文章编号:1001-9014(2010)04-0241-04

MINIATURIZATION Ka-BAND RECEIVER USED FOR PASSIVE MILLIMETER WAVE IMAGING

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Abstract: A miniaturization of Ka-band direct detection receiver based on monolithic microwave integrated circuit (MMIC) used for passive millimeter wave (MMW) imaging was proposed. This receiver was composed of wideband low noise amplifier (LNA) module, small signal diode detector and dc amplifier. Each module was designed, fabricated, and tested. The performance of the receiver was also tested. The measured results show that the receiver achieves a RF gain above 30dB with noise figure less than 3.8dB and an effective bandwidth 7.4GHz. Some MMW images obtained with this receiver using a horn antenna prove the receiver's applicability in passive MMW imaging.

Key words: passive millimeter wave imaging; millimeter wave receivers; monolithic microwave integrated circuit (MMIC)
CLC number: TN957; TN409 **Document**: A

用于被动式毫米波成像的小型化 Ka 波段接收机

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摘要:研制了一种工作于 Ka 波段用于被动式毫米波成像的基于单片微波集成电路(MMIC)的小型化接收机.该接收机主要由毫米波宽带低噪声放大器模块、毫米波小信号二极管检波器和视频放大电路组成.设计、制作、测试了接收机各个组成模块,对接收机的整体特性进行了测试.测试结果表明,该接收机的有效带宽约为 7.4GHz、噪声小于 3.8dB、增益约为 30dB.应用喇叭天线和该接收机获得的一些毫米波图像表明,该接收机可以应用于被动毫米波成像.

关 键 词:被动式毫米波成像;毫米波接收机;单片微波集成电路
中图分类号:TN957;TN409 **文献标识码**:A

Introduction

Various passive MMW imaging systems which measure the apparent temperature of an object via the energy emitted or reflected from the target objects have been developed for great interest in some biomedical, remote sensing, and homeland security applications, due to a possibility to penetrate moisture, dust, and smoke far better than infrared or visible systems. Furthermore, the ability to penetrate dielectrics such as plastic and cloth has opened up the opportunity of detecting weapons and contraband hidden under people's clothing[1~3]. In recent years, MMW imaging technology has got huge advancement benefited from the rapid development of microwave and millimeter integrated circuit (MMIC) and multi-chip module (MCM) technology[4]. The most important element of MMW imaging system is a single-pixel receiver. Compared with heterodyne receivers made of RF mixer and IF amplifier, the direct detection receiver requiring a low noise amplifier (LNA) and a detector has many advantages which become more pronounced in focal plane staring array

Received date: 2009-03-30, **revised date**: 2010-04-08 **收稿日期**:2009-03-30, **修回日期**:2010-04-08
Foudantion item: Supported by the "973" Program (NO. 2009CB320207) and Science and Technology Commission of Shanghai Municipality (NO. 08DZ1110500);
Biography: GUAN Fu-Hong (1976-), female, Shanghai China, PhD. Research field is RF&MMW integrated circuit, system integrated technology and MMW imaging system.

system. Up to now, various direct detection receivers had been developed[5].

This paper presents a MMIC direct detection MMW receiver operating in Ka band in two sections. In section 1, the operation principle is described, each component of the receiver is designed and measured, and the supporting measured data are also presented. In section 2, the performance of the receiver is presented, and some experiments using this receiver have been done to validate its applicability for passive MMW imaging application.

1 Circuit design and performance

Detecting the apparent temperature of targets through the energy emitted or reflected from the objects is the fundamental of a passive MMW system. Supposing the system noise temperature $T_{sys} \approx F_{rn} T_0$, gain fluctuation $\Delta G/G = 0$, the minimum detectable temperature change is $\Delta T_{min} \approx F_{rn} T_0 / \sqrt{B\tau}$. (Where F_{rn} is noise factor of the receiver, T_0 is environment temperature, τ is integral time). A block diagram of a total power direct detection receiver is shown in Fig. 1. It is made of a LNA with a bandwidth of B and a gain of G, a diode detector with a voltage sensitivity of C (V/W), and video amplifiers. The output voltage of the receiver V_d is given by[6]

$$V_d = CGG_v(W_s + W_{rn}) \quad . \tag{1}$$

1.1 LNA module and the MMIC LNA

The LNA module is composed of two cascaded MMIC chips to provide both enough gain and a RF signal in the square-law region of the diode detector. The MMIC amplifier shown in Fig. 2 has been designed by our group and manufactured with an advanced 0.15μm GaAs phemt process. Measured results on wafer show the MMIC LNA has a gain of 15 ~ 17dB and a noise of 2 ~ 3dB within the band 26.5 ~ 40GHz.

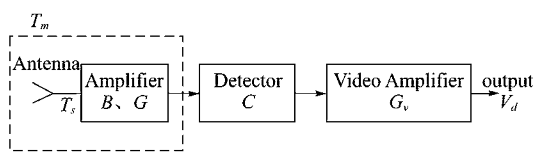

Fig. 1 Block diagram of the direct detection receiver
图1 直接检波接收机框图

Fig. 2 MMIC LNA
图2 MMIC 低噪声放大器

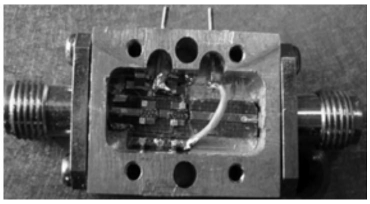

Fig. 3 Photograph of LNA module
图3 低噪声放大器模块

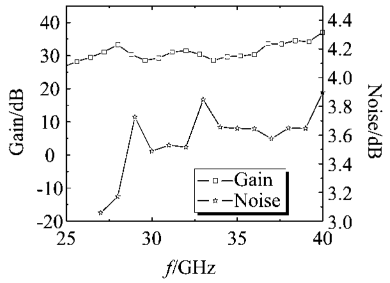

Fig. 4 Measured gain, noise figure versus frequency of the LNA module
图4 LNA 模块增益、噪声测试曲线

In the mechanical design, assembly, and interconnections special attention was paid to some aspects beyond the basic electrical performance in order to obtain better matching between the LNAs and reduce the ripple in band[7] because the module is a MMW system. The two MMIC chips are assembled in a gold-filled box. Fig. 3 shows a detail of the modular. Interconnections between microstrip lines and MMICs are made using 25μm gold wires by ultrasonic bonding. The bonding wires are as short and low as possible in order to minimize the effect on the LNA. Bias MMIC networks are composed of a MIM and chip capacitors to assure amplifier stability at low frequencies. Signal at input and output comes from two K connecter connection through the microstrip line transition. The module's measured noise and associated gain are shown in Fig. 4. It has achieved a gain of 29 ~ 31dB and a noise figure of 3.4 ~ 3.9dB for frequency from 30 ~ 40GHz.

1.2 Diode detector

After the signal is amplified, a square-law detec-

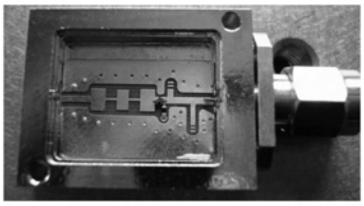

Fig. 5　Photograph of the detector
图 5　检波器图片

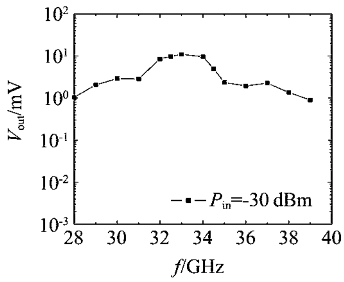

Fig. 6　Frequency dependerce of voltage response of the detector
图 6　检波器探测电压对应频率特性测试曲线

tor is designed to convert the MMW signal to dc voltage[8]. The detector is composed by a hybrid reactive/passive matching network and a beam-lead diode HSCH9161. A high-low impedance lowpass filter is used to provide RF ground and a 100kΩ load resistor is used as video load. The input and output microstrip network had been manufactured on dielectric substrate with the thickness of 0.254mm and permittivity ε_r = 2.2. The diode is attached to the microstrip by silver-filled epoxy. Fig. 5 is a photograph of the diode detector. Fig. 6 depicts the measured detected voltage versus frequency when the input power is -30dBm. The detected voltage versus input power at 34GHz and 32.5 GHz, respectively, is shown in Fig. 7.

1.3　Video amplifiers

Video amplifiers which were designed to make the

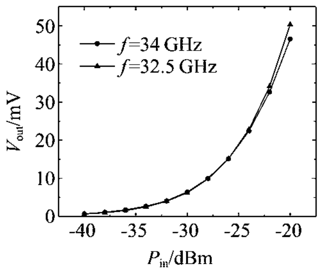

Fig. 7　Voltage response versus imput power at two different frequencies
图 7　检波器探测电压对应输入功率特性测试曲线

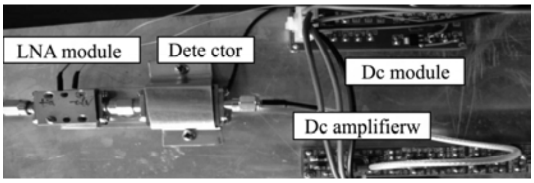

Fig. 8　Photograph of the receiver
图 8　接收机照片

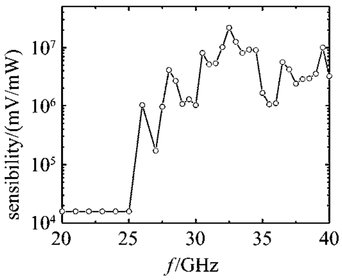

Fig. 9　Dependence of the receiver's sensibility on frequency
图 9　接收机灵敏度对应频率测试曲线

detected voltage suitable for data acquisition electronic module. There is often a small dc bias, since the output voltage of the detector being boosted is so low, there is often a small dc bias, a band pass filter is used to modulate the input signal in order to limit the effect of $1/f$ noise and keep the amplified signal within the limits of the op-amp and filter power rails. An OP27 precision operational amplifier is selected as the first stage. Connecting to the OP27 are two LF353 FET operational amplifiers which have functions of filtering and amplifying the signal. Video amplifiers was designed to make the detected voltage suitable for data acquisition electronic module. Measured results indicate the video amplifiers a voltage gain about 40dB and a bandwidth of 15 ~ 40Hz.

2　The receiver performance and experimental results

2.1　The receiver performance

The receiver as shown in Fig. 8 is formed by connecting the LNA module, the diode detector and video amplifiers. The receiver's performance at different frequencies was measured from 20 to 40GHz for several input powers. The sensibility with the －62dBm input power is shown in Fig. 9. The effective bandwidth of the receiver is 7.4GHz which was calculated using output voltage values taken at discrete frequencies as in

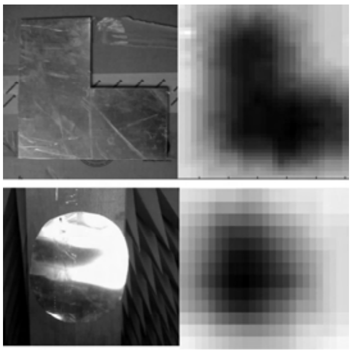

Fig. 10 Comparison between optical and passive MMW images with the designed sensor
图10 光学照片及其用接收机所成的对应的毫米波图像

equation (6) since the receiver is a direct conversion system[5]. The system minimum detectable temperature change is less then 1K calculated using equation(1), supposing $T_0=290K$, $\tau=1ms$. The specifications for the receiver are summarized below in table 1.

$$BW_{eff}=\Delta f\cdot\left(\frac{N}{N+1}\right)\frac{\left(\sum_{i=1}^{N}V_{out}(i)-V_{off}\right)^2}{\sum_{i=1}^{N}(V_{out}(i)-V_{off})^2}\quad,\quad(2)$$

where N is number of frequency points, Δf is frequency step, $V_{out}(i)$ is dc output voltage at each frequency point, V_{off} is dc output voltage with input power off.

2.2 Experimental results

Some experiments of the receiver have been done with a Ka-band horn antenna (gain 24dB and 3dB beam width 5 degree) by 2-D mechanical scanning. Two of the passive millimeter-wave images are shown in Fig. 10 for metal boards with different shape placed at the distance of 100cm from the receiver.

Table 1 The receiver specifications
表1 接收机指标

System parameter	Value
Centre frequency	35GHz
RF bandwidth	7.4GHz
RF gain(in operation frequency range)	≈30dB
Noise figure (in operation frequency range)	<3.8dB
Dynamic range	−70 ~ −50dBm
Video bandwidth	15 ~ 40Hz
Video gain	≈40dB

3 Conclusion

This paper describes the basic principle of a direct detection receiver, presents the design fundamentals, and tests the performance of each part of the receiver. The receiver has been tested to obtain the sensibility, effective bandwidth, minimum detectable temperature change and dynamic range. The passive MMW images performed using the receiver by 2-deminsonal mechanical scanning illustrate efficiency of the designed receiver for imaging applications.

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