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A Novel Dual-polarization Total Power Radiometer with Single Channel Based on TSPW Technique

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Abstract: A dual-polarization total power millimeter wave (MMW) radiometer with single channel and based on time sequence phase weighting (TSPW) was proposed in this paper. It completed the subtraction of two orthogonally polarized signals in the RF front-end. The system only used one channel to achieve the function. The performance of the system was analyzed and simulated on the basis of discussing the theory and the configuration of the system. Based on SNR theory, the ability to identify the false target was analyzed. The results showed the system could solve the problem that the performance of dual-polarization radiometer becomes weak because of gain inconformity with two channels. The system was small in size and saved cost. It could identify the false target which has different apparent temperatures at vertical and horizontal-polarized radiations. *Copyright © 2013 IFSA.*

Keywords: Millimeter wave radiometer, Dual-polarization, Single channel, TSPW.

1. Introduction

In passive millimeter-wave (MMW) detecting technique and imaging application, the MMW radiometer is one of the key technologies. The performance of radiometer directly affects the final performance of the system, and it is a high sensitivity receiver used for measure MMW radiation of objects. The radiation of objects in MMW band is mainly depends on their different emissivity. The target will be detected, identified and located basing on the different intensity levels of the target and background. Since MMW radiometer can easily identify metal and non-metal, it can be applied in searching and rescuing cars, aircraft navigation and safety checking in severe environment [1-3].

Pond and metal targets are usually met in passive MMW detecting experimental study. Their MMW radiation temperatures are both lower than background temperature, so, they can hardly be distinguished by general single-polarization millimeter wave radiometer with single channel. A K_a band dual-polarization direct detection total power MMW radiometer is designed in literature [4], the system designed in literature receives signal's horizontal polarization component and vertical polarization component through dual-channel receiver, after comparing the differences, the system detects and identifies some false targets whose level and polarization has great difference on temperature. This project can distinguish false target like ponds and real target like metal easily, but it has a high demand on the consisting of the two receivers which can hardly be guaranteed at current technologic level, besides, using two receivers leads to the huge volume and high cost.

In this paper, TSPW technique [5] is applied to MMW dual-polarization radiometer, then a new dual-polarization total power MMW radiometer system with single channel is designed, it not only finishes the subtraction of two orthogonal polarization signals through radio-frequency head but also makes targets' detection and identification be achieved by using single channel. In each channel of the system, there is a $0/\pi$ phase shifter, and a two-way equal-split power divider is used to combine two elements into one channel [6]. This project can solve the performance deterioration problem of dual-polarization MMW radiometer which led by the channel gain's inconsistency of dual-channel receiver well, it is small in size and cost low, meanwhile, it has better identification performance on false targets which exists differences on horizontal and vertical polarization on temperature.

2. System Configuration and Working Principle

2.1. System Configuration

The designed dual-polarization total power MMW radiometer with single channel using TSPW technique in this paper is shown in Fig. 1. The antenna received the MMW radiation and the received signal will enter into polarization separator to be separated into horizontal polarization signal and vertical polarization signal, then the horizontal polarization signal will phase shift 180° and vertical polarization signal will phase shift 0°, then both enter into power divider together with vertical polarization signal, the two signals will composite one signal. Through amplifying by MMW LNA, detecting by MMW detector, and integrating, the signal will be processed by signal processor, finally, it finishes positing the detection and identification of the target.

2.2. Working Principle of the System

The MMW radiometer system designed in this paper does the conical scan on ground with 30° angle of declination which is perpendicularing to ground, scanning cycle is 4rps, as shown in Fig. 2.

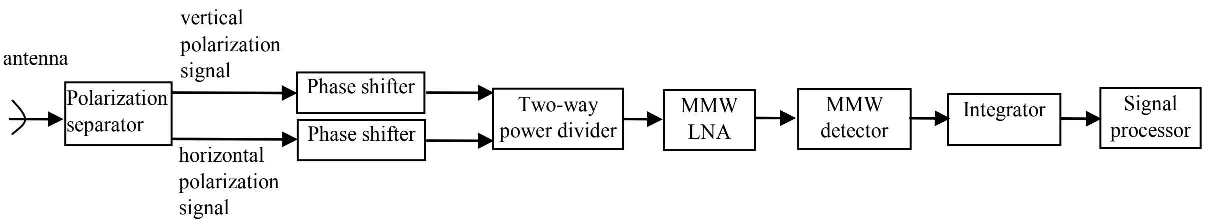


Fig. 1. Configuration of the dual-polarization total power millimeter wave radiometer with single channel.

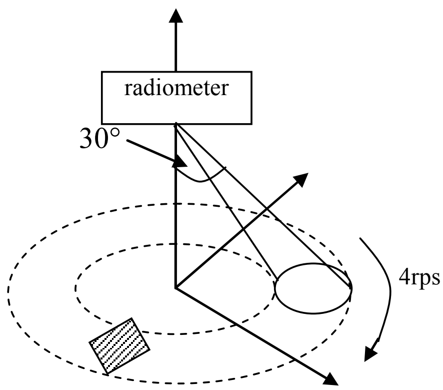


Fig. 2. Diagram of the principle of the system.

When system works, the horizontal polarization signal will phase shift 180° and the vertical polarization signal will phase shift 0°, and the weight of horizontal polarization signal channel is -1, the weight of vertical polarization signal channel is 1, then they both through power divider, it is equivalent to complete two way signals' subtraction in radio-frequency head. In order to achieve the function of this system, power divider is designed into unequal two-way power dividers. Power output formula is P1=1.25P2, P1 is horizontal polarization signal and P2 is vertical polarization signal.

3. Analysis of System Performance

3.1. Output Signal to Noise Ratio (SNR)

We can consider that the antenna receives is background temperature of MMW noisy when antenna beam is not on the target. The effect of atmospheric attenuation can be neglected. So, background antenna temperature is $T_{Ag} = T_{gAP}$ (T_{gAP} is background apparent temperature).

When antenna beam is on the target, the antenna beam solid angle which taken up by the target could be either greater or less than the solid angle of main beam of antenna. While general detection is applied, antenna gain is higher, antenna beam is narrow and the antenna beam solid angle taken by the target is not big, so we can consider that the antenna receives is just background MMW radiation outside the main beam, antenna temperature of the target is

$$T_{AT} = \begin{cases} \eta_M T_{AP} + (1-\eta_M)T_{Ag} & \Omega_T \geq \Omega_M \\ \eta_M \dfrac{\Omega_T}{\Omega_M} T_{AP} + (1-\eta_M \dfrac{\Omega_T}{\Omega_M})T_{Ag} & \Omega_T < \Omega_M \end{cases}, \quad (1)$$

η_M is efficiency of Antenna main beam, Ω_M is solid angle of Antenna main beam, Ω_T is solid angle of antenna beam which taken by target, T_{AP} is target apparent temperature.

Signals combine into one-way signal after pass phase shift and power divider, then the output temperature is

$$\Delta T_A = \begin{cases} \frac{\eta_l \eta_m}{L}[(T_{AP1} - T_{Ag}) - \frac{(T_{AP2} - T_{Ag})}{1.6}] & \Omega_T \geq \Omega_M \\ \frac{\Omega_T \eta_l \eta_m}{\Omega_M L}[(T_{AP1} - T_{Ag}) - \frac{(T_{AP2} - T_{Ag})}{1.25}] & \Omega_T < \Omega_M \end{cases}, \quad (2)$$

where T_{AP1} is the horizontal polarization apparent temperature of target, T_{AP2} is the vertical polarization apparent temperature of target, η_l is the radiant efficiency of antenna, L is the loss of input circuit.

In the situation that weather is clear and dip, angle of radiometer is 30°, the apparent temperature of background, metal target, and pond is shown in Table 1 [7].

Table 1. Radiation temperature of object.

Parameter	Apparent temperature
Apparent temperature in horizontal polarization of metal	50 K
Apparent temperature in vertical polarization of metal	50 K
Apparent temperature in horizontal polarization of pond	140 K
Apparent temperature in vertical polarization of pond	170 K
Apparent temperature in horizontal polarization of background	290 K
Apparent temperature in vertical polarization of background	290 K

The loss of phase shifter is about 3 dB, and the system efficiency $\eta = \frac{\eta_l \eta_m}{L} = 0.3$. When the antenna beam width is 3°, the target is full of 60 % of the antenna beam, radiation temperature difference of target calculated by formula (2) is shown in Table 2.

Table 2. Output radiation temperature difference of target.

Parameter	Target full of antenna beam	Target full of 60 % antenna beam
Temperature difference between metal and background	14.4 K	8.64 K
Temperature difference between pond and background	0 K	0 K

Output SNR can be worked out by SNR formula which is $SNR = \frac{\Delta V}{\delta} = \frac{\Delta T_A}{\Delta T_{\min}}$, with radiometer sensitivity $\Delta T_{\min}$ =1 K already known, as shown in Table 3.

Table 3. Output SNR.

Parameter	Target full of antenna beam	Target full of 60 % antenna beam
Scanning metal target	14.4	8.64
Scanning pond	0	0

According to the radiometer performance parameters, when temperature changes one degree, the output voltage changes 50 mV, we can get the output voltage value as shown in Table 4. The parameters can be changed to enlarge the difference between metal and pond.

Table 4. Output Voltage.

Parameter	Target full of antenna beam	Target full of 60 % antenna beam
Scanning metal target	0.8 V	0.4 V
Scanning pond	0 V	0 V

According to analysis on Table 3 and Table 4, due to power divider, great difference in temperature on metal target is produced and shown as a higher crest signal, and the output voltage of pond is close to zero. Then metal target and false target pond can be distinguished directly through the judgment on output SNR and output voltage.

3.2. Maximum Detection Range of the System

The system maximum detection range is determined according to

$$R_{\max} = \left(\frac{A_T \Delta T_A}{\Omega_M \Delta T_{\min} SNR_{\min}} \right)^{\frac{1}{2}} \quad (3)$$

where $SNR_{\min}$ is the minimum input SNR needed in the system which needs to reach false alarm time requirements [4].

When system false-alarm time demand is not less than 60 s, and according to relational graph between false-alarm time and SNR [8], we can get that $SNR_{\min} \geq 7$, let $SNR_{\min} = 7$, antenna beam width is 3°, then $R_{\max} = 160m$, finally we can get that system maximum detection range is 160 m.

4. The Solution of Inconformity in Gain

According to above analysis we can get that system detect and locate target and identify false target through output signal SNR. If output signal range is higher than threshold, then the target which detected by system is real target, otherwise, it is false target.

In ideal conditions, the polarization difference in temperature of dual-polarization MMW radiometer with dual channel designed in literature [4] is 0 K to real target metal, 30 k to false target pond. So, the false dismissal probability which get from the diagram on which homologous detection probability varies with SNR is less than 1 %, the probability of eliminating the false of the system is more than 99 %. But in the actual situation, the gain of the receiver can not be in full accord through existing technology, so that the system performance of the dual polarization radiometer which adopts two receivers will be serious effect, also, erroneous judgment will occurs. Below is concrete analysis.

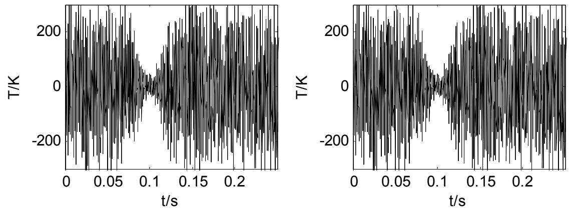
According to physical truth, the inconsistency of the gain of receiver is 10 %. Due to the effect of gain inconformity, when detect pond, the output SNR from subtracter is SNR =6 according to literature [6]. That means difference in temperature of polarization is ΔT =15 K, at this time, probability of distinguishing false target is reduced to 90 %.

In a similar way, when detect metal target in fact, the output SNR from subtracter is SNR =8, that means difference in temperature of polarization is ΔT =20 K, false dismissal probability of real target is more than 50 %.

From above analysis that in actual situation, it is shown that due to inconsistency of the gain of receiver, recognition performance of dual polarization radiometer with dual channel will became worse. So, the study of reducing two channels to one channel is very important. The radiometer system this paper designed does not have above problems because only one receiver is used. Probability of eliminating the false will be more than 99 % and false dismissal probability is less than 1 % through choosing threshold reasonably.

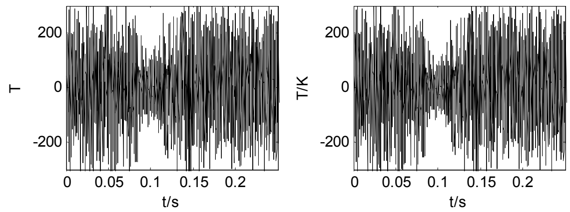
5. Simulation Results

To prove the feasibility of the theory, dual-polarization MMW radiometer with dual channels and the MMW system designed in this paper are simulated, then, the simulation results are compared. First of all, band-limited Gaussian white noise is produced, then it will produce a MMW signal collecting cycle with 4 rps, finally it produces RF input signal of metal target and pond by simulation together with noisy signal. As shown in Fig. 3 and Fig. 4.



(a) Input signal of metal target in horizontal polarization (b) Input signal of metal target in vertical polarization

Fig. 3. RF input signal of metal target.

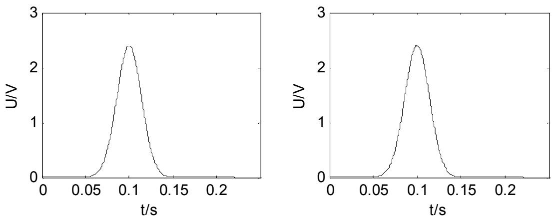


(a) Input signal of pond in horizontal polarization (b) Input signal of pond in vertical polarization

Fig. 4. RF input signal of pond.

5.1. Simulation Results of Dual Polarization Radiometer with Dual Channels

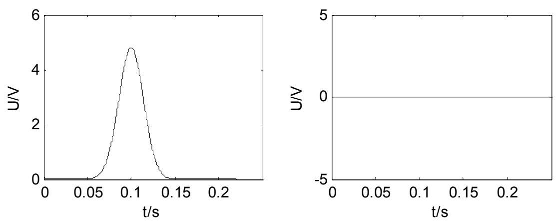
Metal target output result will be got after amplification, detection, integral and opposition through receiver, as shown in Fig. 5.



(a)Result of horizontal polarization channel (b) Result of vertical polarization channel

Fig. 5. Output result of two-way receivers.

At last, two-way signals will be added and subtracted in signal processor, the result is shown in Fig. 6. We can get that if metal target's horizontal polarization signal and vertical polarization signal adding, then a great crest signal will be outputted, if subtracting, output is zero.



(a) Addition result of two-way signals (b) Substract result of two-way signals

Fig. 6. Output result of signal processor.

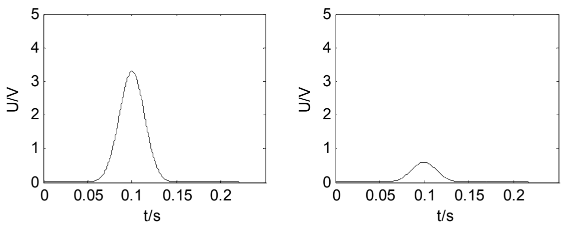
In a similar way, we can get output result of signal processor when detecting pond, as shown in Fig. 7.

According to the figure, a crest is outputted after subtracting between pond's horizontal polarization and vertical polarization signal, so, we can identify false target through judging the output voltage of subtracter.

5.2. Simulation Result of Radiometer System This Paper Designed

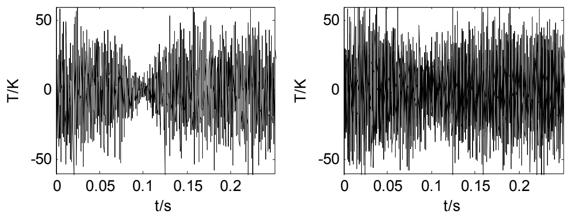
After horizontal polarization channel signal phasing shift 180° and vertical polarization channel signal phasing shift 0°, then the signal go through power dividing, we can get the signal of metal target inputting receiver and the signal of pond inputting receiver, as shown in Fig. 8.

The output result will be got after amplification, detection, integral and opposition through receiver, the final output result is shown in Fig. 9.



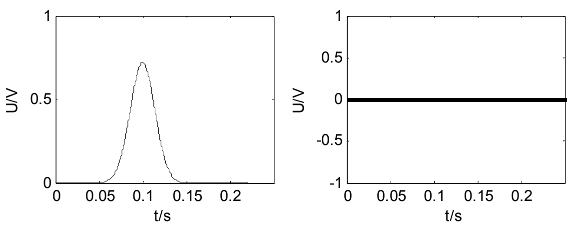
(b) Addition result of two-way signals (b) Substract result of two-way signals

Fig. 7. Output result of signal processor when detecting pond.



(a) Input signal of receiver by metal target (b) Input signal of receiver by pond

Fig. 8. Input signal of receiver.



(a) Output voltage of metal target (b) Output voltage of pond

Fig. 9. Result of single channel.

We can get from Fig. 9 that metal target output a higher crest signal and false target pond output is close to zero. Also we can posit and judge the output signal according to setting threshold and identify whether the target is false or not.

6. Conclusions

The dual-polarization total power MMW radiometer system with single channel based on TSPW technique this paper designed solves the problem of recognition performance of dual polarization radiometer with dual channels becoming worse which caused by the inconformity of gain of receiver. It has a recognition performance on the false target which has great difference on the apparent temperature of horizontal and vertical polarization. The simulation results validate the project. Meanwhile, this system just uses one-way direct-detection receiver, it is cheap and small. It reduces summator and related hardware when deals with back-end signal processing.

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