Research of MMW radiometer virtual prototyping technology

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Abstract: The idea of millimeter-wave (MMW) radiometer virtual prototyping is discussed in this paper. Designing environment, designing method and the main modeling components of virtual MMW radiometer are researched. Important external parameters, which have significant influence to composing system, are used to components modeling, and then components are taken to buildup virtual MMW radiometer system. Moreover, the effect to output is contrasted whether there is a low-noise amplifier or not.

Key words: MMW radiometer; virtual prototype technique; component model

1 Introduction

Virtual prototyping technology is a computer-aided engineering technology, flourishing with the development of information technology and computer technology in 1990s. It is a new research and developing method of product design, which uses digital method simulated by computer model to replace real physical designed prototype[1].

MMW radiometer virtual prototype builds the model of main components of MMW radiometer on computer. Considering the generalization of components, important external parameters of the model are used to components modeling, and then components are taken to buildup virtual MMW radiometer system. Signal with background noise is adopted to simulate the output of MMW radiometer in different environments, and the system is taken to evaluate the designing plan of MMW radiometer.

The design environment of MMW radiometer virtual prototype is defined as the software and hardware system of computer to meet the following requirements: providing the modeling method of virtual prototype and satisfying the need of up-to-down software designing and hierarchical model.

Modeling library of components, building library of target signal, modeling library of background noise and module of signal processing of MMW radiometer virtual prototype are established respectively on computer. The established virtual prototype can reflect the characteristics of target of MMW radiometer in different environments. It also can test the capability of MMW radiometer and provide an effective method for MMW radiometer design and debug.

2 Design environment and modeling structure of virtual MMW radiometer

2.1 Design environment of virtual MMW radiometer system

Design environment of virtual MMW radiometer system includes software, hardware platforms and model of components, background noise, and target signal generated. Platform of software uses a powerful scientific computing tool named as MATLAB with high efficiency for programming, strong capability for expansion, convenient capability for graphics and computing of matrix or array, especially the sparse matrix of MATLAB. It can reduce the amount of storage and computing of data, which decreases the demands for hardware platform. Analyze and process ability of complex model requests high-speed computing capability of hardware platform. Then we compile the library function for model of components, background noise and target signal generation to realize the whole virtual system. Adjusting the parameters of function to simulate system, the output can be displayed as the form of data and image by MATLAB.

2.2 Model structure

Model of virtual prototype adopts hierarchical structure, including component model and system model.

1) Component model. Component model includes

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three parts of main components, background noise and signal processing. The function documents of components are established by MATLAB (Fig. 1).

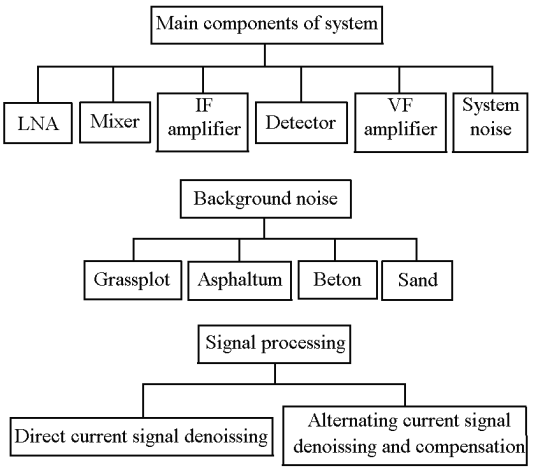


Fig. 1 Component model

2) System model. System model is composed by component model, that is corresponding components constitute the corresponding type of millimeter-wave radiation (Fig. 2).

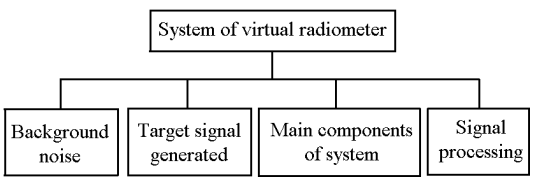


Fig. 2 System model

3 Modeling of main components

Low noise amplifier of MMW radiometer deals with the RF signal of GHz, compared to the intermediate frequency amplifier with IF signal of MHz and video amplifier with low-frequency signal of kHz. The frequency of the whole channel differs greatly, which causes much difficulty in simulation [2, 3]. In order to overcome this problem, we simulate the components before detector in frequency domain and the components after detector in time domain [4].

3.1 Low noise amplifier

Input signal is filtered and amplified by low noise amplifier. Suppose the middle frequency of low noise amplifier is f_0. It will magnify the RF signal with bandwidth B, which is equivalent to a quadratic band-pass filter with conjugate complex apices. The transmission function is:

$$H_1(j\omega) = H_1/(1 + jQ(\omega/\omega_0 - \omega_0/\omega))$$

Where, H_1 is the gain of band-pass filter, ω_0 is middle angle frequency and $Q = \omega_0/(\omega_2 - \omega_1) = f_0/B$, with ω_1, ω_2 are the angle frequencies when the gain falls 3 dB.

3.2 Mixer

Due to the function of low noise amplifier, the noise coefficient of mixer influence little to system, so it can be ignored. Mixer completes the move of frequency spectrum through multiplication. If the input signal in time domain is $s(t)$, the output in time domain is $m(t) = s(t)\cos \omega_L t$. The Fourier transform of output in time domain is $M(\omega) = [S(\omega + \omega_L) + S(\omega - \omega_L)]/2$.

Considering the frequency conversion wastage of mixer, the model of mixer can be expressed as:

$$M(\omega) = 10^{-G/20} S(\omega - \omega_L).$$

Where G is the wastage of frequency conversion.

3.3 Intermediate frequency amplifier

Generally, the intermediate frequency amplifier is wideband amplifier. So we can model as: $A(\omega) = H_2 S(\omega)$, where H_2 is enlargement factor. For non-wideband amplifier, we modeling follow the method of low noise amplifier.

3.4 Detector

In general, detector chooses square-law detector which can square-law demodulate IF signal. So that, the output voltage and the input luminance temperature is linear relationship. It is equivalent to a transform function of square relations added a low-pass filter. Because there is a direct isolation network behind, a band-pass filter replaced low-pass filter combined with direct isolation network of detector shown in Fig. 3.

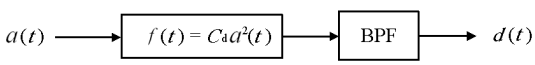


Fig. 3 Model of mixer

Model of square transform function in time domain is: $f(t) = C_d a^2(t)$.

Where, $a(t)$ is output of IF amplifier in time domain and C_d is power sensitivity constants of square-law detector.

3.5 Video amplifier

Video frequency of MMW radiometer system is several kHz. As the enlargement factor of amplifier in this band is small, the amplifier can be considered be linear. It is modeled as:

$$v(t) = \beta s(t)$$

where, $s(t)$ is input, $v(t)$ is output and β is enlargement factor.

3.6 Noise source of system

System noise is defined as the noise generated from internal system when signal goes by the system. It is always inevitable. For radiometer, from temperature

of system noise $T_{sys} = (F_{sys} - 1) T_0$ and noise power $P = kBT$, it is known:

$$P = kBT_{sys} = (F_{sys} - 1) kBT_0$$

Where, F_{sys} is coefficient of system noise, B is bandwidth of noise and T_0 is temperature of exterior environment [5, 6].

When $T_0 = 290$ K, $F_{sys} = 2.09$, $B = 500$ MHz, the power of noise is $P = 2.18 \times 10^{-12}$ W.

When $T_0 = 290$ K, $F_{sys} = 7.94$, $B = 500$ MHz, the power of noise is $P = 1.388 \times 10^{-11}$ W.

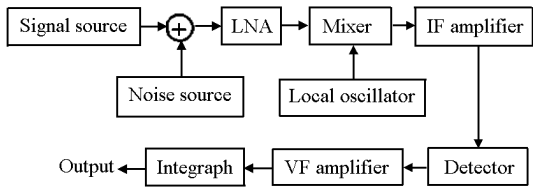
Known from Fourier transformation, $f_{max} = 1/2\tau$, $f_{min} = 1/N\tau$. Where, f_{max} is the maximal observed frequency at this sampling rate and f_{min} is frequency resolution. The frequency difference of neighboring Fourier coefficients is:

$$f_{max}/f_{min} = N/2, \text{ namely } N = 2f_{max}/f_{min}.$$

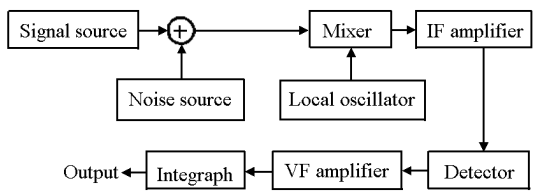
Frequency range of effective input of 8 mm radiometer is 34.5 ~ 35.5 GHz, and frequency resolution is 500 Hz. Considered the invalidation of signal outside 34.5 ~ 35.5 GHz, effective signal band is taken 1 GHz. So the sampling points: $N = 2 \times 10^6$.

4 Virtual MMW radiometer system and experiment results

Signal source built by generated signal multiplied carrier wave and noise source built by background noise added system noise. The source of signal and noise mixed as input signal. The input changes to intermediate frequency signal after mixer. Going by IF amplifier, detector, video amplifier, direct isolation network and integrator, we get output signal named as alternating current MMW radiometer signal. Low noise amplifier, mixer and IF amplifier simulated in frequency and detector, video frequency and integrator, which can be considered as accumulator simulated in time domain. Fig. 4 shows the chart of virtual system whether there is a low noise amplifier or not.



(a) Virtual system with low noise amplifier



(b) Virtual system without low noise amplifier

Fig. 4 Model of two systems

The output of each level in virtual radiometer system with low noise amplifier or not showed in Fig. 5 and Fig. 6. Compared Fig. 5 (f) with Fig. 6 (e), the noise in signals of detector is almost same. But the amplitude of signal of system with low noise amplifier is much higher. It is obvious that the system with low noise amplifier has better SNR. As the outputs of integrator in Fig. 5(h) and Fig. 6(g), noise of output signal is smaller in the system with low noise amplifier. That demonstrates the system with low noise amplifier can effectively reduce the noise of output signal.

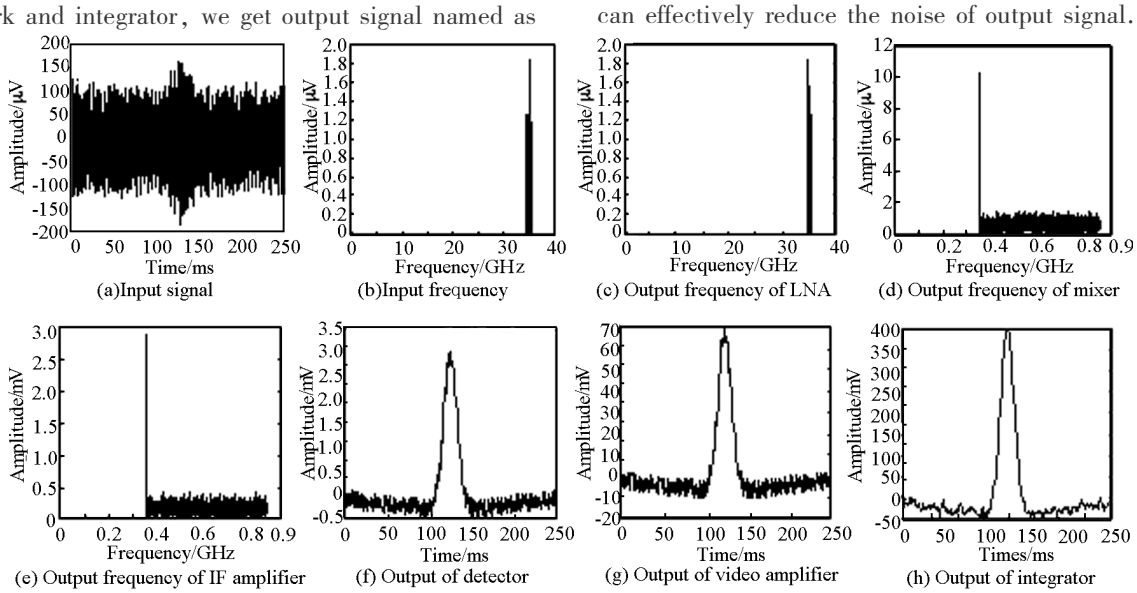


Fig . 5 Output of each level in virtual radiometer with low noise amplifier

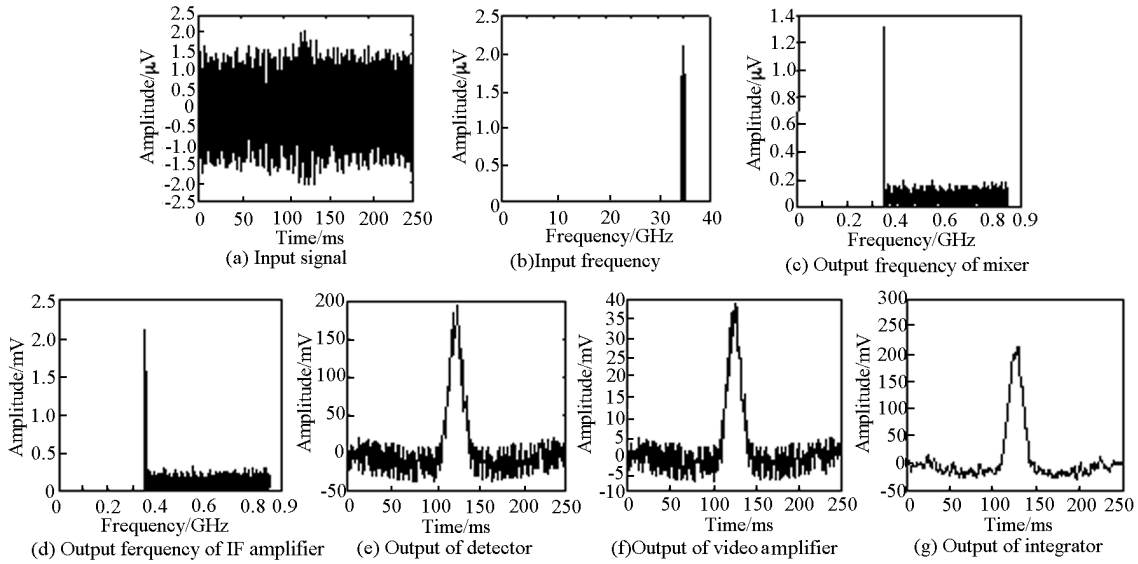


Fig. 6 Output of each level in virtual radiometer without low noise amplifier

5 Conclusion

Designing environment, designing method and the main modeling components of virtual MMW radiometer prototype are researched in this paper. MMW radiometer prototype is constructed on MATLAB software platform. Finally, we use the prototype to verify the influence of system whether there is a low noise amplifier or not, the system with low noise amplifier has better SNR. The results are basically consistent with actual situation.

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