IR simulation of missile closing on a moving textured object with a textured background and EO countermeasure

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ABSTRACT

CI Systems has made progress in the quest for ever more realistic simulation of infrared scenes for testing of advanced missiles. This has been achieved by building a completely automatic PC controlled electro-optical system which reproduces a textured object, moving with respect to a background, as it is seen by an approaching missile with a 3 to 5μ FLIR. An independently moving and approaching countermeasure is also present in the scenario. The missile approach is simulated by a 10:1 infrared zoom; the radiance texture of both the object and the background are achieved by an infrared transparency, whose pixel radiance can be chosen from among 256 grey levels.

1. INTRODUCTION

Infrared seekers and payloads are becoming more and more sophisticated, carrying advanced target acquisition, recognition and tracking capabilities; therefore, testing of these expensive seekers is becoming not only more important, but also more difficult to accomplish. In fact, construction of scenarios in simulation must be more and more realistic in order to be useful.

Hardware-in-the-loop simulation by infrared scenarios is a common testing method of missiles, because it is less expensive than field tests. Examples are the work done by Block Engineering group/Contraves Goertz Corp.[1], and a team of Spar Aerospace Ltd. and Defense Research Establishment, Valcartier[2]. The simulators that were built by these groups, project scenes composed of simple shaped objects such as circular apertures moving with respect to uncontrolled background clutter. The most realistic reproduction of a real object done so far is by silhouettes, and the closing of the missile is simulated by opening irises. These methods do not provide the means of simulating a missile closing over a textured object. (By textured object we mean an object on whose surface the radiance varies as a function of position.)

CI Systems has built an IR Scene Simulator (IRSS), which is capable of simulating a 10:1 ratio missile closing on a textured object, moving simultaneously with respect to a textured background, and with a closing countermeasure.

The IRSS operates in the 3 to 5μ spectral range and is completely computer controlled.

The radiance texture of both the background and the object is achieved by special IR transparencies (called Thermoscenes) which are made of matrices of up to 512 x 512 pixels and are placed on the optical path of IR radiation generated by extended area blackbody sources.

The radiance level of all pixels is fixed for each transparency, but is controlled to 256 grey levels. The number of pixels per picture can be increased at the expense of the number of grey levels.

2. SYSTEM DESCRIPTION

2.1. General description

The Infra-Red Scene Simulator (IRSS) is an electro-optic device which creates a semi-dynamic scene, visible to infrared imagers, of a target moving on a background. The target is capable of dispensing a flare while in motion. In addition, the IRSS simulates closing range to the target and the flare, by changing their angular size. The background is static and at infinity: the angular sizes of its features do not change as the missile closes on the target. The entire system is controlled from a PC through a dedicated software program, which is menu-driven and user-friendly.

2.2. System configuration

The IRSS consists of three main units, as shown in Figure 1:

- The Electro-optical Bench Assembly (EOBA), which contains all the optics and the electromechanics used to generate the IR scene.
- The Control Electronics Rack Assembly (CERA), which is composed of all controllers and electronic hardware to drive the EOBA components.
- A personal computer (PC), which contains all the software to build the simulator scenarios and the interfaces to transfer the scenario information to the CERA unit.

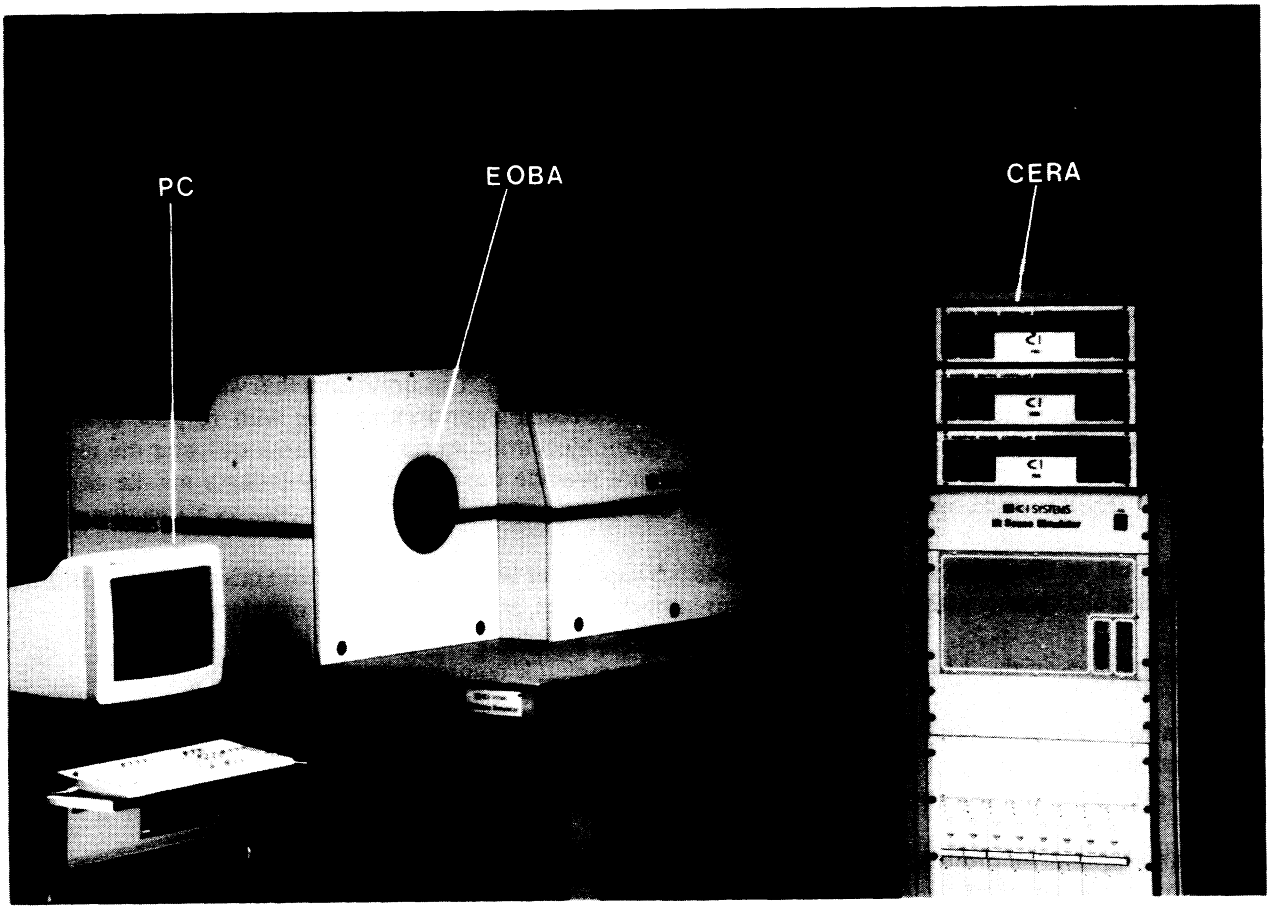

Fig. 1. IRSS general view.

The EOBA consists of four major assemblies, all mounted on the optical table, as shown in Figure 2:

a) The Target Scene Generator (TSG), with zoom optics,
b) The Flare Scene Generator (FSG),
c) The Background Scene Generator (BSG),
d) The Beam Steering Assembly (BSA).

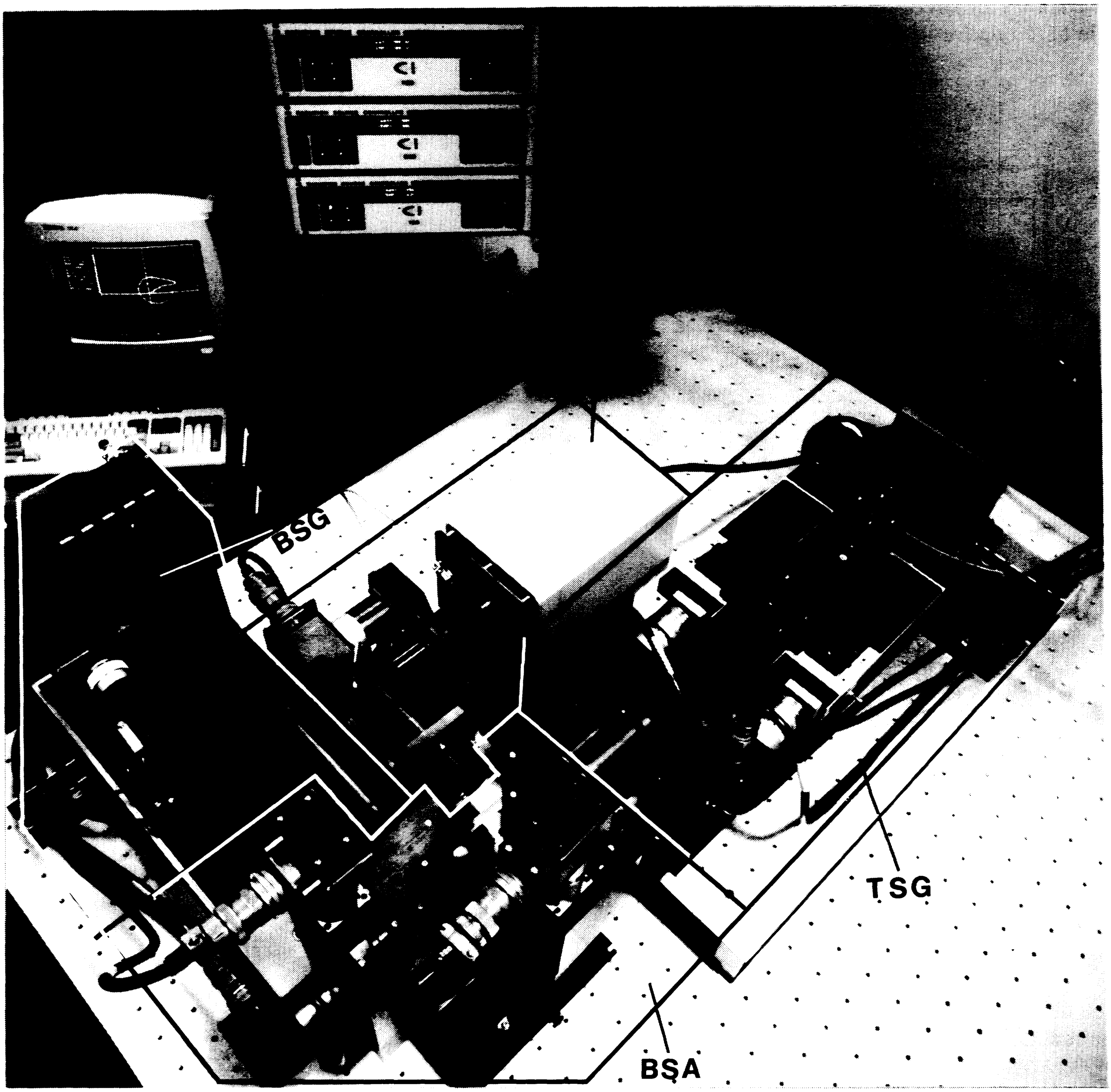

Fig. 2. EOBA general view.

The CERA consists of the following major assemblies:

a) The motor drivers,
b) The motion controllers for all moving components,
c) Blackbody temperature controllers of all three channels (FSG, BSG, and TSG),
d) Shutter controllers.

3. OPTICAL DESIGN

3.1. General Description

The optics consist of three independent optical subsystems: The BSG, the FSG and the TSG. Two beam splitters, each of them with two rotational degrees of freedom, located at the region of collimated beams, perform two functions: i) they combine all three scenes into one, and ii) they steer the target and flare scenes together relative to the background, and the flare relative to the target scene. The optical block diagram is shown in Figure 3.

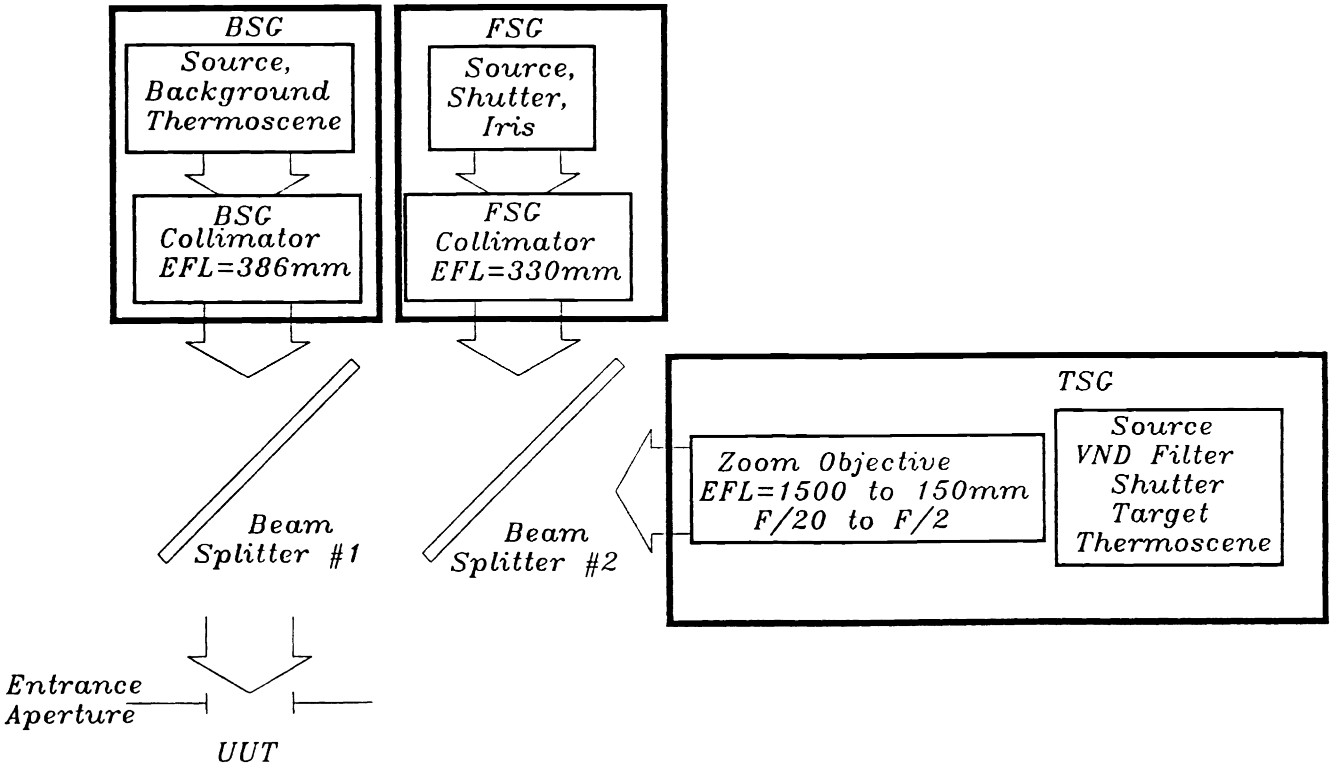

Fig. 3. Optical system block diagram.

3.2 The BSG Collimator

The design of the BSG collimator is based on an achromatic doublet, and a field corrector lens. The corrector lens is required mainly to flatten the focal plane, on which the Thermoscene is placed.

The plane of the exit pupil is placed outside the EOBA, so that the UUT optical aperture can be placed on it. The aperture diameter of the collimator is determined by the size of the exit pupil and by a requirement of zero vignetting at the edges of the field.

The collimator is well corrected for the spectral range of 3 to 5 μm. The performance of the BSG Collimator is close to the diffraction limit over the whole FOV at the relevant spectral frequencies. This can be seen in Fig. 4 in which the optical layout, ray tracing and the optical MTF of the collimator are shown.

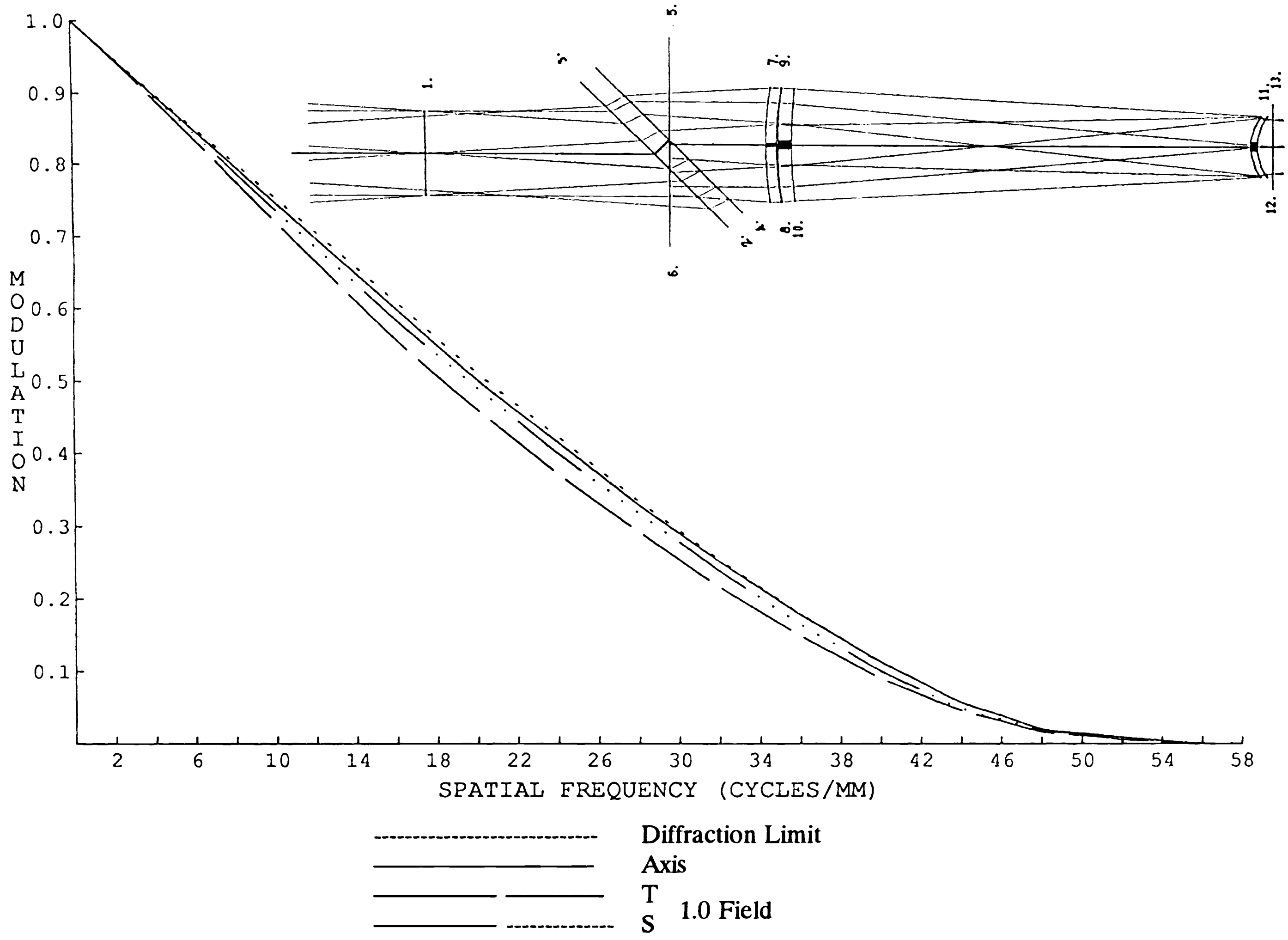

Fig. 4. BSG collimator layout, ray tracing and MTF.

3.3. FSG collimator

The FSG collimator consists of an achromatic doublet. It is fully corrected for the spectral range 3-5 μm. Fig. 5 shows its layout, ray tracing and MTF. The exit pupil is placed coincident with the BSG exit pupil. The aperture diameter of the collimator is determined by trade-offs in which the size of the exit aperture, depth of focus, beam wander on the doublet and vignetting at the extreme countermeasure positions are involved.

In conclusion, the FSG collimator also gives close to theoretical performance throughout the full spectrum and field of view.

3.4. TSG zoom system

3.4.1. Design considerations

The zoom system has several unique features derived from its specific function as a projecting optical device in the simulator. Existing commercial zoom objectives are designed as imaging devices in observation or camera systems, whereas in our case it is used as a projector of radiation: therefore we had to develop an original one tailored to our specific application.

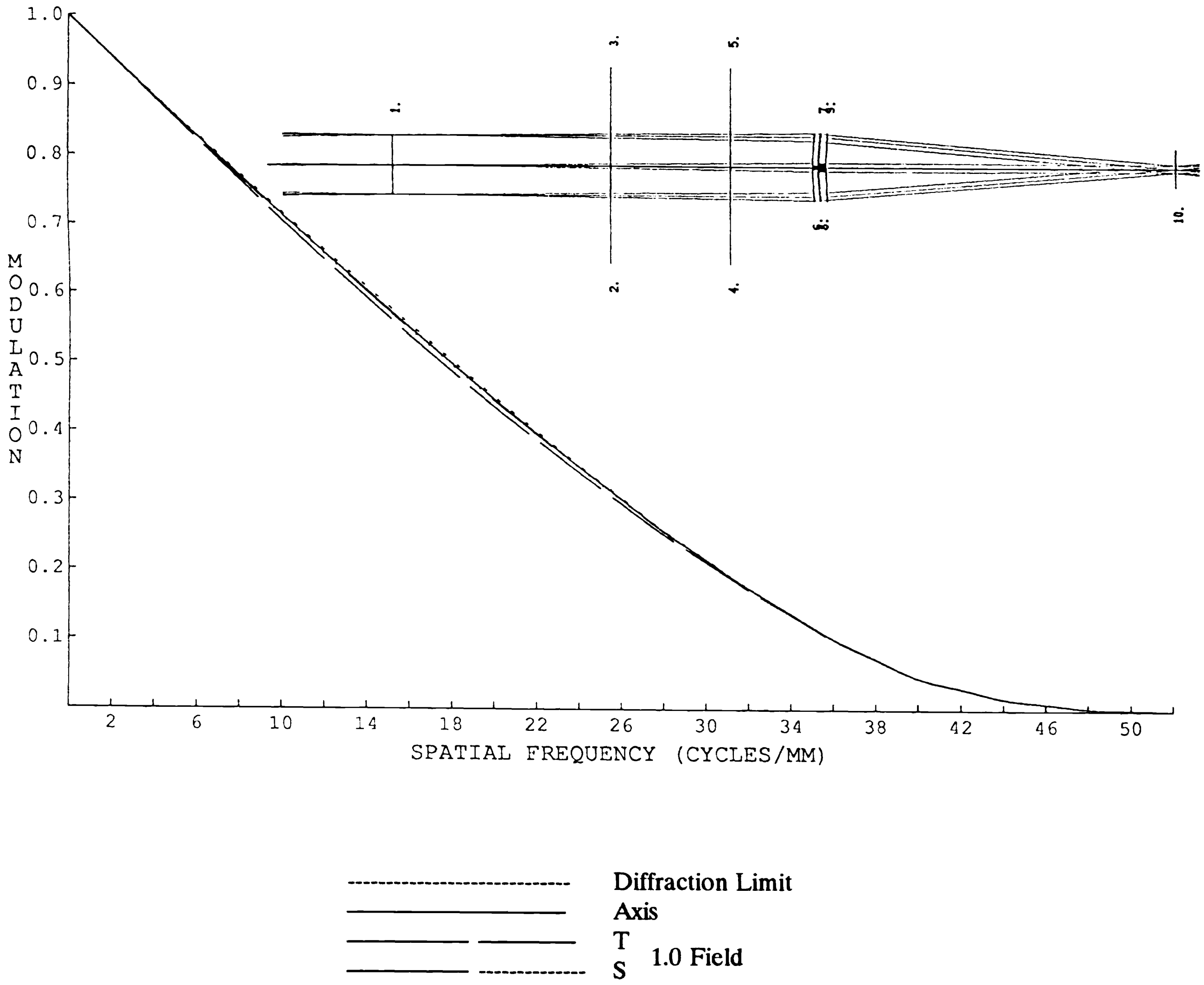

Fig. 5. FSG collimator layout, ray tracing and MTF.

The basic requirements of the design are:

a) the zoom exit pupil must be on the UUT, to minimize optics size: this is due to the so called "beam wander" on the optical elements, which is present when there is beam scanning;
b) the exit aperture must be constant throughout all the zoom positions in order to fill the UUT entrance pupil with the projected image at all times.
c) the total number of optical elements must be kept to a minimum, in order to keep the radiation losses to a reasonable level: this is difficult, considering the zoom ratio of 1:10.

As a result, we have both an f# which varies with the Effective Focal Length (FFL), and a stationary intermediate real image plane.

This image plane introduces inherent, unavoidable, field curvature. The most one can hope is to reduce it to a tolerable value. However, the existence of this plane has a positive consequence as well. In fact, it allows us to decouple lens groups II, III, and IV from group I and to relax the coaxiality tolerance between them.

Because of the large zoom range, there are problems at the two extremes: at the longer focal lengths, there is significant longitudinal chromatic aberration, while the short focal lengths suffer from field curvature.

3.4.2. General zoom construction and description

The TSG zoom belongs to the class known as 'mechanically compensated' to be distinguished from 'optical compensation'. The synchronized movement of the two groups of lenses that perform the zoom effect is achieved by electro-mechanical means.

The zoom consists of four separate groups of lenses, as shown in Fig. 6, which also shows the TSG zoom at three different positions. It will be described below starting from the UUT towards the blackbody, as it was designed. The radiation actually proceeds in the reverse direction, from the blackbody towards the UUT. The performance of the zoom is shown in Fig. 7, depicting the MTF curves at three different zoom positions: 150 mm, 535 mm and 1500 mm EFL.

Group I has two optical functions:
(a) to form an intermediate real image,
(b) to form a virtual image of the UUT entrance pupil inside the zoom mechanism.

This group is composed of a large front air-spaced doublet and a meniscus, and is of course optically positive.

Group II and Group III form together the 'zoom machine' that re-images the intermediate real image onto a virtual image, whose distance from the focal plane is constant, but with variable magnification. This virtual image is located inside Group IV. The variation of magnification is obtained by moving the "Leader", Group II, and compensating for the image shift by the "Follower", Group III. Group II's motion is monotonic, meaning that it moves only in one direction for increasing EFLs, from the shortest to the longest value, while Group III, reverses its direction once (see Fig. 6).

Group II is positive and is composed of two juxtaposed lenses, one of them having the only aspheric surface in this design.

Group III is composed of two air spaced lenses and is negative.

The distance separating Groups II and III goes through a minimum which obviously must have a non zero value.

Group IV is the last image forming portion of the zoom, and has a triple function:
(a) to finalize the exact EFL,
(b) to leave an adequate Back Focal Length (BFL), and
(c) to compensate for residual aberrations.

It is negative, and is composed of two air-spaced lenses.

Figure 8 shows a general view of the TSG.

4. TEXTURED OBJECTS AND BACKGROUND

The common way to generate object images with IR Simulators is by approximating the object with a simple geometric shape[1,2]. This is done by using square, circular or triangular irises which, when placed in front of a blackbody emitter surface, and on the focal plane of a collimator, form simple silhouettes seen by the UUT as though they came from infinity.

These irises have not only simple shapes, but also have uniform radiation distribution within them, and cannot simulate the texture of a real object. Therefore the type of testing that can be done with them is limited.

In order to overcome this limitation, we have developed a proprietary technology, which allows building realistic images of objects and backgrounds, with arbitrary distributions of infrared radiation as a function of pixel position. The technology involves a complex multi-stage deposition process of material on infrared transmitting substrate.

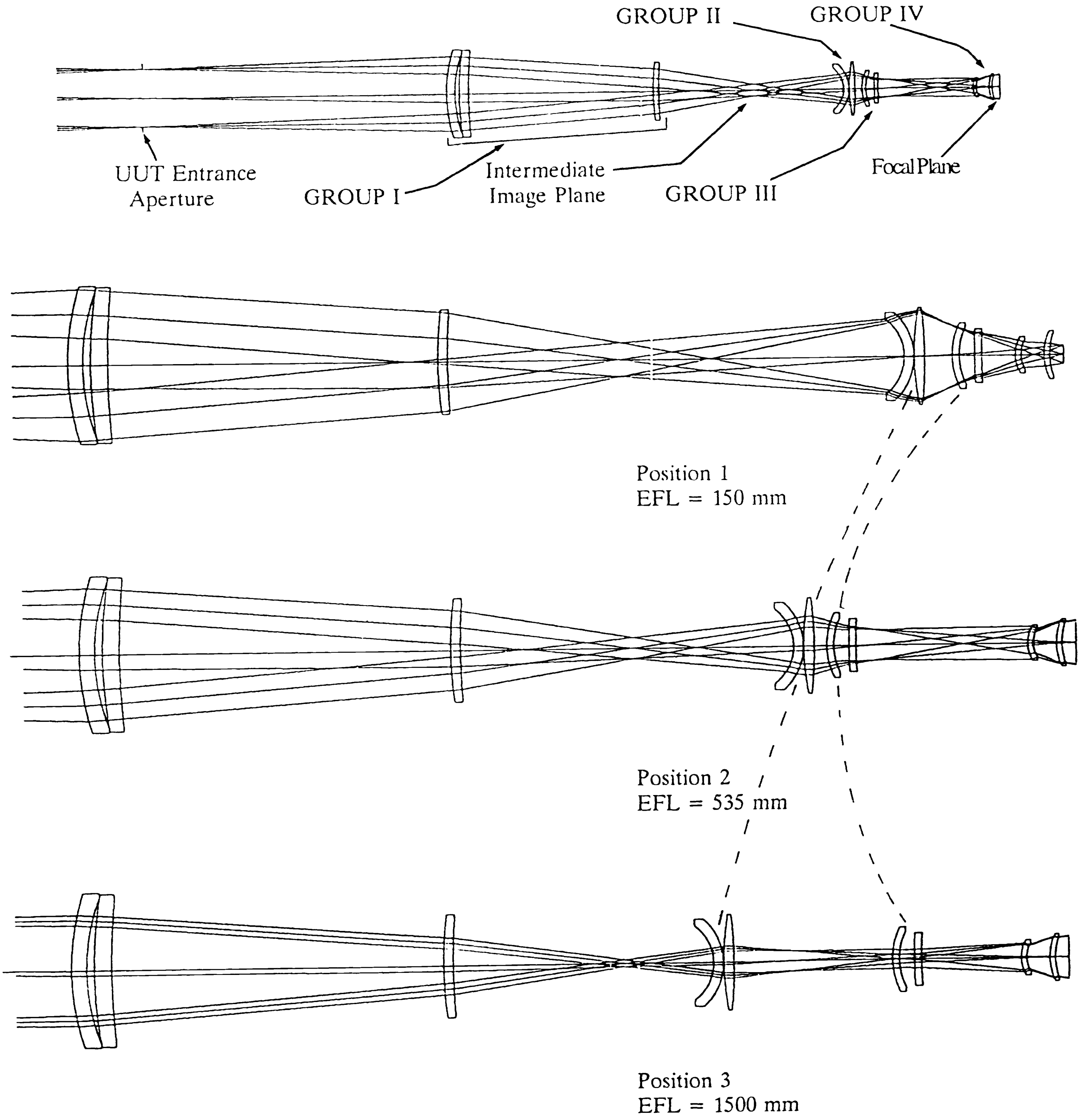

Fig. 6. TSG zoom objective: layout and ray tracing.

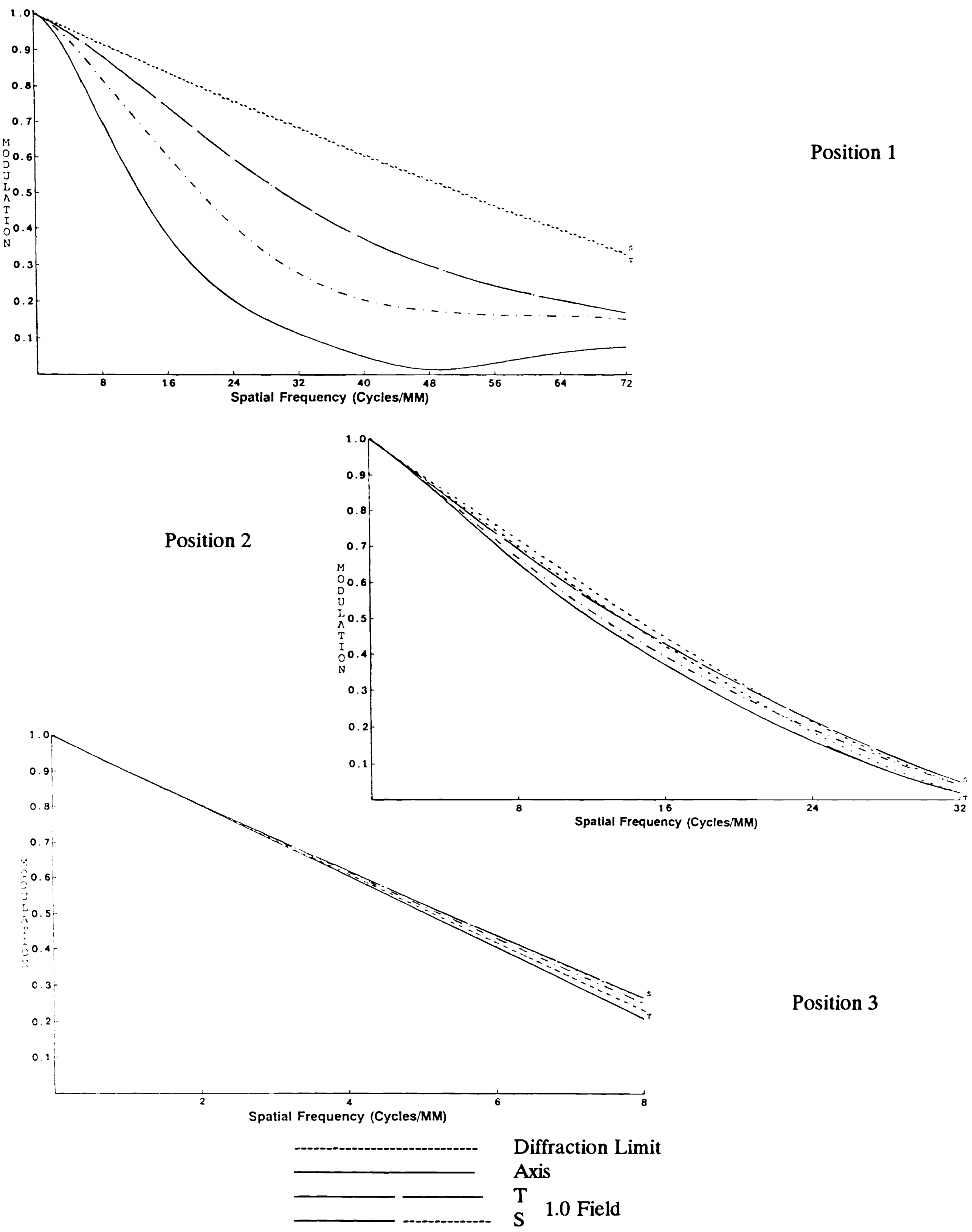

Fig. 7. TSG zoom MTF for three positions.

The device produced using this technology is called Thermoscene, and acts as an IR transparency; when placed in front of a blackbody emitter, it produces the desired scene.

Considering that: i) a typical Thermoscene pixel is a square of 68 x 68μm size, ii) the brightness of the pixel is proportional to the area of "non-coverage" of the deposited metal on the pixel itself, iii) and the smallest hole size into which the pixel is subdivided is 4μm, then 289 different grey levels are obtained.

$$\left(\frac{68}{4} \right)^2 = 289$$

This is equivalent to subdividing each 68 x 68μ pixel into a 17 by 17 subpixel matrix, each of which is 4 x 4μ size. Each subpixel may be either transparent or blocked to the IR energy, thus controlling the total transmittance of the pixel itself. In practice, the number of grey levels is reduced to 256 for convenience of digital definition (8 bit).

5. MECHANICAL CONSTRUCTION

5.1. The background scene generator

The BSG generates a stationary background image from infinity. An infrared radiation source and a Thermoscene, mounted on a motorized, computer controlled wheel, are placed on the focal plane of the BSG Collimator, which projects the scene towards the UUT. The dynamic scenario of the target and flare are superimposed on this background scene.

5.2. The flare scene generator

The FSG simulates the ejection of an electro-optical countermeasure, basically a flare, from the target, during the scenario simulation. The FSG consists of a high temperature cavity blackbody, with a shutter and an iris. The iris has a circular aperture and its diameter varies to simulate the change in the subtended angular size of the flare due to missile closing. The iris is located on the focal plane of the FSG collimator.

5.3. The Target Scene Generator

The TSG is the major and most complex assembly of the IRTG, whose role is to project the target and to change its angular size. It contains a blackbody as a radiation source and the target itself, generated by a Thermoscene. The Thermoscene is placed on the focal plane of the zoom system. Between the Thermoscene and the blackbody there is also a computer controlled variable neutral density (VND) filter, designed to change the radiance of the target, in order to simulate variations in the atmospheric attenuation. A shutter controls the timely appearance and disappearance of the target, and a condenser lens allows convenient positioning of the blackbody relative to the Thermoscene. Fig. 8 is a "close up" view of the TSG.

5.4 The Beam Steering Module

The BSM consists of two beamsplitters, which combine the various IR beams projected by the three different collimators. The first beamsplitter (BS #1, shown in Fig. 3) combines the images of the background with the combined target and flare image, while the second beamsplitter (BS #2, shown in Fig. 3) combines the flare image with the target image. Both beam splitters are mounted on two rotational degrees of freedom pedestals, to enable the movement of the flare and the target, relative to the background, within the whole FOV.

6. CONTROL ELECTRONICS

Fig. 9 is a block diagram of the IRSS electronics. As illustrated in the figure, a PC controls all temperatures of the sources and movements of the optics through standard electronic interfaces.

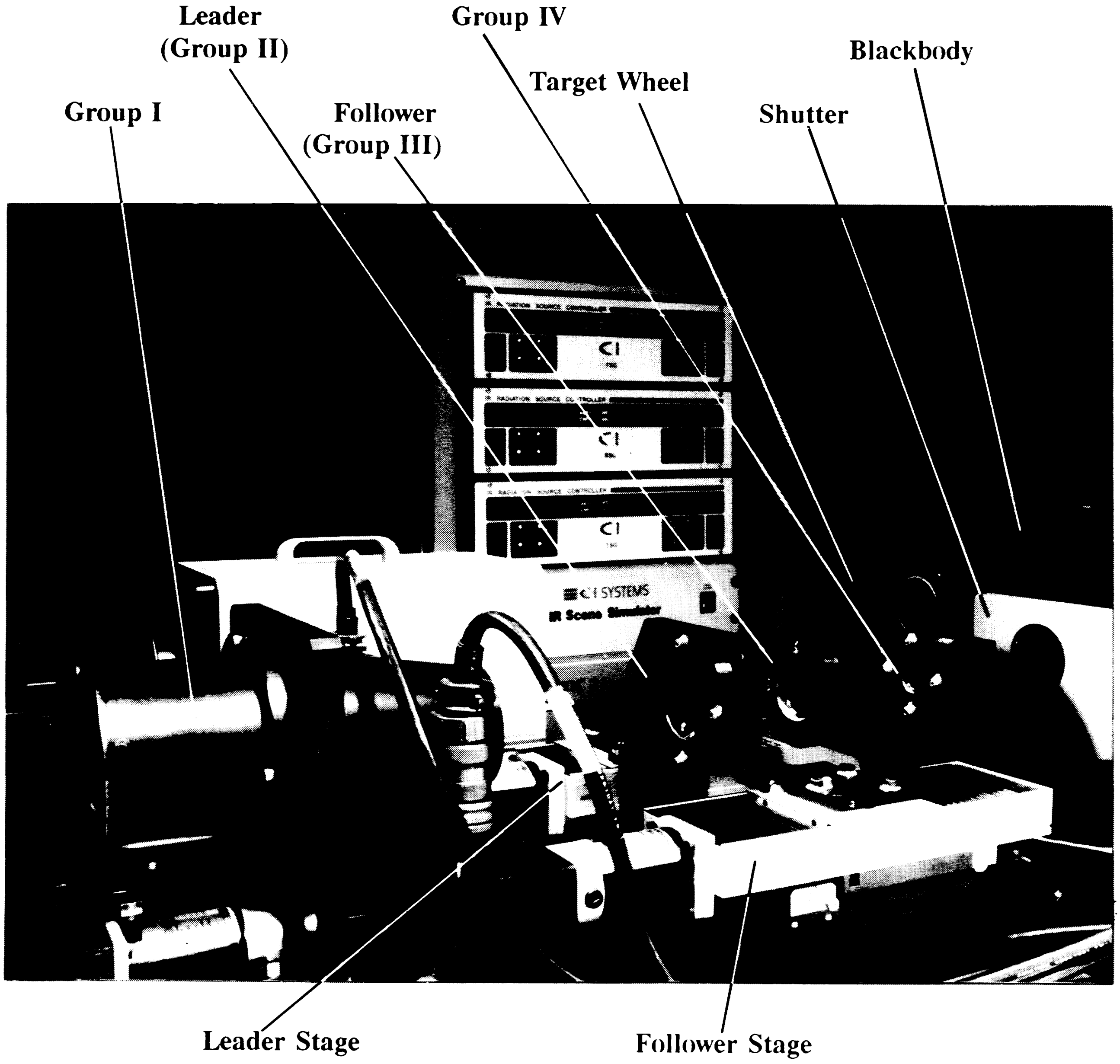

Fig. 8: TSG general view (excluding the VND filter)

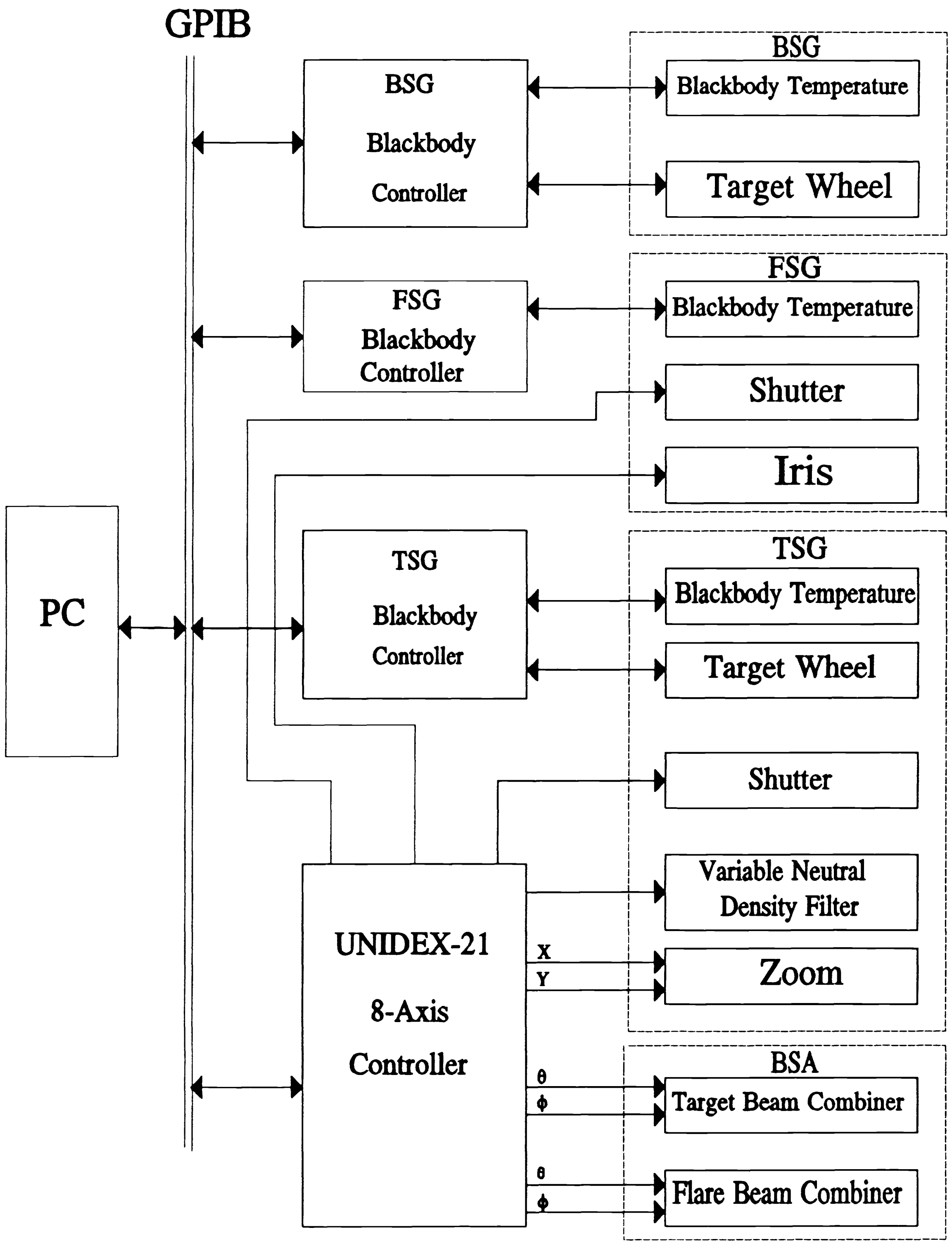

Fig. 9: IRSS Electronic & Communication Block Diagram

7. SOFTWARE

The IRSS software consists of six main functions: a) FILE, b) SCENARIO, c) RUN, d) REPORT, e) MANUAL, and f) SET-UP.

The FILE function enables the operator to build and store a new scenario or to select a previous scenario. These files contain all the information necessary to run the simulation. Other file operations such as choice of Lowtran for atmospheric transmittance are also possible.

The SCENARIO function is used to specify all the initial conditions of the simulation and the behavior of the target and flare in each step of the simulation.

The initial conditions are the background temperature, background scene and target choices, flare temperature and size, initial target range, missile closing velocity, target coordinates and graphics simulation format.

Step parameters consist of a sequence of linear or circular motion parameters, which , when run together, create a scenario in which the target and flare move in different predetermined trajectories and speeds. The atmospheric transmission, which changes with range, can also be used as part of the scenario.

The RUN function executes the simulation scenario. The user can check the scenario before the actual run, by running it as a graphic simulation, and then he can send it to the simulator control unit for execution.

The REPORT function is used to display or print the current scenario or atmospheric transmission. These data are displayed and/or printed in a tabular form.

The MANUAL function is useful to control any of the three scenes (target, flare and background) and all the scenario parameters manually. It can also be used for static UUT tests.

The SET-UP function is used to align and calibrate the simulator.

8. CONCLUSION

CI has made significant progress in realistic IR simulation for testing of advanced sensors. Very advanced IR zoom optics, infrared transparencies of textured objects, and the integration of several optical channels with dynamic beam combination, are the technological basis of this new system.

9. REFERENCES

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