A novel design of focal plane array in PMMW imaging System

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***Abstract*—Typical Passive millimeter wave (PMMW) sensors with focal plane array (FPA) are placed on a rectangular grid to sample the image plane. Since the sensors must be made large enough to sense PMMW wavelengths, the sensor density that can be achieved is limited. In fact, the sensors may not be spaced closely enough to sample the image at Nyquist density. A novel design scheme based on focal plane array is reported in this paper for 3mm PMMW imaging. Image resolution and imaging speed have improved by using large aperture lens and multi-channel receiving array. The arrangement of feeds and scanning model can realize Nyquist sampling rate on focal plane array(FPA) so that the image can be reconstructed as reliably as possible, which means super resolution algorithms can be implied in both vertical and horizontal directions.**

I. INTRODUCTION AND BACKGROUND

PMMW imagery has tremendous potential for imaging in adverse conditions. They have many important applications, both military and commercial [1, 2]. However, poor resolution and long acquisition times pose serious limitations to this potential. A major drawback to PMMW images is poor angular resolution. Resolution is inversely proportional to wavelength and proportional to the size of the aperture [3,4]. Furthermore, the use of a very large aperture is not usually an option because of platform size constraints.

Since the sensors may not be spaced closely enough to sample the image at Nyquist density. Therefore, optimizing the sampling pattern is an important strategy for resolution improvement, since we need as much information in as short a time possible to make post processing most productive. Since the aperture in PMMW imaging is spatially limited, the spatial Fourier transform of the scene is only known over specified limits. This frequency-domain truncation is equivalent to a strictly band-limiting low-pass spatial filter of the image data, which limits the resolution of the image. Typically, the aperture in PMMW imaging is circular, resulting in a circular. Ordinarily, a focal plane sensor array has sensors placed in a rectangular grid pattern at sub-Nyquist density, and the array must be dithered to sample the image plane at the Nyquist density in each dimension. However, the Nyquist density oversamples the image due to the usually circular support of the diffraction limited image spectrum.

To solve the problem, a novel design scheme based on focal plane array is reported in this paper for 3mm PMMW imaging.

This section is the introduction. Section 2 describes the system design and the arrangement of feeds and scanning model. Section 3 describes the simulation. Finally, we present the results and prospects of our research in Section 4.

II. SYSTEM DESIGN AND DESCRIPTION

According to the Rayleigh law, spatial resolution of PMMW imaging system is a function of the beam width of an imaging system [4]. It is expressed as:-

$$\theta_{3dB} = k\frac{\lambda}{D} \tag{1}$$

where λ is the wavelength , D is the dimension of the aperture, and k is coefficient factor .

The cut off frequency of the PMMW lens [5] can be obtain by equation (2),

$$f_{LENS} = \frac{D}{\lambda} \tag{2}$$

According to the Holmes derivation, radiometer receives radiation temperature collected by the antenna [6]:

$$T_A = \iint_{4\pi} T_{AP}(\theta,\phi) \bullet F_n(\theta,\phi) d\Omega \tag{3}$$

where $T_{AP}(\theta,\phi)$ is view temperature of the antenna , $F_n(\theta,\phi)$ is normalized antenna pattern of the *n*-th feed in the multi-beam antenna (MBA) system, Ω is solid angle. One of the antenna pattern $F_n(\theta,\phi)$ is shown as Fig1. Through two-dimensional Fourier analysis, the Spectrum of antenna pattern is shown as Fig.2.

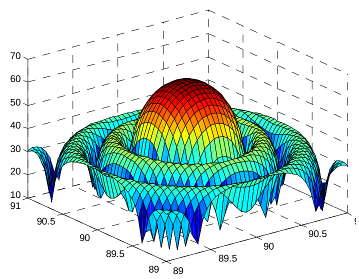

Fig.1 Antenna pattern

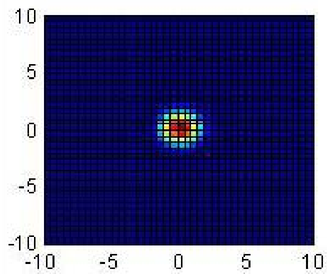

Fig.2 Spectrum of antenna pattern

From Fig.2, we can get cut off frequency of the antenna pattern is $f_o = 1.8$/degree, according to Nyquist sampling law,

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the space sampling interval $\Delta_{\theta,\varphi} = \frac{1}{2f_0} = 2.8°$. Because the aperture dimension of the MBA D =500mm, and $f/D=1$, so f =500mm. Thus sample space in FPA can be calculated:

$$\Delta_{x,y} = f \times \tan(\Delta_{\theta,\varphi}) = 2.43mm \quad (4)$$

From equation (4), we can see that the feed distance of the sensor is $\Delta_{x,y} = 2.43mm$. In other words, the sensor density that can be achieved is limited. In fact, the sensors may not be spaced closely enough to sample the image at Nyquist density. So a novel design scheme based on focal plane array is assigned as Fig.3.

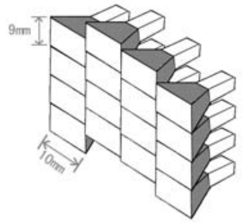


Fig.3. 3-D diagram of MBA feeds

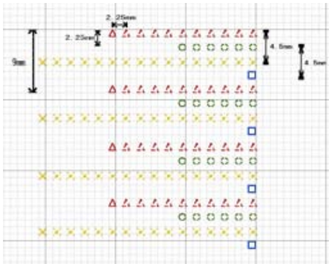


Fig.4. Scanning model

A simple approach to work out MBA pattern is proposed. It is called half-simulation method, for it uses HFSS software to simulate electronic field distribution on feed's aperture, and then uses geometry optics method to attain MBA's pattern. The result is quite similar in comparison with FEKO software, however the computational speed is quickened. Through correction of antenna gain, the MBA pattern is calculated, which is shown as Fig 4.

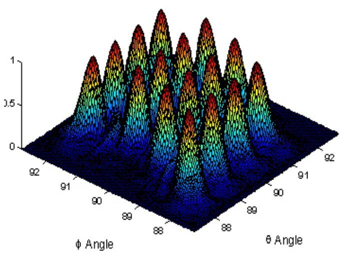
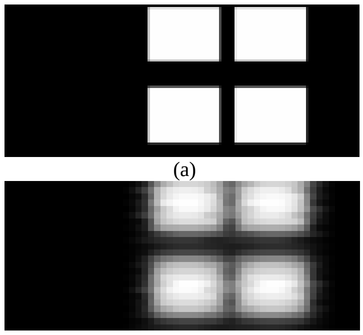


Fig4. MBA pattern

The arrangement of feeds and scanning model can realize Nyquist sampling rate on focal plane and the image can be reconstructed as reliably as possible from a periodic nonuniform set of samples, which means super resolution algorithms can be implied in both vertical and horizontal directions and 3dB beam is come across.

III. SYSTEM SIMULATION

PMMW image scanning-method decides the field of view. In Fig.4, we use a rising-head scanning method: When MBA completes one-dimension scanning from left to right, it will rise up 3.8° , and fly back to the left. This method can duplicate view of field in vertical angle. On the other hand, horizontal view of field depends on one-dimension horizontal scanning angle.



(a)

(b)

Fig. 5 (a) visual image (b) PMMW image

In experiment, a small number of test images is collected in the lab and around surroundings, shown as Fig.5. Fig.5 shows a image of a house window, it is imaged by MBA imager. As can be seen from the figure, the more near the sky, the temperature is colder.

IV. RESULTS

Based on the research of multi-beam antenna design method, a 4×4 linear feed-array staggered arrangement is presented for reducing the non-uniformity of the beam. The system scans in horizontal direction. The working frequency of the system is 92 GHz with large diameter lens antenna. It is mainly used in 100-1000 m distance from the scene monitoring and 300 meters vehicles imaging. The angle resolution is superior to 0.57°.The arrangement of feeds and scanning model can realize Nyquist sampling rate on focal plane array (FPA) so that the image can be reconstructed as reliably as possible, which means super resolution algorithms can be implied in both vertical and horizontal directions.

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