The Simulation of Terahertz Wave Radar System

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Abstract—From the system simulation perspective, the thesis is about testing the coming multi frequency multiplexing Terahertz radar system and take the 340GHz as the example to design and analyze the system. With the adoption of 21.6 GHz Bandwidth and the foundation of the Matlab/Simulink, the Frequency multiplication module, Mixing module and Quadrature demodulation module, etc., are designed so as to build the Terahertz radar system. Then, the three target points are taken as the example for simulation, and the spectrum charts of radar signal at every phase are obtained. The range image, range image position and resolution of the three target points are consistent with the theoretical value. The detection error and existing problem are analyzed in the end.

Keywords-Simulink;Terahertz wave; radar system; system simulation

I. INTRODUCTION

Terahertz (THz) wave, a kind of electromagnetic radiation wave, with electromagnetic frequency between 0. 1~10THz, is becoming one of the hotspots in communications. Because it is located in a transition zone from electronics to Photonics, between the microwave and far-infrared, it has its own peculiar features besides those features of microwave communication and Light Wave Communication. At present, with the rapid development of communications, the traditional microwave communication can hardly meet the demand of the high speed, broadband wireless communication, while the Terahertz wave, with its high - rate transmission and broad band spectrum, make it possible to become the main force of future wireless communications. On the other hand, contrary to the high attenuation coefficient of light wave when transmitting through non-metal or nonpolar substance, e.g., soot, wall, plastic, cloth, etc. Terahertz wave can transmit through those materials with a relatively small attenuation, which makes it work perfectly under harsh environments. Undoubtedly, the Terahertz wave has its own disadvantages, and the worst one is that it is extremely easy to be absorbed by the polar molecules in the atmosphere, thus its atmospheric attenuation is relatively high, which makes it can hardly transmit signal in rainy days.

Due to the above features of Terahertz wave, it can mainly be used for interstellar communications in the future, the short range wideband mobile communication in the ground, and the battlefield communications with its harsh and dry environment full of smoke and dust, etc. The Terahertz wave, with its wide bandwidth, high classified, strong anti – jamming, is becoming another important frequency band in communications after the microwave communication and light wave Communication. Because the Terahertz devices and Terahertz integrated technology are not mature enough now, the simulation is increasingly employed as a means of testing and assessing feasibility and validity of the system scheme in studying and building the Terahertz wave radar system so as to optimizing the components selection, reducing the prediction error and risk. In the thesis, the Simulink is chosen as the tool of Terahertz wave radar simulation due to its ample signal processing modules and radio frequency module, convenient graphical output interface as well as low cost, ease of operation and reuse.

II. THE WHOLE RADAR SYSTEM MODELING OF TERAHERTZ

There are mainly two kinds of THz communications, the indoor short distance high speed wireless broadband communication and the interstellar long distance broadband digital communication. Although the two schemes have a totally different demand toward the Communication device index and complexity of the system, they are based on the same basic communication principles. A Schematic diagram of typical Terahertz communication system is shown in Fig .1:

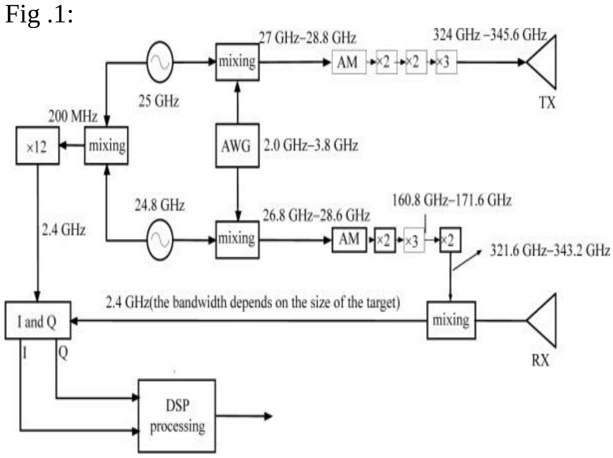

Figure1． Schematic diagram of THz communication system

A 25GHz Local Oscillator (LO) signal and a 24.8GHz LO signal first respectively mix with the Frequency Modulated Continuous Wave (FMCW) output from Arbitrary Waveform Generator (AWG), through the high-pass filter, the sum-frequency signals are generated. Then The signals are respectively going on 12 frequency doubling , with one signal as the transmits signal which will be launched by the Antenna TX , another as the Demodulation Reference Signal which is to demodulate the high frequency signal from the RX receiver to low-frequency stage.

This method is analogous to the dechirping processing of pulse signal with linear frequency modulation, which can reduce the sampling bandwidth (from GHz to MHz magnitude). Because of the relatively short operating distance, Demodulation Reference Signal need not to be delayed all the way, so the mixed and demodulated signals are Narrow band signals consisted of multi- harmonic waves, with each waves corresponding to a scattering point. The center frequency of the Narrow band signals is located on 2.4GHz added by a range delay, added by a Frequency caused by range delay, at the same time, in order to continue quadrature demodulation on the relatively low band, the two LO signals are also mixed, and the 200MHz beat frequency caused by the mixing is going on 12 frequency doubling, thus a 2.4GHz reference signal is obtained. Finally, the reference signal comes to I/Q quadrature demodulation with the demodulated echo signal and the I signal and the Q signal are generated, with their approximately 0 GHz center frequency.

III. THE SIMULINK MODULE DESIGN OF TERAHERTZ RADAR SYSTEM

Simulink is a Simulation tool based on the flow of time, frequently applied in communications and controlling domains. According to the above principle diagram, the Simulink Simulation of Terahertz radar system is developed. The setting of the sampling time needs special attention in the Simulation radar system so as to fulfill the requirement of Nyquist sampling theorem. When the Simulation radar system is dealing with the radio frequency, the efficiency always decreases, so the highest frequency of RF is controlled in Simulation in the thesis, while the signal duration is also controlled to avoid the slow speed.

A. *AWG module*

Without loss of generality, a linear frequency modulation signal generator, with its 2.9GHz center frequency, 1.8GHz Bandwidth, 1 μs Pulse Width is replacing the AWG in the Schematic diagram, and the simulation time assumes a pulse length, which can be regarded as a part of FMCW signal. There is already a linear FM signal Module, the “chirp” in the Simulink, and its mathematical expression is shown in formula 1:

$$f(t) = A\,\mathrm{rect}\left(\frac{t}{\tau}\right)\sin\left(2\pi f_0 t + \frac{1}{2}Kt^2\right) \quad (1)$$

In the equation, A is the amplitude, rect(t/τ) is the rectangular window with its τ width f0 is the initial frequency, and K is the frequency rate

B. *Mixing module*

According to the Prosthaphaeresis trigonometric function, the product of the two cosine signal f1and f2 is equal to the sum of (f1−f2)+(f1+f2), as the mathematical expression is shown in formula 2:

$$\cos(2\pi f_1 t)\cos(2\pi f_2 t) = \frac{1}{2}[\cos(2\pi(f_1+f_2)t) + \cos(2\pi(f_1-f_2)t)] \quad (2)$$

Therefore, after the multiplication of the two signals, the expected signals can be obtained through filtering. According to the Schematic diagram, the sum-frequency signals can be generated after the multiplied signals getting across the high-pass filter. The mixing Simulink simulation chart, as well as the similar down road, is shown in the Fig .2.

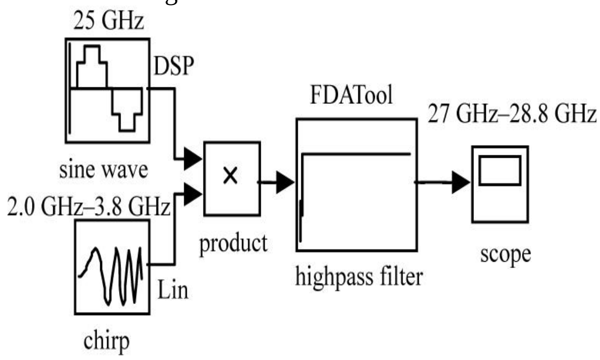

Figure 2. Mixing module

C. *Frequency multiplication module*

For the convenience, the Multiplying filter is used for frequency multiplication. A signal with the initial frequency f can become Signals of arbitrary frequency after a series of multiplying filter, and the same method, three road 12 octaves, is applied in the simulation. Its foundational principle is shown in the Fig .3, corresponding to the Simulink module shown in Fig .4.

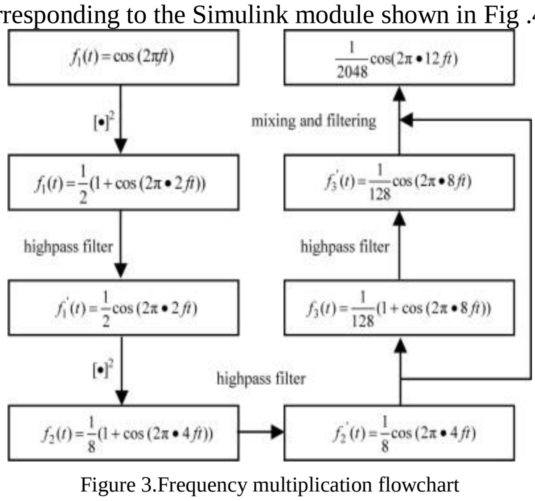

Figure 3.Frequency multiplication flowchart

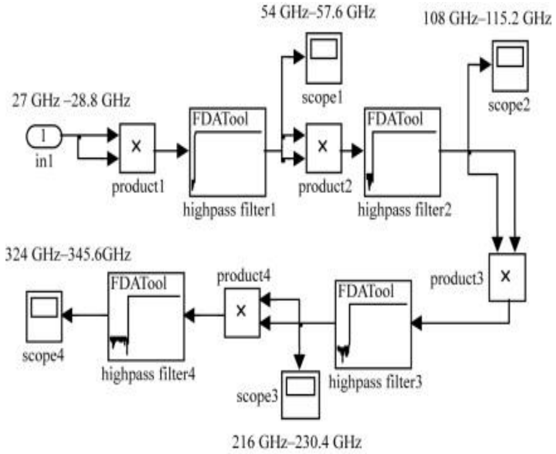

Figure 4.12-octave module

During the course of Frequency multiplication, the design of the filter is the most important. In order to minimize the clutter in the outputting signals, the Astop value of the filter should be properly decreased or the multiple filters is needed. The other two roads of Frequency multiplication adopt the similar methods.

D. Demodulation module

The main function of the receiver is to convert the radar signal center frequency to baseband and measure the phase information at the same time. I/Q Demodulation is a classical design method of the receiver, shown in the Fig .5. The received signal is divided into two 2 mutually orthogonal channel, with one called the in-phase channel receiver or the I channel, in which the receiving signal and a oscillator (called local oscillator, having the same frequency with the Radar center frequency) are mixed and the beat frequency and sum frequency components are generated,. After the sum frequency components is filtered in the I channel, the Modulation $A(t)\cos[\theta(t)]$ is obtained. The another channel is called the Orthogonal channel receiver or the Q channel in which the receiving signal and local oscillator are also mixed, with a 90 degrees shifted phase of local oscillator before the mixing. The function I and Q is shown in formula 3 and formula 4.

$$I: 2\sin(\omega t)A(t)\sin[\omega t+\theta(t)]=A(t)\cos[\theta(t)]-A(t)\cos[2\omega t+\theta(t)] \quad (3)$$

$$Q: 2\cos(\omega t)A(t)\sin[\omega t+\theta(t)]=A(t)\sin[\theta(t)]+A(t)\sin[2\omega t+\theta(t)] \quad (4)$$

After the sum frequency components is filtered in the Q channel, the Modulation A(t)sin[θ(t)] is obtained. As the Schematic diagram of I/Q quadrature demodulation is shown in Fig .5, as well as the Block of I/Q quadrature demodulation simulation in Fig .6

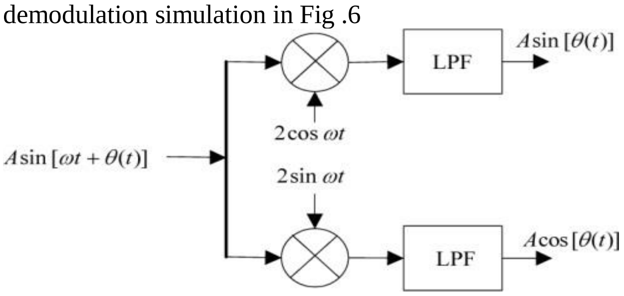

Figure 5 .Schematic diagram of I/Q quadrature demodulation

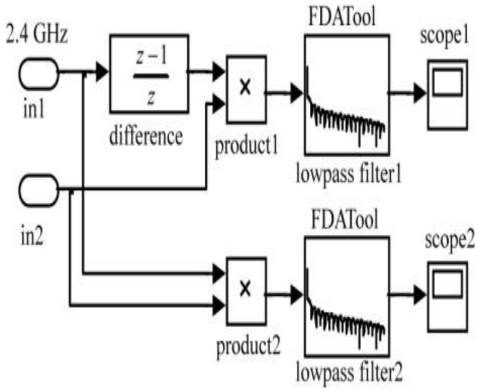

Figure 6. Block of I/Q quadrature demodulation simulation

E. The simulation results and analysis

A 340GHz radar is simulated in the above Simulink system. The local oscillator of 25GHz,24.8GHz and its beat frequencies signals are respectively divided into 3 channels and 12 frequency doubling and the result is a 324GHz~345.6GHz transmit signal, 321.6GHz~343.2GHz Demodulation Reference Signal, and a 2.4GHz Quadrature demodulation of the vibration signal, its frequency spectrum ,as shown respectively in Fig .7,8 and 9.

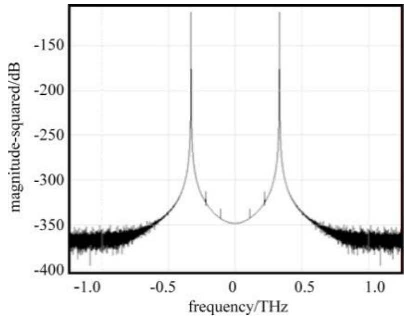

Figure 7 .Spectrum of the 324GHz– 345.6GHz transmitted signal

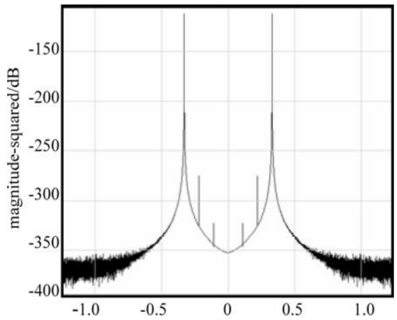

Figure 8.Spectrum of the 321.6GHz– 343.2GHz reference signal for demodulation

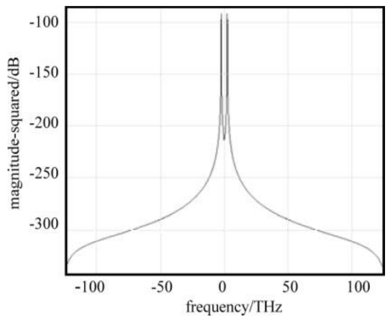

Figure 9. 2.4GHz local oscillating signal for quadrature demodulation

As shown in the Fig .7 and Fig .8 , the signal can obtain relatively high frequency after the frequency doubling in the Simulink, but the performance of the filter is greatly affected when the frequency is relatively high, and the received high frequency signal has clutters as shown in figures. A certain degree of clutter occur at the 110GHz， 220GHz position, and after multiple filters, the clutter can be reduced and become 100dB below the signal, which can be ignored. As shown in the Fig .9, the Simulink performance of the frequency doubling is better in the relatively low band, and the relatively ideal 2.4GHz signal can be obtained.

In simulation, three target points are assumed respectively in the distance of 10m, 13m, and 16m from the transmitting antenna. Ideally, without considering the distortion of the signal and the attenuation, the corresponding frequencies of the three targets can be calculated. After calculation, the corresponding frequency's of the three targets are prospectively 1.44GHz ， 1.872GHzand 2.304GHz 。 Through simulation, the received I channel' and the Q channel's Signal spectrum are shown respectively in Fig .10 and Fig .11.

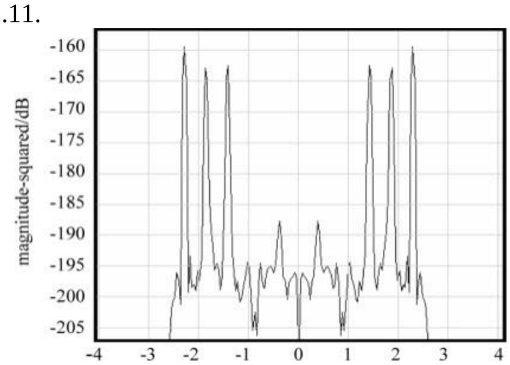

Figure 10. Spectrum of the channel I signal

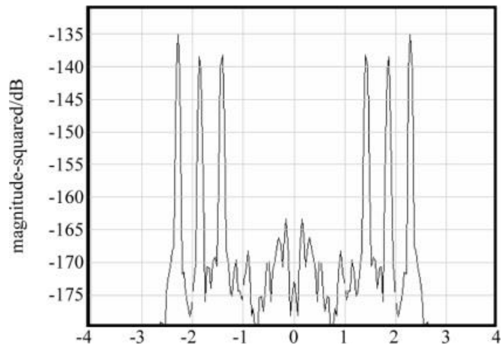

Figure 11. Spectrum of the channel Q signal

As shown in the Fig .10 and Fig .11, the results of simulation are consistent with the calculated results, with the three peaks coinciding with the three assumed target points, whose frequencies are about 1.44GHz, 1.872GHz and 2.304GHz respectively. However, the clutter also can be seen from the signals. The reason for it is that, on the one hand, the SHG signal is impure, on the other hand, the White noise is added into the echo signal. The preliminary results above demonstrated the feasibility of the designed system.

IV. CONCLUSION

In summary, the Simulink can simulate the Terahertz radar system and achieve good forecasting result, which is of great importance in Optimization design system and components selection. Because its powerful module database and excellent calculation ability, the Simulink can build plenty of modules to simulate the real physical components from baseband to radio frequency. At the same time, the good open ability to other system of Simulink makes it possible to develop new modules to enhance its own performance. Of course, in simulation, the rate limitations the Simulink are also detected in the terahertz frequency simulation, so the velocity, time and precision of the simulation need to be weighed and balanced according to the actual situation. In addition, compared to the communication and signal processing module library, the RF module library of the Simulink contains less modules, which is difficult to meet the actual needs. At last, although the influence of noise is taken into consideration, the thesis is simulating the Terahertz radar system theoretically. In order to meet the need of more vivid simulation, firstly, more modules need to add to the system, such as , Crystal Oscillator, power amplifier, low - noise amplifier , coupler, and isolators, etc. the more important point is that, according to the features and standard of the actual device, the error model and noise model need to add into all modules so as to display the effect of Signal flatness, Linearity, Gain Reduction, system loss, noise coefficient, the consistency of amplitude and phase, etc., which is the focus of the further research.

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