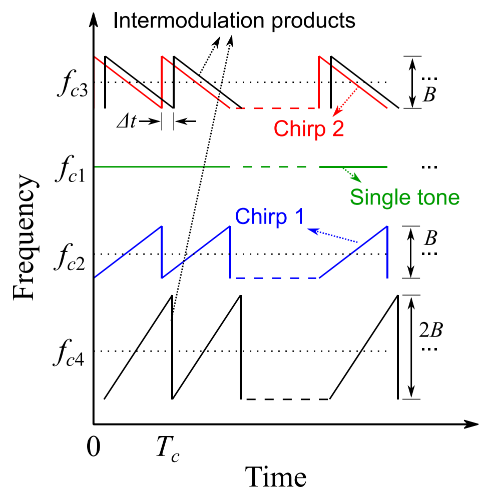

Fig. 2. Frequency configurations of the signal generators.

II. IM-FMCW RADAR PRINCIPLE AND DESIGN

The top-level block diagram is illustrated in Fig. 1. In the demonstrated application in Fig. 1, the human target wears a tag, which has non-linear effect at the transmitting frequency of the IM-FMCW radar. There also exits another natural target, which does not have non-linear effects.

On the transmitter channel, a single tone signal and a chirp signal (Chirp 1) are generated by the single tone generator and chirp generator 1, respectively. These two signals are combined after being amplified by their corresponding power amplifiers. On the receiver channel, the received signal is processed by a band-pass filter and a low noise amplifier (LNA). Then, this

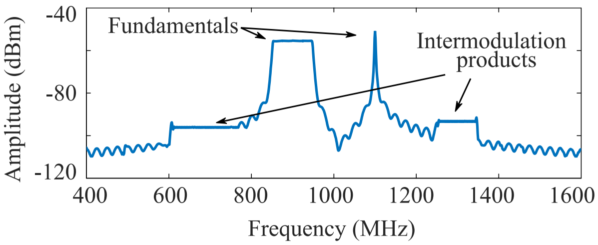

Fig. 3. Spectrum of the received signal.

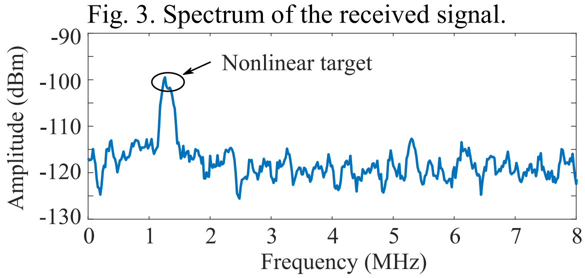

Fig. 4. Simulated baseband spectrum.

signal is mixed with Chirp 2 generated by chirp generator 2. After the mixer, the baseband signal can be obtained.

The principle of the proposed IM-FMCW radar is illustrated in Fig. 2. Single tone and Chirp 1 are the transmitted signals. f_{c1} is the frequency of Singe tone and f_{c2} the center frequency of Chirp 1. The bandwidth of Chirp 1 is B. When a non-linear target exists, third-order intermodulation products are generated from Single tone and Chirp 1 as shown in Fig. 2. The upper-band third-order intermodulation product has the center frequency $f_{c3} = 2f_{c1} - f_{c2}$, and it also has a bandwidth B and an inverted ramp. On the other hand, the center frequency of the lower-band third-order intermodulation product is $f_{c4} = 2f_{c2} - f_{c1}$. The bandwidth of the lower-band third-order intermodulation product is expanded into $2B$. In order to obtain the range information of the non-linear target, Chirp 2 is generated as the local oscillator to de-ramp the upper-band third-order intermodulation product. The single tone generator, the chirp generator 1 and the chirp generator 2 should share the same reference to make signals coherent.

For a linear target, it simply reflects the fundamentals, which are Single tone and Chirp 1. There is no third-order intermodulation product coming to the receiver channel, thus, no beat signal can be detected after the mixer.

III. Simulation and Analysis

The National Instruments (NI) AWR Design Environment with Visual System Simulator (VSS) was used for the system level simulation of the proposed IM-FMCW radar. The frequency configurations of Single tone, Chirp 1 and Chirp 2 are listed in Table I. Parameters of the components in the simulation were carefully selected based on realistic devices, especially the non-linear parameters for the amplifiers. The power amplifier (Broadcom MGA-31589-BLKG) has a gain of 20 dB and an output P1dB of 27.2 dBm. The LNA (Skyworks SKY67151-396LF) has a gain of 19 dB and an output P1dB of 2 dBm. The band-pass filter is a fifth-order Butterworth filter. Its pass band is 1200 MHz – 1400 MHz.

An RF propagation model with two targets were created. Target 1 is the human target wearing a non-linear tag. The tag generates -60 dBm third-order intermodulation products when there are two -20 dBm input fundamental tones. In the simulation, Target 1 is located at 9 m, and its radar cross-section (RCS) is 0.1 m^2. Target 2, which is a natural target, doesn't have any non-linear effects. Target 2 is located at 15 m and its RCS is 1 m^2. The range of Target 2 is larger than that of Target 1. However, since Target 2 has larger RCS, its reflection is still much stronger than Target 1's reflection.

Table I. Parameters of the IM-FMCW Radar.

	Frequency (MHz)	Power (dBm)	Repetition period (µs)
Single tone	1100	20	N/A
Chirp 1	850 – 950	10	5
Chirp 2	1350 – 1250	0	5

Figure 3 is the spectrum of the reflected signal received by the receiver antenna. The strong fundamentals and weak third-order intermodulation products can be clearly seen. The spectrum of baseband is shown in Fig. 4. A peak can be seen at around 1.2 MHz, which is the signature of Target 1. There is no signature of Target 2, even its reflection is much stronger. The simulation result proves this proposed radar can detect non-linear targets, while rejecting the clutters with linear response.

IV. Conclusion

In this paper, an IM-FMCW radar is proposed. By utilizing third-order intermodulation of non-linear targets, the proposed IM-FMCW radar eliminates the requirement of two frequency bands for a harmonic radar and significantly reduces the stringent requirements for filters. A system level model was carefully designed with NI AWR. The simulation results prove that the proposed IM-FMCW radar has the capability to detect the range of a non-linear target while rejecting the clutters from linear targets. This IM-FMCW can be used for health monitor, as well as secure drone or personal authentication.

Acknowledgement

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