Narcissus Analysis For Cooled Staring IR System

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ABSTRACT

Narcissus can have a deleterious effect on image quality for cooled infrared imaging systems. Therefore, analysis of narcissus is important for designing both scanning and staring optics. Narcissus is generally assumed to be negligible in staring IR optical designs because the shading effects can be removed by calibration of the detector array data. However, the calibration usually decreases sensitiveness of the system and Narcissus variation may be noticeable for sensors when the conditions changes as follows: 1. warming and cooling the optical housing, 2. zooming optical elements, 3. movement of lenses for focus. In that case, it will result in shading and other image defects even after calibration. To minimize these effects, narcissus should be assessed and controlled during the design of staring array IR system. We provided a direct and fast method for analyzing the narcissus variation in the presence of software such as LightTools, TracePro and ASAP, and proposed the principles in optical design of staring IR systems to reduce narcissus. A cooled staring IR system with serious narcissus was estimated and reoptimized. Narcissus analysis of this IR system confirmed the efficiency of the analysis method.

Keywords: Narcissus, Cooled staring IR, Cooled stop,Raytracing

1. INTRODUCTION

Narcissus is the image nonuniformity due to the detector receiving its retro-reflection from lens surfaces. It gives rise to a false image signal, which can mask the true information content of the image. Even though the amount of spurious energy reflected off a coated surface is very small the effect may be serious because the main signal received by the instrument may come from a low contrast object. As to staring cooled infrared imaging systems, the degrading effect of Narcissus reflection can be eliminated by calibration, if narcissus effect is slight and constant with the changing conditions. Unfortunately, serious Narcissus or Narcissus variation detrimentally affects image quality. However, narcissus analysis tools available in some optical program are not optimized for staring sensor and time-consuming.

This paper provides a direct and fast method for narcissus analysis, which employs simulation software such as LightTools, TracePro and ASAP. The analysis results are in good consistent with data from CODE V. Since analysis of narcissus variation is more significative for cooled staring IR system. We assessed the narcissus variation introduced by changing conditions of the system referred above. Additionally, we evaluated the distribution of stray light due to hot surface of optical housing. The validity of the new analysis method was demonstrated with a cooled staring IR system.

2. ANALYSIS METHOD OF NARCISSUS

2.1 Narcissus caused by temperature difference and retro-reflection

The temperature difference between FPA and lens environment is the main cause of narcissus. FPA and cold stop are housed in a cooled Dewar, usually at 77K; while working temperature of lens and housing is at abut 300K. Retro-reflection of lens surfaces happens unavoidable, for transmission ratio of each surface cannot reach 100%. Narcissus arises from the difference of radiant energy reaching the detector from warm and cold instrument areas. The detected temperature on the area which receives FPA ghost reflection is much lower.

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2.2 Tracing the rays to get the energy distribution of Narcissus

Narcissus analysis tool in CODE V is not optimized for staring sensor. It needs a lot of time to get distribution of NITD (the narcissus induced temperature difference) on the FPA, for one raytracing execution only provides narcissus distribution of one point on FPA. In our method, energy distribution on FPA is obtained with one raytracing execution. Narcissus effect described by a map of energy density on the receiver seems direct and clear.

We set up three-dimensional space model of optical system using software specialized in raytracing, such as ASAP, Trace Pro, LightTools. The system model comprises lenses, cold stop, FPA, mounts, and so on. Both the source and receiver are set on FPA. Tracing the rays reflected off each coated surface separately, we can obtain the distribution of energy on the receiver. Such spurious energy represents narcissus effect. If the distribution of energy is uniform and not concentrated on the center of FPA, narcissus effect induced by this surface is not serious. Otherwise, narcissus effect must be terrible. Changes of temperature difference between FPA and lens are simulated through changing the source power. Analysis of narcissus variation during focusing or zooming is performed by moving the optical elements related. Analysis results may be quit accurate, provided that rays for tracing are sufficient. The energy density coincides with NITD from CODE V.

3. NARCISSUS ANALYSIS OF LENS

3.1 Narcissus from lens surfaces

We designed an IR lens with serious problem of narcissus to perform narcissus analysis surface by surface. Fig. 1 illustrates overlay distribution of Narcissus due to retro-reflection from all lens surfaces. Optical surface reflectance was assumed to be 1%. As shown in Fig 1, energy distribution of Narcissus is quit non-uniform.

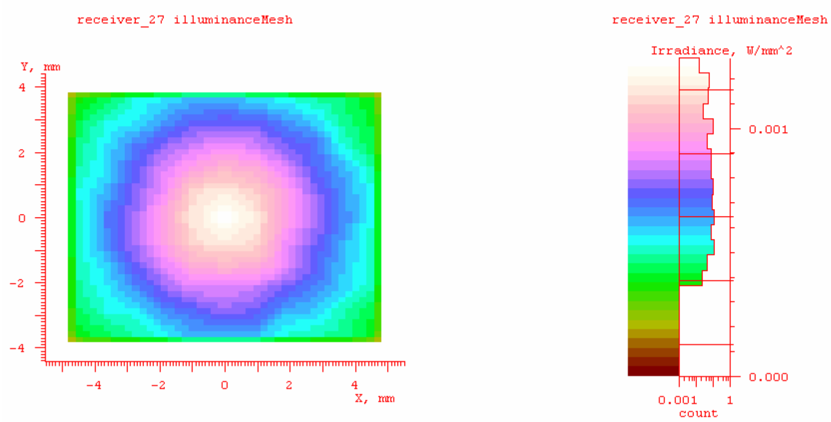


Fig. 1. Overlay distribution of narcissus induced by all lens surfaces. The energy density of center is about 3.4 times that of the edge.

After Narcissus analysis, we found the two surfaces of lens 6 mostly contributed to the non-uniform energy distribution, and Narcissus from other surface was slight. Fig. 2 gives energy distribution induced by surfaces (S1 and S2) of lens 6. We can see that the energy is focused on the center in which energy density is high.

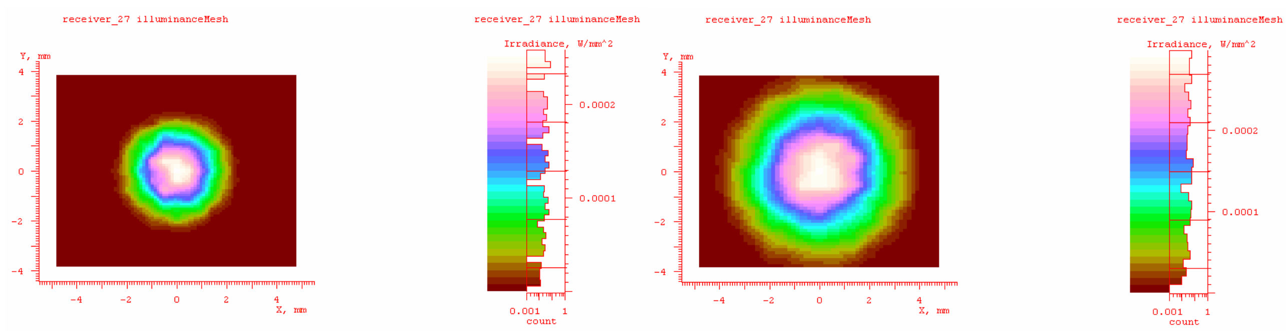


Fig. 2. Distribution of narcissus energy on FPA reflected off S1 and S2 of lens6.

3.2 Tracing the rays back from the surfaces in trouble with code V

We traced the rays reflected off lens 6 with CODE V to find out Narcissus variation versus detector position. Rays are traced from the FPA, through the cold stop, Dewar window, lens from 1 to 5, to retro-reflection surfaces of lens 6. The retro-reflection returns to the FPA. Such reflections were cut off gradually by the cold stop, as sensing point was moved from the center to the edge of the FPA. Finally, reflections traced outside a critical poison of the FPA were totally clipped. This results in a cold disk with sharp boundary.

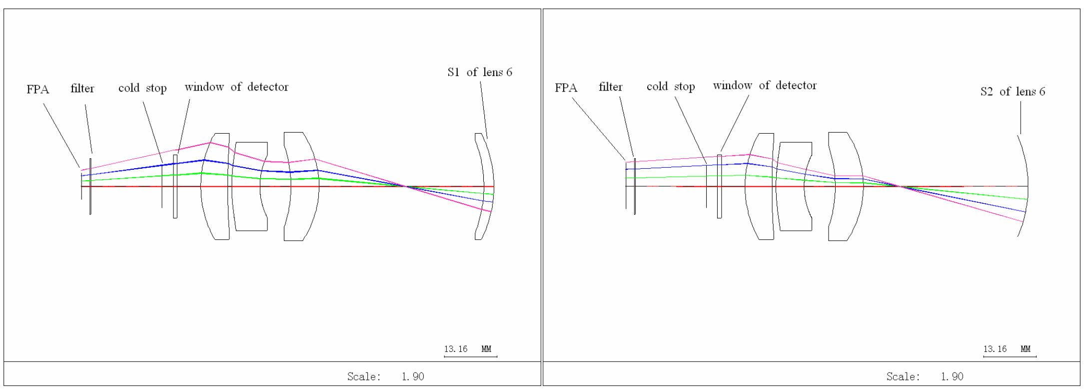


Fig. 3.Raytrace in code V. Detector from the center out to 2.5mm sees retro-reflection from S1 of lens 6. Detector from the center out to 4.5mm sees retro-reflection from S2 of lens 6.

NITD calculated in CODE V is in good agreement with distribution of energy density from our analysis. NITD and energy density due to Retro-reflection from surfaces of lens 6 dropped to zero at the same critical poisons of the FPA. (See Fig. 4)

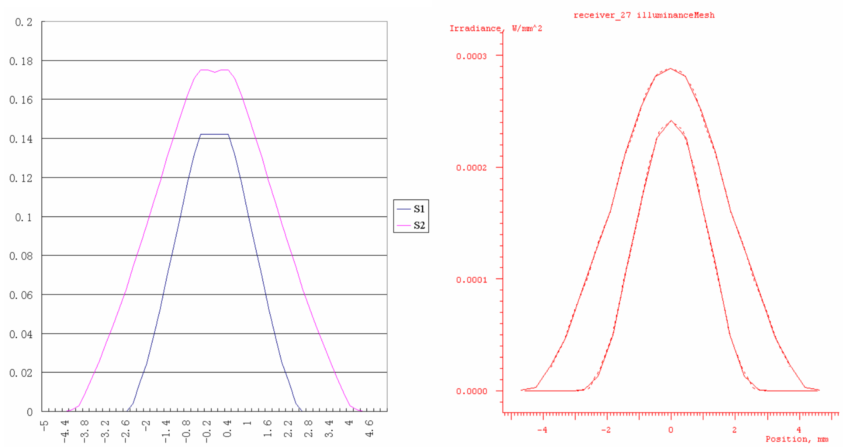
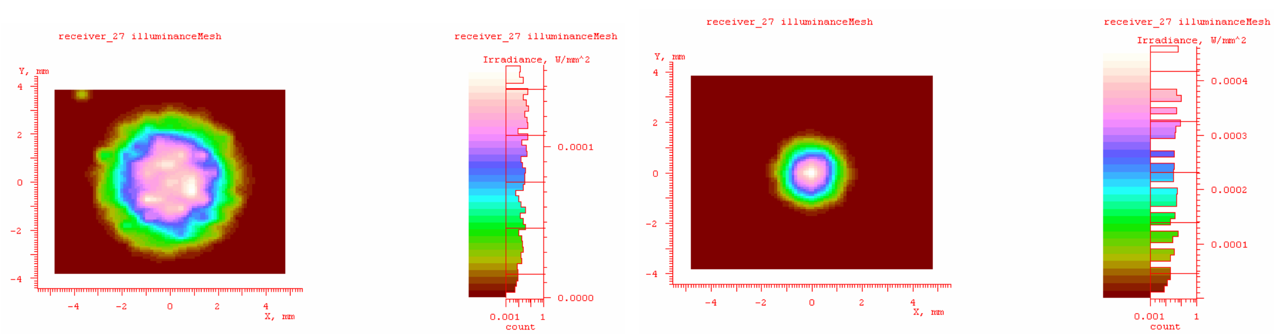


Fig. 4. NITD calculated in code V and the distribution of narcissus energy.

3.3 Narcissus variation during focusing or zooming

Movement of lenses during focusing or zooming may change the solid angle of narcissus, which causes narcissus variation in the system. Possibility of narcissus variation introduced by optical elements moving will increase, if such elements have trouble in serous Narcissus. Fig. 5 shows the dramatic narcissus variation due to adjustment of lens 6



(a) (b)

Fig. 5 Narcissus changes, as lens6 moves along Z axis. (a) and (b) show narcissus variation from S1 of lens6, with movements of +7mm and -7mm.

3.4 Narcissus variation due to the changes of temperature

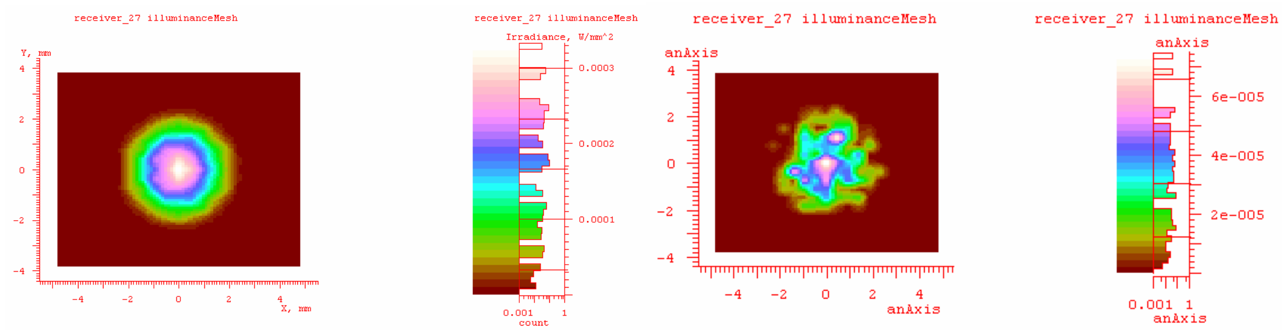
Working temperature of detector is usually controlled to be constant, while temperature of optical system is a labile factor. Narcissus variation happens when T_{HOU} (temperature of housing) and T_{BAC} (temperature of background) change with environment varying. NITD is a direct indicator influenced by T_{HOU} and T_{BAC}, given by the sum over all surfaces of the Narcissus Intensity Ratio (NIR) for each surface times the reflectivity for that surface and times a radiometric conversion term.

$$NITD = \sum_{j=1}^{scn-1} NIR_j r_j \frac{t_j^{\ 2}}{t_0} \frac{\left(W_{HOU} - W_{DET}\right)}{\left(\Delta W / \Delta T\right)_{BAC}} = \sum_{j=1}^{scn-1} NIR_j \frac{t_j^{\ 2}}{t_0} r_j \frac{\int_{\lambda_1}^{\lambda_2} \left[W\left(\lambda, T_{HOU}\right) - W\left(\lambda, T_{DET}\right)\right] \frac{\lambda}{\lambda_2} d\lambda}{\int_{\lambda_1}^{\lambda_2} \frac{\partial W\left(\lambda, T_{BAC}\right)}{\partial T} \frac{\lambda}{\lambda_2} d\lambda} \tag{1}$$

where j goes from 1 to SCN-1. tj is the transmittance between surface j and the detector and to be the transmittance of the lens from surface 1 to the image. The (λ /λ 2) term in the integrals is the idealized detector spectral response. If single surface is considered, NITD is expressed as follow:

$$NITD_{S1} = NIR_{S1} r_{S1} \frac{t_{S1}^{\ 2}}{t_0} \frac{\left(W_{HOU} - W_{DET}\right)}{\left(\Delta W / \Delta T\right)_{BAC}} = NIR_{S1} \frac{t_{S1}^{\ 2}}{t_0} r_{S1} \frac{\int_{\lambda_1}^{\lambda_2} \left[W\left(\lambda, T_{HOU}\right) - W\left(\lambda, T_{DET}\right)\right] \frac{\lambda}{\lambda_2} d\lambda}{\int_{\lambda_1}^{\lambda_2} \frac{\partial W\left(\lambda, T_{BAC}\right)}{\partial T} \frac{\lambda}{\lambda_2} d\lambda} \tag{2}$$

Narcissus reflection can be eliminated by calibration. However, uncompensated narcissus will appears after calibration when the housing temperature changes. Serious narcissus often aggravates narcissus variation due to temperature varying. Changes of temperature difference between the housing and the FPA can be simulated through changing the source power in the model. We analyzed narcissus variation reflected off surface 1 of lens6, with 20% power added to the source. According to Fig. 6, narcissus changes a lot compared to the one without temperature changing.



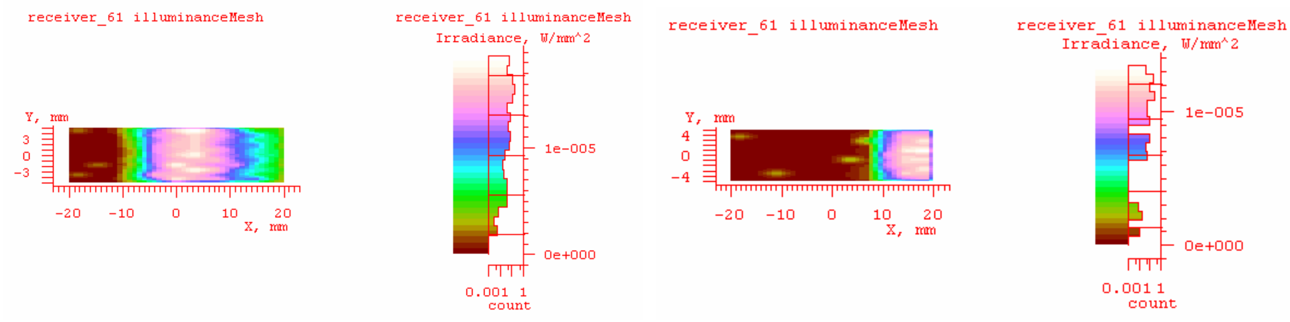
(a) (b)

Fig. 6. (a)Distribution of narcissus reflected off surface 1 of lens 6 with 20% power added to the source and (b). uncompensated narcissus due to energy added.

4. ANALYSIS OF ENVIRONMENT

4.1 Energy distribution on the housing

Analysis above is concerned with the energy returning to FPA through retro-reflection. Now we focus on the energy which did not return to the FPA but reached housing after retro-reflection. In order to find out distribution of energy tracing from the FPA to the housing, we set receiver on the housing between lens 6 and lens 7. Fig. 7 gives the distribution of energy on housing.



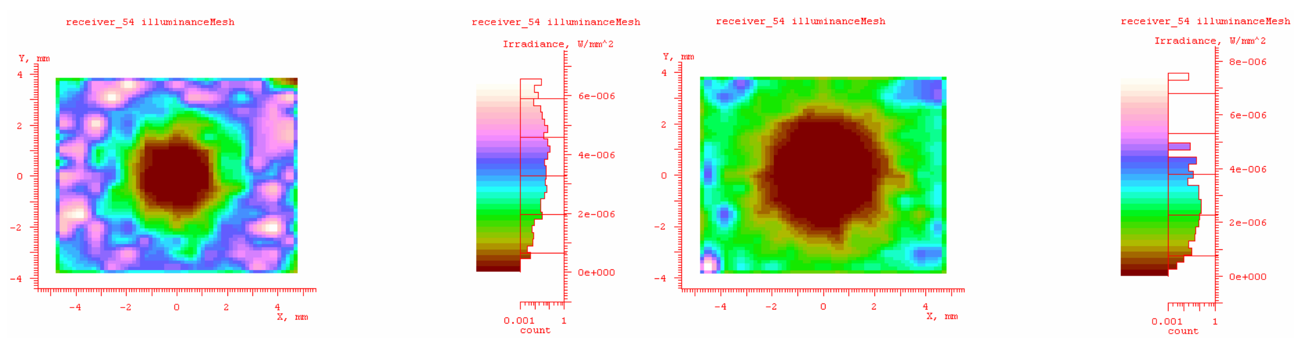
(a) (b)

Fig. 7 Energy distribution on the housing between lens6 and lens7. (a) energy distribution due to retro-reflection from surface 1 of lens6, (b) energy distribution due to retro-reflection from surface 2 of lens6. X axis is parallel to Z axis of lens.

4.2 Effect of stray light arising from thermal radiation on housing

Stray light arising from thermal radiation on housing may degrade image uniformity. Viewed from the front, setting receivers on housing in which we are interested, we can estimate whether the housing will affect image quality. Then we exchange the receivers with the source to gain distribution of stray light on the FPA. (See Fig. 8)

This method can be applied to analyzing the effect of thermal source exposed to optical system nearby. It is fairly efficient for hot surfaces and surfaces with high reflectance near the optical system not enveloped in housing.



(a) (b)

Fig. 8. We put source on the housing where narcissus energy is focused. (a) Distribution of stray lights on the FPA reflected off S1 of lens6. (b)Distribution of stray lights on the FPA reflected off S2 of lens6.

5. REOPTIMAZE THE LENS TO REDUCE NARCISSUS

5.1 Principle for reoptimizing

Reflections off surfaces will focus the ghost near the FPA, with incident angle or marginal ray height of incidence closed to zero. Such reflections lead to serious narcissus on the FPA. Moreover, excessive concentration of spurious energy on the FPA makes narcissus sensitive to conditions variation, such as focus adjustment and changes of housing temperature. And excessive concentration of spurious energy on the housing produces massive stray light on the FPA. So, factors referred above should be avoided during reoptimizing.

5.2 Result of reoptimizing

Lens was reoptimized under the analysis method. Narcissus was reduced and energy distribution on the housing was dispersive. Narcissus image is given in Fig. 9, from which it can be seen that energy distribution is uniform.

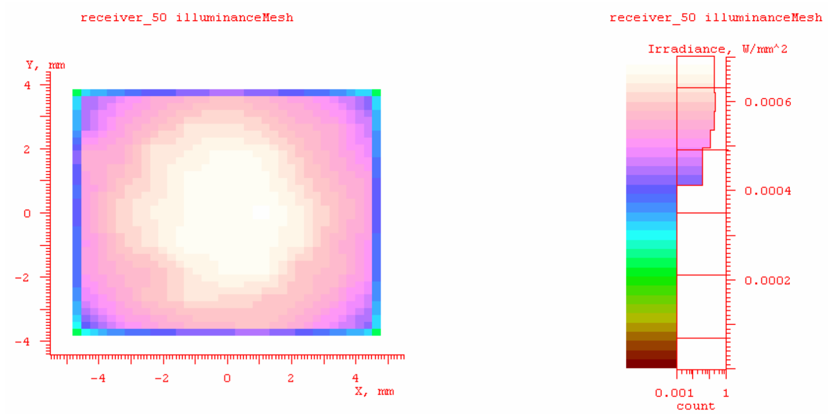


Fig. 9. Energy distribution taking account of retro-refection from all surfaces. Energy density drops to 50% of the former. The energy density on the center is 1.6 times that of the edge and 1.4 times that of the 98% FOV.

6. CONCLUSIONS

Narcissus variation can not be ignored during design of staring IR optics. This paper propose a direct and fast method for Narcissus analysis, which can also be applied to the analysis of stray light emitting from thermal source. Results of the reoptimized system verified the efficiency of the analysis method.

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