5.8-GHz ISM Band Intermodulation Radar for High-Sensitivity Motion-Sensing Applications

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***Abstract*— Many electronic components such as diodes and transistors exhibit certain degree of nonlinearity. In this paper, this nonlinearity is used for a radar target to generate intermodulation tones from incident waves with two fundamental frequencies, so that the radar detects only the target and rejects clutter reflections. In this paper, the intermodulation radar at 5.8 GHz ISM band and the passive tag were designed, fabricated and characterized. The motion and the intermodulation generated by the tag were measured, as compared with undesired fundamental reflections. This intermodulation-based nonlinear radar approach can overcome some drawbacks of harmonic radars. It has wide potential applications in clutter noise rejection and detection of unauthorized electronic devices.**

***Index Terms* — intermodulation, nonlinear target, diode, passive target, third order intermodulation.**

I. Introduction

There has been a lot of research in the field of harmonic radars [1]-[4]. These radars mostly detect the second harmonic of the fundamental transmission frequency generated by passive or active tags, as they are the strongest signal after the fundamental frequency. Because naturally occurring objects do not have or have very low nonlinear characteristics, these harmonic radars use nonlinearity to detect man-made targets of interest or unauthorized devices. Background/clutter rejection is achieved by detecting harmonic reflection from tags and blocking fundamental reflection from clutters.

However, harmonic radars suffer from two major drawbacks: one is stringent requirement on filters [4] and the other is broadband spectrum coverage [5]. Because conventional filters cannot meet the stringent requirement, Diplexers are necessary to isolate the second harmonic from the transmitter chain and block the fundamental frequency from the mixer local oscillator (LO) drive and the radar receiver chain [4]. Unfortunately, these diplexers are expensive and bulky, limiting these radars for cost-effective portable applications. On the other hand, unauthorized electronic devices can work in a large frequency band. As a result, the corresponding harmonic radar must be broadband so that the unauthorized devices can be identified for security applications [5].

In this paper, an advanced intermodulation radar system is designed to detect the target-reflected third-order intermodulation of two fundamental tones transmitted by the radar. Because all the signals are in the same band, the design of the tag is straightforward, i.e., unlike harmonic radars the design does not have to cover two bands that are widely separated. It also eliminates the need of high performance filters, because frequency selectivity is achieved by synchronized signal synthesizers. This makes intermodulation radar simple to design and operate.

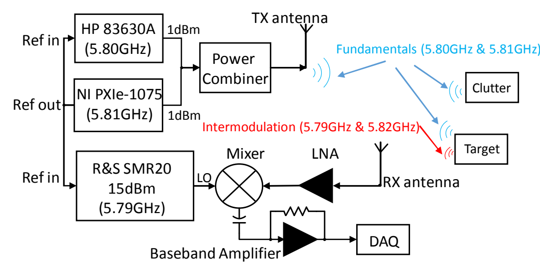


Fig. 1. Block diagram of the intermodulation radar.

The paper is divided into four sections. Section II gives a brief theory about intermodulation radar and presents the designed radar architecture and the nonlinear target. Section III presents experimental results. A conclusion is drawn in Section IV.

II. Intermodulation Radar Theory and Design

Intermodulation is a process by which, when two or more frequency tones pass through a nonlinear device, additional frequency components are generated. These additional frequency components are the nonlinear tones. For example, if two tones are sent at f_1 and f_2 then additional frequencies are formed at frequencies such as $2f_1$-f_2, $2f_2$-f_1 (third order intermodulation), and $3f_1$-$2f_2$, $3f_2$-$2f_1$ (fifth order intermodulation) [6]. In this paper, the third order intermodulation generated by the target at $2f_1$-f_2 is utilized.

Fig. 1. shows the designed intermodulation radar system. Two tones at 5.80 GHz and 5.81 GHz are transmitted simultaneously. These tones are sent to a power combiner and then to a transmitting antenna. For the receiver part, the signal received by the receiving antenna is sent to a low noise amplifier (LNA) with a gain of 15 dB and then sent to a mixer. The LO input of the mixer is fed with a 5.79-GHz signal with a power level of 15 dBm. The output of the mixer is sent to a baseband amplifier with a gain of 26

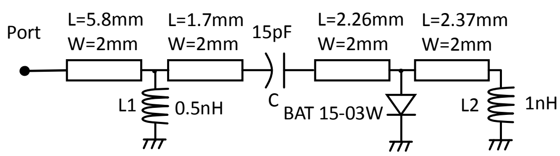


Fig. 2. Matching circuit of the target.

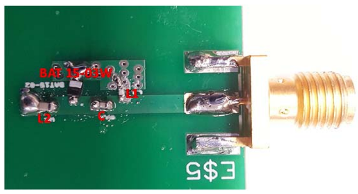


Fig. 3. The diode-based nonlinear target on an FR4 substrate.

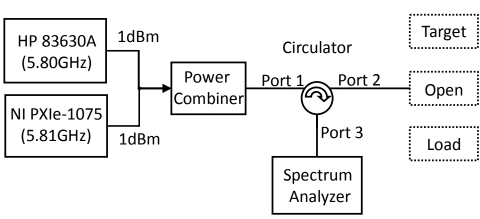


Fig. 4. Nonlinear target characterization setup.

dB. The baseband output signal is read through a data acquisition module (NI USB-6009 DAQ).

To maintain the coherence of the radar system, all the three generators are tied to the same reference as shown in Fig. 1. The NI PXI-1075 was used to provide reference to the two other signal generators HP 83630A and R&S SMR20. This means the "Ref Out" of the NI PXI-1075 was connected to "Ref In" of HP 83630A and R&S SMR20. Tying the three signal generators to the same reference is very critical for the motion radar to maintain a high detection sensitivity based on the range-correlation effect that largely cancels the correlated phase noise in the system [7]. The fundamental two tones received by the target reached the anode side of the diode. The diode uses this signal as an energy source and reemits the nonlinear products of the received signals.

Fig. 2. shows the matching circuit of the diode. Inductor L1 and capacitor C were used to match the target and the matching circuit was designed with the S-parameter model of the diode at 0 V and 0 mA bias in NI AWR software. Infineon BAT15-03W diode was used and the matching circuit was designed on the 0.062" FR4 substrate. Inductor L2 was used to provide zero bias to the diode and it also served as the DC path to prevent any damage to the diode. A photo of the target is shown in Fig. 3. The target can be connected to a patch antenna to receive the two tones from the radar and send the return signal with all the fundamental and intermodulation tones back to the radar.

III. Experimental Results

The target was first characterized to evaluate its nonlinearity. The measurement setup is shown in Fig. 4. The two tones at 5.80 GHz and 5.81 GHz were sent from two signal generators and fed into a power combiner. The output of the power combiner was connected to Port 1 of a circulator. Then, open, 50-Ω load, and the fabricated target were connected to Port 2 of the circulator. The output at Port 3 of the circulator was recorded by a spectrum analyzer and shown in Figs. 5 (a) ~(c).

From the results, the open circuit led to the highest fundamental return, but no intermodulation were generated. When the 50- Ω load was attached, the fundamental tones were absorbed by the load and no intermodulation were generated either. When the designed nonlinear target was inserted, the power level of the fundamental tones was reduced by 5 dB and third-order intermodulation tones were observed at 5.79 GHz and 5.81 GHz, respectively. This confirms that the design in Fig. 3 can serve as the nonlinear target for the intermodulation radar.

Then a patch antenna attached to a moving phantom with mm-scale periodic motion was used for system level test. For this measurement, the patch antenna serves as the reflecting surface and three cases were considered. First, the nonlinear target was connected to the antenna port, emulating the case of the intermodulation radar detecting a

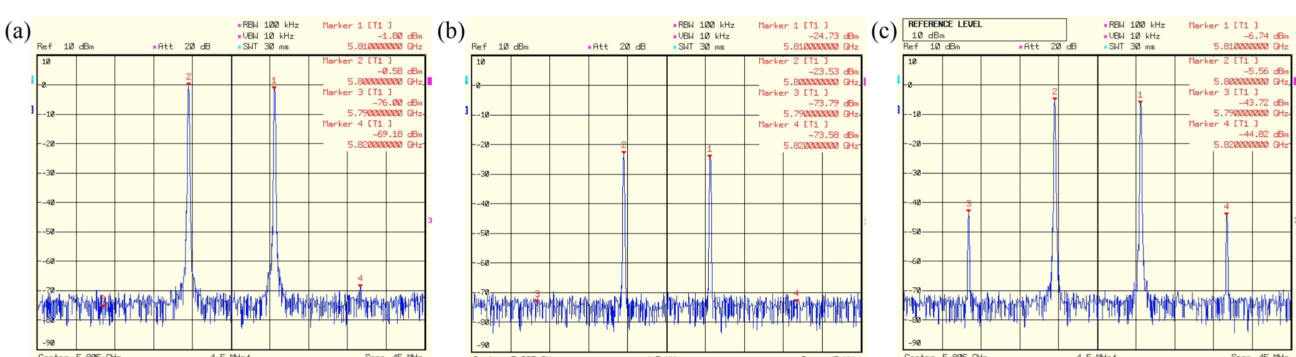


Fig. 5. Measured spectrum when the circulator Port 2 is terminated with: (a) open circuit; (b) 50- Ω load; (c) the nonlinear target.

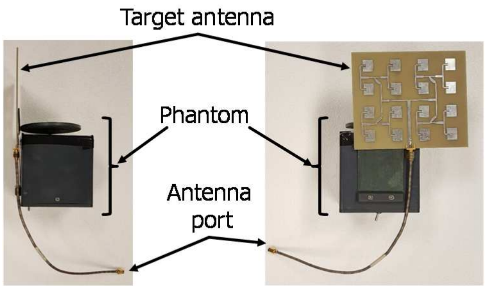
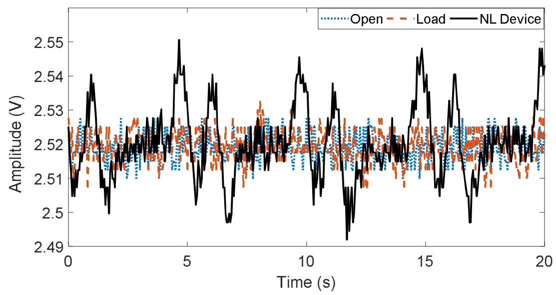
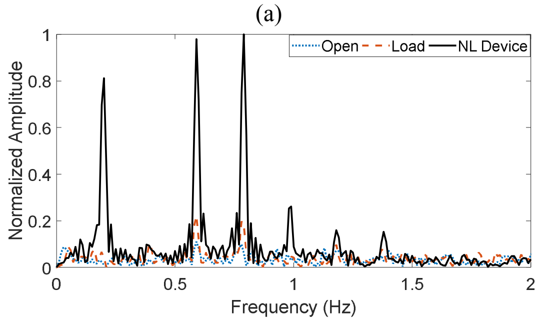


Fig. 6. Patch antenna attached to a moving phantom. Three different ways to terminate the antenna were compared.



(a)



(b)

Fig. 7. (a) Radar detected baseband voltage waveform; (b) Spectrum of the baseband output.

nonlinear target. Second, a 50- Ω load was connected to the antenna port. Third, the antenna port was left open. The second and third cases aim to provide a reference of the radar response under the situation of background absorption and reflection. The measurements were recorded by placing the phantom at 0.5 m in front of the radar. Fig. 6. shows the image of the phantom, which was used to generate the periodic back-and-forth motion of the antenna plate. The movement by the phantom was caused by rotating the oval disc behind the rectangular plate.

The output of the baseband amplifier is shown in Fig. 7(a), and the fast Fourier transform (FFT) of the time-domain signal is plotted in Fig. 7(b). The peak of the FFT was normalized to 1. From the results in Fig. 7, the baseband output responded to the phantom motion only when the nonlinear target was present. It should be noted that the phantom has a complex motion pattern and thus the FFT spectrum illustrates multiple tones of the movement. By comparing the results with and without the nonlinear target, it is demonstrated that the intermodulation radar can effectively detect small motion of nonlinear target while rejecting undesired reflections from passive clutters that do not exhibit nonlinear properties.

IV. Conclusion

An intermodulation radar was successfully designed and tested with the aim of detecting a nonlinear target. It can be potentially used for background and clutter noise rejection in motion sensing applications, and used for the detection of un-authorized electronics devices in security applications. Compared with harmonics radars, the intermodulation radar operates in the same frequency band for its transmit and receiver chains, and thus simplifies the hardware and avoid licensing issues of radio frequency bands.

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