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Circuit Simulation Analysis of Electromagnetic Pulse Effect in the RF Front-End of Radar Receiver Based on ADS

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Abstract

This article is based on the ADS circuit simulation software to model the components of the radar receiver. First introduced two common receiver RF front-end structures. Secondly, build the receiver circuit model in ADS according to the actual device. Finally, the useful signal is superimposed with some electromagnetic pulse interference, and the simulation is carried out in the circuit model, and the influence of these electromagnetic pulse interference on the circuit is analyzed to provide certain help for electromagnetic protection.

Keywords

Electromagnetic pulse, coupling effect, RF front-end, circuit simulation.

1. Introduction

The radar receiver is an important part of the wireless communication system and communication equipment. It is a component that receives the target reflected signal and performs frequency conversion and amplitude adjustment to meet the requirements of the signal processing unit. Radar systems of different types and working systems often have very different requirements for receivers. Important indicators such as the sensitivity and dynamic range of the receiver that affect the detection capability of the radar system will be adjusted according to specific conditions. However, the function of the radar receiver is generally to complete the frequency spectrum and amplitude conversion of the high-frequency space signal received from the antenna, so that the signal processing unit can extract information. At present, the most widely used receivers are superheterodyne receivers and zero-IF receivers [1-3].

2. Typical radar receiver RF front-end structure

2.1. Superheterodyne receiver

Figure 1 shows a schematic diagram of the structure of a superheterodyne receiver. The RF front-end is mainly composed of filters, low-noise amplifiers, mixers, etc. There are also many documents that add limiters before the low-noise amplifiers and high-band pass filters to protect sensitive components [4-6]. After being filtered and amplified, the externally received signal is down-converted and mixed with the local oscillator signal in the mixer to form an intermediate frequency signal, which is filtered and amplified again to meet the requirements of the signal processing unit. The superheterodyne method can realize automatic frequency control by changing the frequency of the local oscillator signal to keep the frequency of the intermediate frequency signal unchanged. At the same time, the gain of the intermediate frequency amplifier can be changed to ensure that the signal amplitude remains stable to realize automatic gain control.

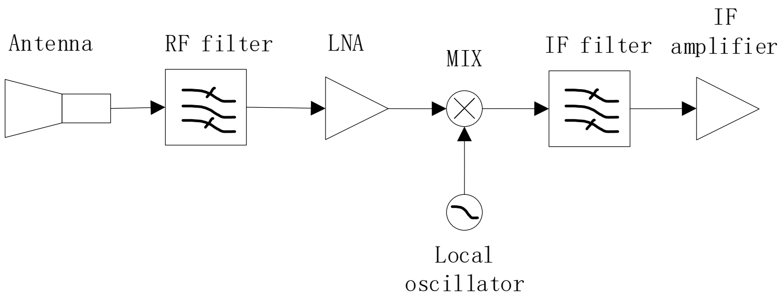

Figure 1: Schematic diagram of superheterodyne receiver structure

The above structural block diagram contains the basic components of the primary frequency conversion of the RF front-end part of the receiver. However, in practical applications, the secondary frequency conversion scheme is often used, because the secondary frequency conversion can obtain better performance than the primary frequency conversion. Among them, the intermediate frequency after the first-stage frequency conversion uses a higher frequency, and the second-stage frequency conversion uses a lower intermediate frequency, which can improve the performance of the receiver to suppress image interference. We all know that the system sensitivity and noise figure of the receiver are often determined by the first-stage amplifier. The general definition of noise figure is: the ratio of the input signal-to-noise ratio of the network under test to the output signal-to-noise ratio.

$$F = \frac{S_{in} / N_{in}}{S_{out} / N_{out}} \tag{1}$$

In the formula, it is assumed that the input signal is composed of two parts: input useful signal S_{in} and input noise N_{in}, so that the signal-to-noise ratio (SNR) at the input of the DUT is S_{in} / N_{in}. If the gain of the DUT is G, $S_{out} = G \cdot S_{in}$,then the output signal-to-noise ratio is S_{out} / N_{out}, which is substituted into the general definition formula of noise figure:

$$F = \frac{N_{out}}{G \cdot N_{in}} \tag{2}$$

In the actual situation, there will be n-level devices or modules cascaded, then the system noise factor F calculation formula is

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots \frac{F_n - 1}{G_1 \cdot G_2 \cdots G_{n-1}} \tag{3}$$

Among them, F_1 , F_2 , F_3 ... F_n represent the noise figure of the first to nth stage devices, respectively, and G_1, G_2 , G_3 ... G_n represent the gain of the first to nth stage devices. It can be seen that the noise figure of each stage device will contribute to the final noise figure of the system, but the farther the input end of the device is, the more the gain of the previous stage device will be weakened. Therefore, the first stage often chooses a device with a very low noise figure such as a low noise amplifier. At the same time, a higher gain can effectively reduce the contribution of the noise figure of the subsequent stage device to the system. Therefore, in some documents, the weak signal received by the antenna is amplified by the low-noise amplifier, and then enters the high-frequency band-pass filter, thereby improving the overall system sensitivity and noise figure of the receiver. But it also reduces the anti-interference ability of the receiver and is vulnerable to the threat of strong electromagnetic pulse [7]. On the contrary, if the high-frequency band-pass filter is placed before the low-noise amplifier, although the anti-interference ability of the receiver can be improved, it will reduce the noise figure of the receiver. Therefore, the receiver should be designed in accordance with the actual situation and specific functions of its use. In addition to the advantages of a superheterodyne receiver that can better suppress out-of-band interference, large dynamic range, high gain, and sensitivity, it can also obtain a fixed-frequency intermediate frequency signal by changing the local oscillator frequency. It can fit well with the frequency conversion technology of the radar system. However, the superheterodyne structure also has the defects of multiple interference frequency points and serious image interference phenomenon. For example, it needs to add a filter before the frequency conversion to filter out the image interference, which will increase the volume and design cost of the receiver.

2.2. Zero-IF receiver

Figure 2 is a schematic diagram of the structure of a zero-IF receiver. Compared with the problem of image frequency suppression in the superheterodyne receiver, its local oscillator frequency is equal to the RF signal frequency after two-way frequency division. It directly converts the radio frequency signal into a baseband signal through a down-conversion mixer, and then passes through a low-pass filter and amplifier to complete the channel selection. There is no need for an image rejection filter and no intermediate stage, thereby solving the problem of image frequency rejection [8, 9] . The structure of the radio frequency part of the zero-IF receiver is similar to that of the superheterodyne receiver. The signal received by the antenna enters the next stage after passing through the filter and amplifier. The frequency of the local oscillator is usually twice that of the received signal. Two signals with phase differences are generated by dividing by two for separate processing, and then converted into a baseband signal by a down-converter. In this way, strong interference caused by the signal of the local oscillator can be avoided.

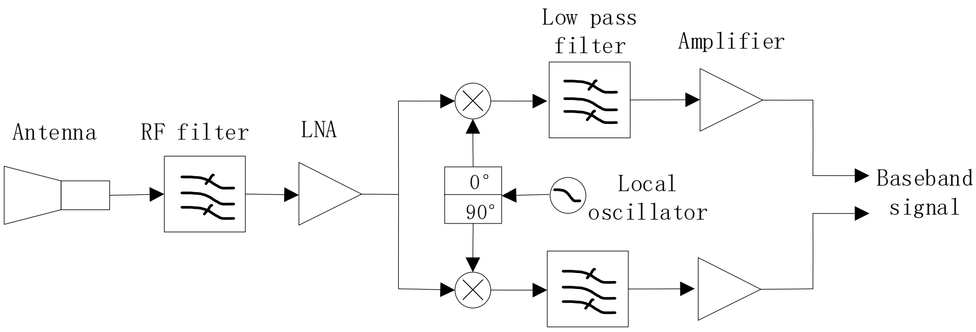

Figure 2: Schematic diagram of zero-IF receiver structure

This kind of scheme has many advantages: First, the image frequency generated by the zero-IF receiver can be solved only by two separate processing methods, and there is no interference from the image frequency signal. Because the two branches are themselves mirror images of the useful signal spectrum; Second, there is no need to consider adding an integrated frequency suppression filter in the circuit, which greatly reduces the volume occupied by the receiver, the difficulty of system integration, and the cost of design and manufacturing; The third is that the baseband signal replaces the intermediate frequency signal, so this type of receiver does not need to consider how to determine the appropriate intermediate frequency point, which greatly saves the cumbersome procedures and verification time of the system design; Fourth, it is easy to solve problems such as matching and linear dynamic range. While the zero-IF receiver has many advantages, it also has some shortcomings: One is the self-mixing problem of the local oscillator. This is because the local oscillator signal is directly connected to the mixer from the low-noise amplifier or high-frequency band-pass filter to generate a DC component;

Second, the flicker noise of the zero-IF receiver of this type of structure will seriously affect the signal-to-noise ratio of the receiver; Third, the zero-IF receiver of this type of structure will have problems such as local oscillator leakage and second-order distortion, and its performance indicators are lower compared to receivers of other architectures. Through comprehensive comparison and consideration, the first frequency conversion superheterodyne receiver is selected for the radio frequency front-end structure of the radar receiver in this paper.

3. Interference of electromagnetic pulse to radar receiver

3.1. Radar receiver RF front-end circuit construction

According to the actual device, the circuit structure of the superheterodyne receiver is composed of a low noise amplifier, a power amplifier and two filters as shown in Figure 3. The receiver operating frequency is set to 2GHz, and the intermediate frequency after mixing is 70MHz .

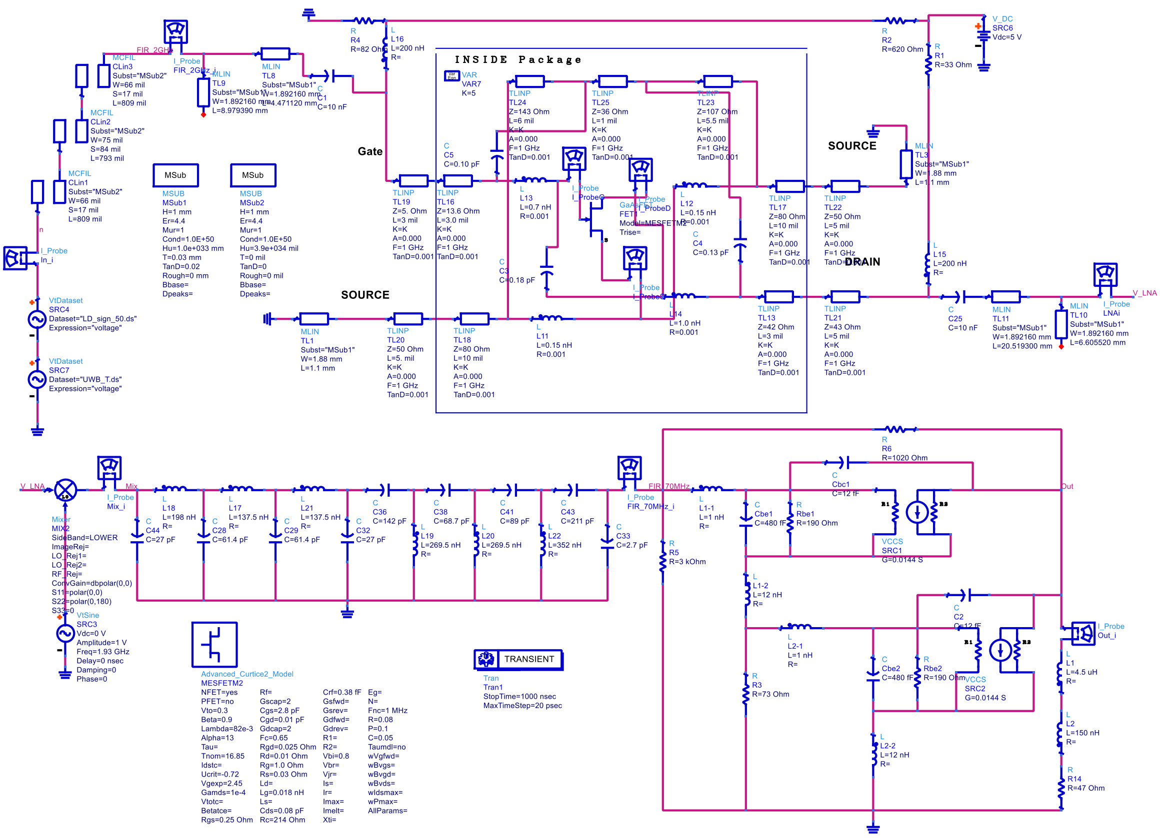

Figure 3: Simulation circuit diagram of superheterodyne receiver

Assume that the radar receiver antenna receives an echo pulse that is 900m away at this time, the voltage amplitude is 100mV, the pulse delay is 0.3us, the pulse period is 1us, and the pulse width is 100ns. The response of each module of the receiver to the echo signal is shown in Figure 4. In the figure, In is the echo signal used as the voltage source of the receiver, with a frequency of 2GHz; FIR_2GHz is the output signal after passing through the high frequency band pass filter, at this time the voltage is reduced to about 70mV; V_LNA is the output signal of the ATF54143 low-noise amplifier. At this time, the voltage signal amplified by the amplifier is 500mV on average, and the gain is about 17dB; Mix is an intermediate frequency signal after mixing. Its local oscillator frequency is 1.93GHz. After down-conversion, it becomes an intermediate frequency signal of 70MHz, and the voltage signal is slightly reduced to 400mV; FIR_70MHz is the output signal of the mid-band pass filter, and the signal amplitude is further reduced to 250mV at this time; Out is the final output signal of RF3376 low noise amplifier as the intermediate frequency amplifier, the signal amplitude is about 3V. On the right is the frequency spectrum of the corresponding signal, the dominant frequency is 70MHz, and the corresponding gain is 22dB. The arrival time of the pulse and the leading edge does not produce obvious distortion, and the target information can be obtained through further calculation by the signal processing unit. By further adding electromagnetic pulses as the input signal superimposed by the receiver, the degree of interference of the electromagnetic pulses to the radar receiver can be observed.

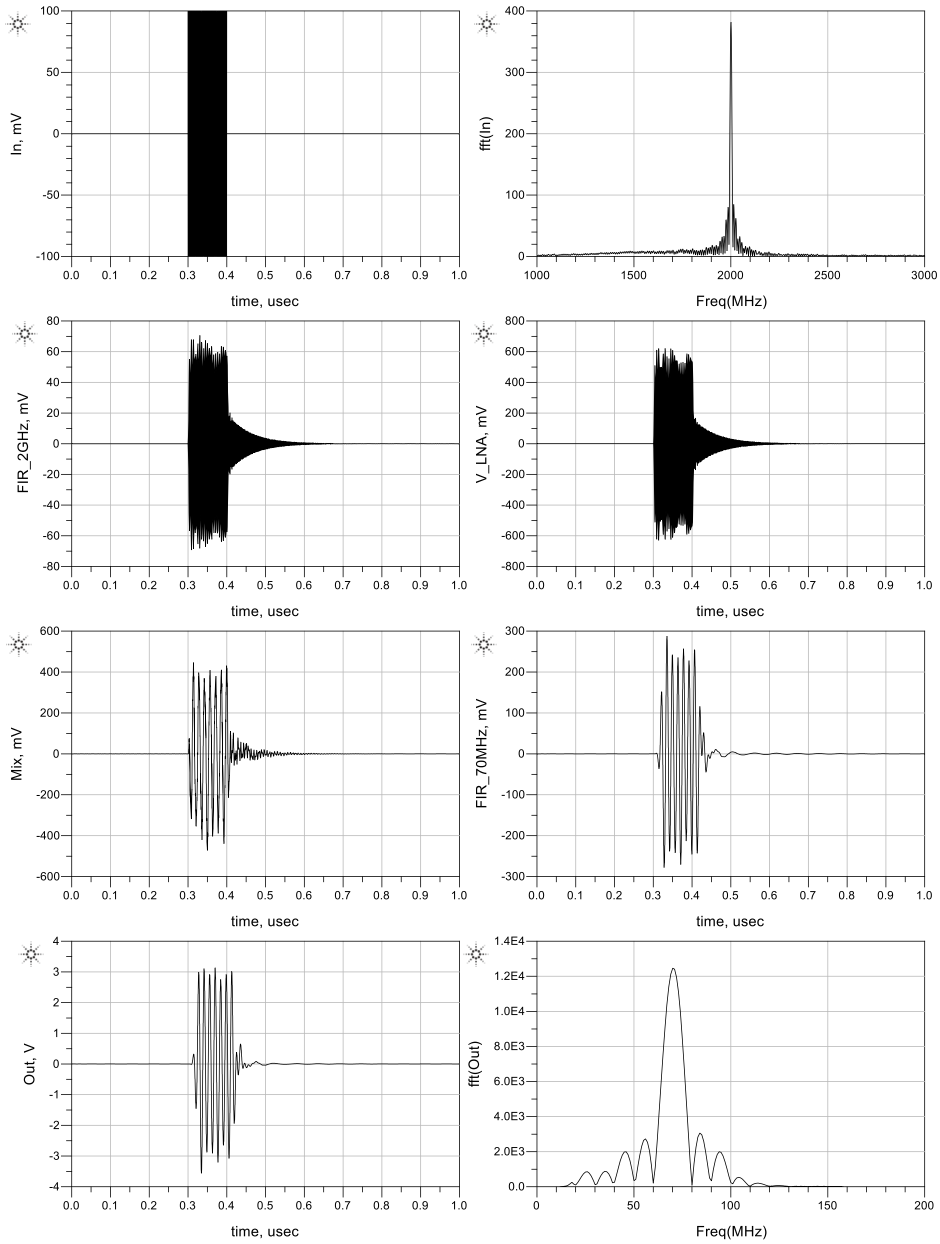

Figure 4: The response of each module of the receiver to the echo signal

3.2. Interference of electromagnetic pulse to radar receiver

The frequency components in electromagnetic pulses are relatively low. First observe the degree of interference to the echo signal of the receiver. The energy of the electromagnetic pulse is mainly concentrated below 100MHz, the electromagnetic pulse coupling response after filtering by the horn antenna is reduced to 0.8A, and the maximum load voltage in the matching state is 40V. As shown in Figure 5, the echo signal amplitude is much smaller than the superimposed electromagnetic pulse interference. The frequency spectrum of the electromagnetic pulse also covers the frequency of the echo signal. Finally, after a series of conversions, a noise interference with a peak value of 40V is generated in front of the echo signal, which can easily cause the receiving equipment to malfunction. Through the analysis of the final signal, it is found that the energy of the interference signal is concentrated below

50MHz, indicating that the interference effect of the electromagnetic pulse can be minimized by reducing the passband bandwidth of the mid-band pass filter or performing echo detection.

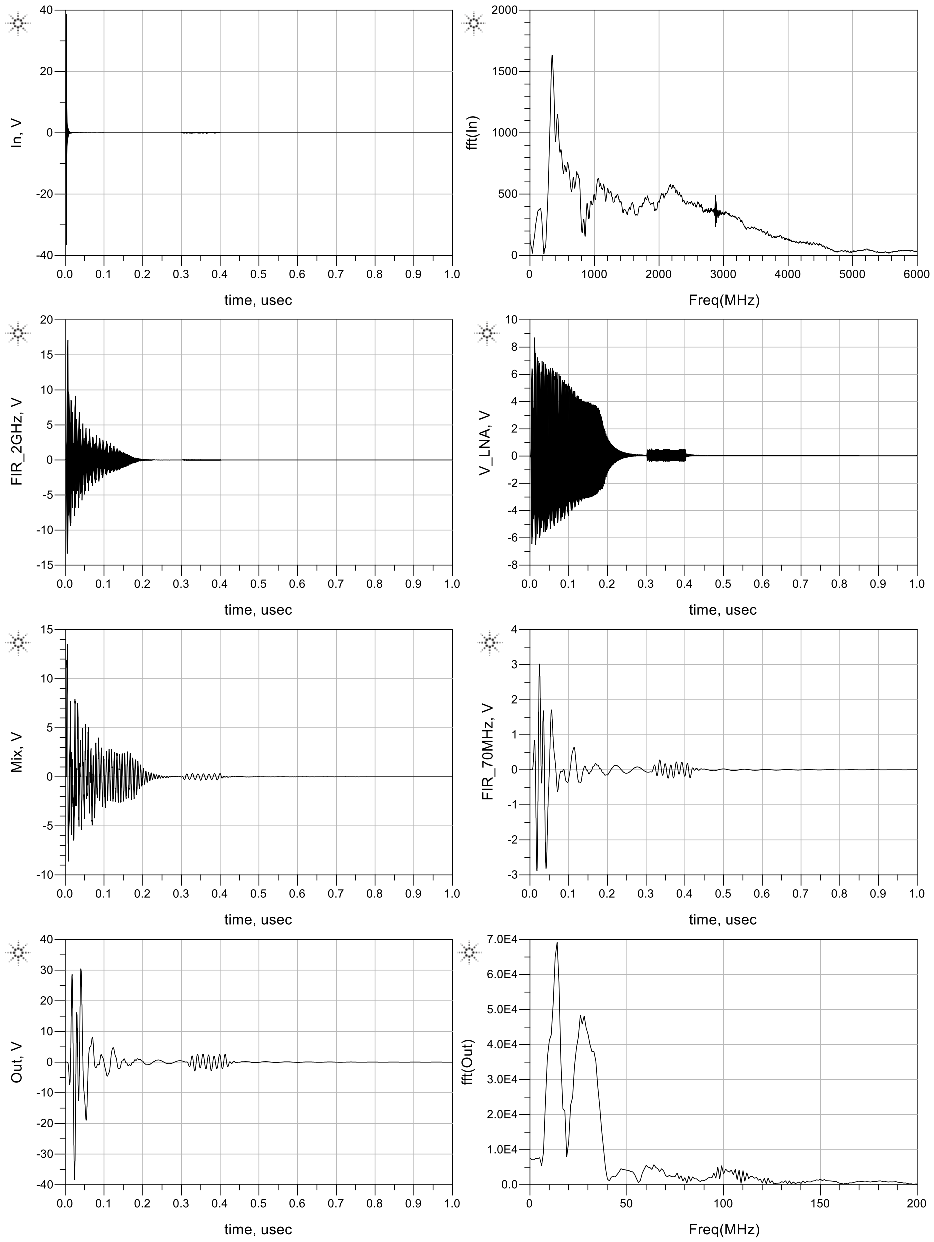

Figure 5: Response of receiver modules to echo signals under electromagnetic pulse interference

4. Conclusion

The article first introduces two typical receiver structures, and chooses a superheterodyne receiver as the RF front-end circuit structure. Through circuit simulation modeling, the receiver circuit model is built. Using a certain electromagnetic pulse as the input source, the output response of each module of the receiver is simulated, and it is found that the interference of the electromagnetic pulse produces an interference signal of about 40V, which is likely to cause the system to malfunction. However, the interference can be minimized through further signal processing or improved circuit settings.

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