Missile warning and countermeasure systems in-flight testing, by threat simulation and countermeasure analysis in the field

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ABSTRACT

Proliferation and technological progress of Mid Wave Infrared (MWIR) sensors for Missile Warning Systems (MWS)[1,2] and increased sophistication of countermeasures require demanding in-flight testing. The IR sensors are becoming more sensitive for longer range of detection, the spatial resolution is improving for better target detection and identification, spectral discrimination is being introduced for lower False Alarm Rate (FAR), and the imaging frame rate is increasing for faster defensive reaction. As a result, testing a complex MWS/countermeasure system performance before deployment requires more realistic simulation of the threats in their natural backgrounds, and faster measurement of the radiometric output, directionality and time response of the countermeasures. Existing stimulator systems for MWS testing during R&D and production can only be used in the laboratory, and cannot reproduce the flight conditions with natural backgrounds faithfully enough, so that it is possible to rely on them for the most sophisticated MWS' testing.
CI has developed a unique integrated MWS/countermeasure test system, to test the MWS and countermeasure in-flight. The test system is field deployed, to produce natural backgrounds, and it is composed of: i) high intensity dynamic Infrared Threat Stimulator (IRTS), based on large optics and high speed shutter for time dependent scenario construction and projection to several kilometers; ii) fast response IR Jam Beam Radiometer (JBR) for countermeasure testing. The IRTS/JBR system uniquely tests the MWS/countermeasure combination: efficiency range, probability of detection, reaction time, and overall well functioning[2] can be determined in-flight through projection of threat profiles prepared in advance by the user, and through measurement of the countermeasure IR radiation output as function of time.
Design, performance, and example of operation of the IRTS/JBR are described here.

Keywords: Infrared Missile Warning Systems testing, Infrared Countermeasure testing

1. IRTS DESIGN, MAIN FEATURES AND ADVANTAGES

IR stimulators for laboratory use were built in the late '90's[1,3,4] for Hardware-In-The-Loop testing (HITL). Reference 2 is a review of the most important parameters which are to be detected and measured in a real engagement situation in order for the MWS to distinguish between a threat and its background with high confidence, and analyzes the performance of the existing sensor technologies vis-à-vis those parameters. It is shown there that due to the rapid advances of the IR imaging sensors technology, there are indications that 3rd generation infrared Focal Plane Arrays (FPA's), dual band FPA's, and a combination of both 3rd generation and dual band FPA's will be able in the future to improve on the more conventional Ultra Violet (UV) detection technology[5], as far as earlier detection with higher confidence is concerned. As a result, it is likely that the IR spectral range will be the basis for the most advanced Missile Warning Systems (MWS) technology in the near future[2]. As the IR solution will become more popular and advanced, the IR MWS testing needs will also become more widespread and demanding.

CI Systems has responded to this recent shift in MWS testing trend by developing the Infrared Threat Stimulator/Jam Beam Radiometer (IRTS/JBR), a comprehensive field deployed system (in contrast to the existing laboratory based stimulators) that is able to test, not just the ability of the MWS to detect the threat and recognize it as such, in-flight, but also the performance and well functioning of its defensive reaction. The IRTS is stationary on the ground, and it closely mimics the IR emission of a missile after launch as it is measured and detected by a MWS. This is done by stimulating the MWS with realistic threat intensity values and time behavior within a natural background environment, while the MWS is flying in the aircraft, and automatically operates a dedicated IR radiometer (JBR) to measure the resulting

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radiation output of the IR countermeasure. An IRTS/JBR system mounted in the field as shown in figure 1 is typically used at a distance of a few kilometers from a flying aircraft equipped with an MWS/countermeasure system.

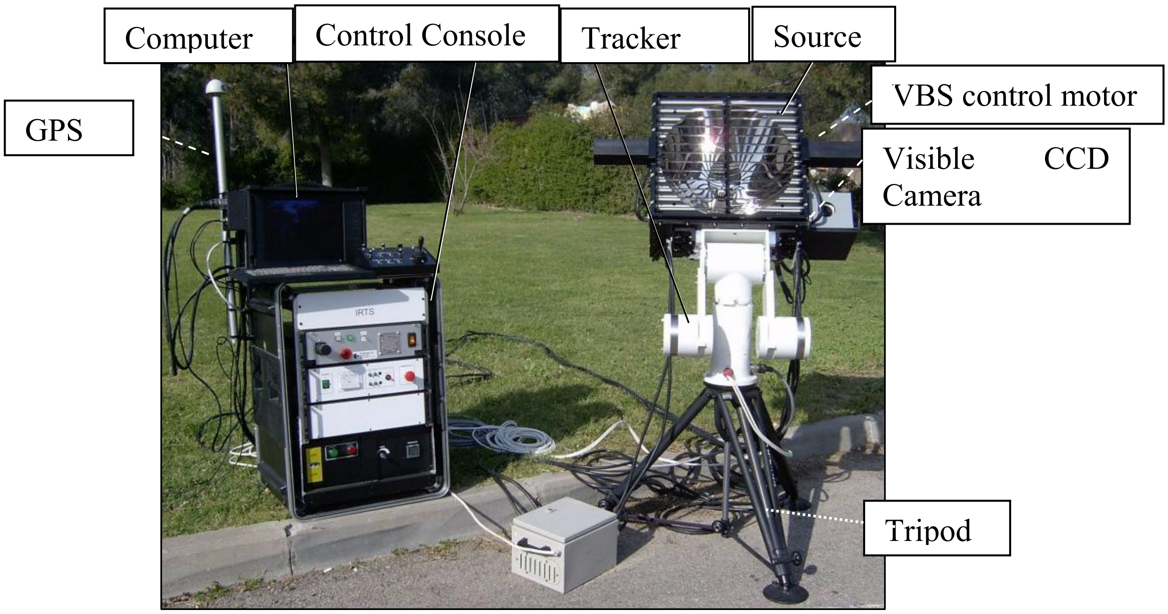

Figure 1: General view of the Infrared Threat Stimulator (IRTS) system, being used in the field to test an IR MWS during flight. The dedicated IR radiometer for countermeasure testing is not shown in this image.

The amount of infrared radiation emitted by the IRTS source can be controlled so that when it reaches the aircraft it is of the same intensity as of a missile at a distance of up to 5 Km. from it. The presence of a natural background due to the field deployment instead of a lab set-up, and the fact that both the MWS and countermeasure are flying in the aircraft during the test, makes this simulation of ground-to-air attack more similar to real mission conditions than achieved so far with other methods. To test an MWS in an air-to-air attack, the IRTS/JBR system can be modified to be mounted on a second aircraft, for a simulation which is more suitable to this situation.

The most important design guidelines for the IRTS are that it should fulfill the testing requirements of the present and future IR MWS'. The central item, around which the instrument is designed, is the infrared source, composed of a hot radiating element and reflective projection optics. The amount of projected intensity in the useful wavelength range (2 to 5 μ), its wide wavelength and angular distribution, and characteristic time behavior are of fundamental importance for highly realistic simulation scenarios. The first parameter must be of a value which is close to the actual radiant intensity emitted by the threat, by taking into account the fact that the distance between the aircraft and the IRTS is in general different than between the aircraft and the missile. The angular distribution of the projected intensity must be uniform over a solid angle dictated by the ratio of the typical variations in position of the aircraft during the test and the distance from the IRTS, in order to avoid loss of signal. The time behavior must be fast enough to be able to faithfully reproduce the short burst of the missile ejection and subsequent boosting stages (the approaching stage has less stringent time requirements). All the rest of the hardware is to support and control the operation of the source.

1.1. User interface screen

In figure 2 the IRTS user interface screen is shown. The screen includes three main areas: i) The threat IR emission scenario, ii) the CCD image for test configuration recording area, and iii) the scenario control inputs and reports area.

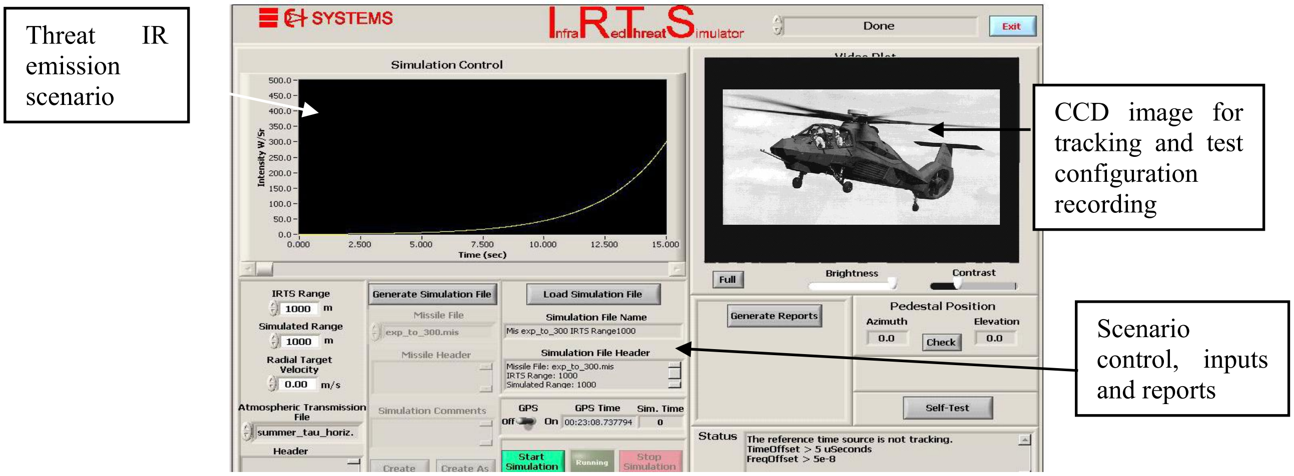

Figure 2: IRTS user interface screen. The threat IR emission scenario area shows the missile emission scenario as it is built by the user, with usually a first burst at launch and then a fast intensity increase during approach. The CCD image area shows the image of the platform being tested in real time, for tracking and test recording, and the scenario control, inputs and reports area is used to key-in the scenario parameters in the software, and to produce the reports.

1.2. System configuration

As seen in figures 1 and 3, the IRTS/JBR system is composed of the following subsystems:

1. The Source is a special filament on the focal plane of a parabolic reflector, in front of which is a Venetian Blind Shutter (VBS), made of a set of 13 simultaneously rotating and parallel slats that controls the projected intensity, similar to a Venetian blind. The shape and orientation of the filament in the focal point of the reflector has been optimized for most uniform angular distribution of a maximum projected intensity of 350 W/steradians within a circular solid angle of 6 degrees diameter, and an angular uniformity of 90% within a smaller solid angle of 2 degrees diameter. The filament temperature is set at the beginning of the simulation scenario to 1800 C, which gives maximum projected intensity. The maximum intensity is achieved with the Venetian blind slats in the "open" position, i.e. the slats plane parallel to the projected beam direction. Variation in the projected intensity is achieved by rotating the slats around their longest axis, so that the minimum (zero) intensity is achieved with the slats in the "closed" position, i.e. their plane perpendicular to the beam direction, and any intermediate intensity can be achieved by all the intermediate slats positions. A calibration look up table of intensity versus slats rotation angle is built in the factory by radiometric measurement of the IR output, and stored in the memory of the computer in a special file. The provided software program enables the operator to construct the projected IR intensity versus time profile, which is then converted into a slats rotation angle versus time profile, through the look up table previously built. When running the simulation scenario, the computer runs the slats rotation angle time profile by controlling the VBS control motor (see figure 1). The minimum time for full close to open transition is 15 milliseconds (10 in the enhanced mode), and the refresh time resolution for the intensity values is 8 milliseconds (5 in the enhanced mode). Here the limitation is due to the mechanical properties of the slats-motor combination, and is fast enough for most MWS sensors. 120 Watts is the power consumption of this Source at maximum temperature.

2. The Visible CCD Camera (figure 1) is mounted on the same pedestal as the Source and is optically aligned with the Line of Sight (LOS) of the projection optics, to track the platform and to visualize and record the platform scene during the test, for later analysis.

3. The Jam Beam Radiometer (JBR), mounted on the same pedestal as the Source (shown in figure 3), is boresighted with the Source and is used to measure the countermeasure coded output, to insure its performance and well functioning. The JBR may be equipped with a dedicated CCD for independent alignment and convenient viewing of the countermeasure on a separate screen.

4. The Tracker uses the Visible CCD Camera to enable the automatic alignment of the Source on the flying aircraft platform at all times, thereby insuring continuous illumination of the platform by the IRTS during the test, as the platform moves in space.
5. The Tripod, on which the Tracker, Source, JBR and Visible CCD Camera are sturdily mounted.
6. The GPS, for time and position recording. The GPS can be used to synchronize the simultaneous testing of several MWS' on the same platform with a number of deployed IRTS'.
7. Control Console, Computer and Software for the operation, control and data recording of the Source, CCD Camera, Tracker and GPS according to user designed scenarios.

Figure 3: Diagram of the IRTS Source, reflector and VBS, accompanied by the JBR and the Visible CCD Camera

1.3. The Source

The Source, as mentioned above, is a hot filament placed on the focal plane of a parabolic mirror, and behind a set of rotating slat shutter, as in figure 4.

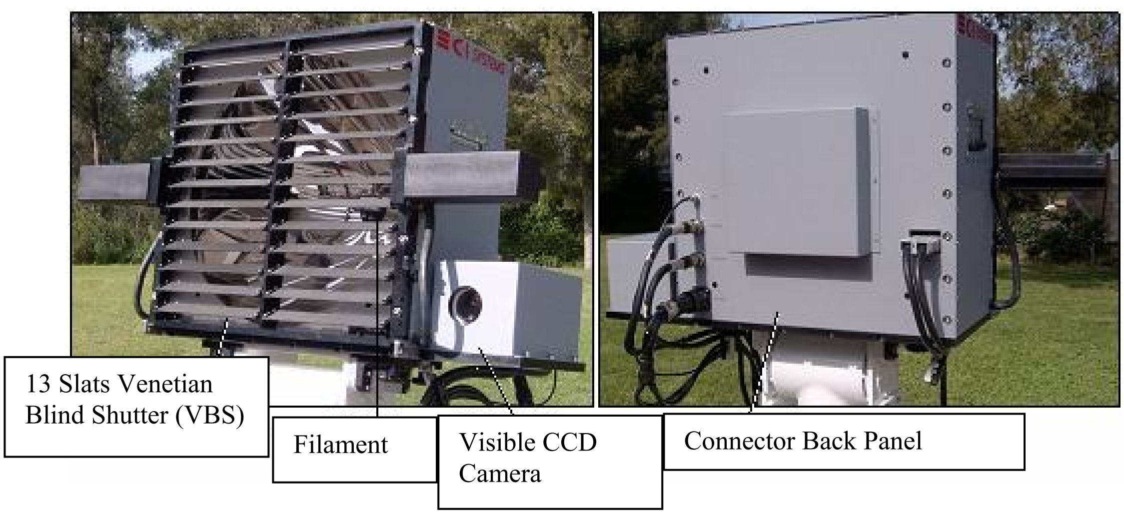

Figure 4: The Source and its components.

The source is a special thick filament, designed to be heated up to 1800 C without appreciable oxidation, for long life time. The optics is a replicated parabolic reflector of 20" diameter and 2.35" focal length.

Full analysis of spatial and angular distribution of the radiation was performed for different theoretical source shapes: spherical and ellipsoidal of different sizes. A high quality off-the-shelf component was then selected to approximate the best theoretical results, as far as intensity and spatial distribution of the IR radiation are concerned. Figure 5 shows a head-on photograph of the projector at full source intensity.

Figure 5: Filling of the parabolic reflector surface by the Source radiation. It is shown that the surface is not 100% uniformly illuminated: this is due to the discrete shape of the Source filament surface, which causes a periodic obscuration of loops of the filament. This lack of uniformity is not important in practice, since the surface area of the projector does not fill the field of view of an MWS pixel.

The angular distribution of the projected radiation is shown in figure 6, as measured with the SR 5000 IR spectroradiometer of CI.

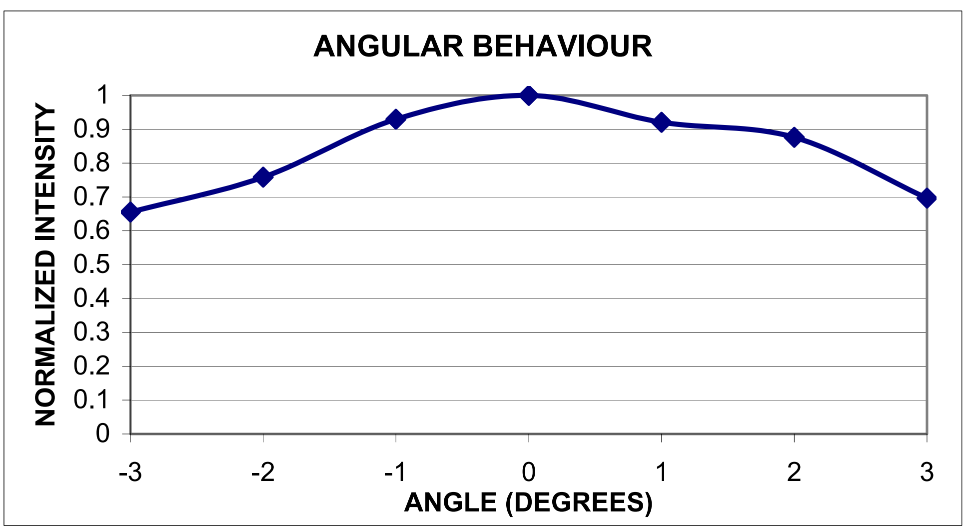

Figure 6: Angular distribution of the projected infrared radiation, as measured by the CI SR 5000 IR spectroradiometer in the range ±3 degrees. Good uniformity in a central region of 2 degrees is observed, with more than 90% of maximum intensity.

The calibrated spectrum of the IRTS is shown in figure 7 in absolute radiance units of Watts/(cm^2.sr.µ), as measured with the SR 5000 IR spectroradiometer of CI.

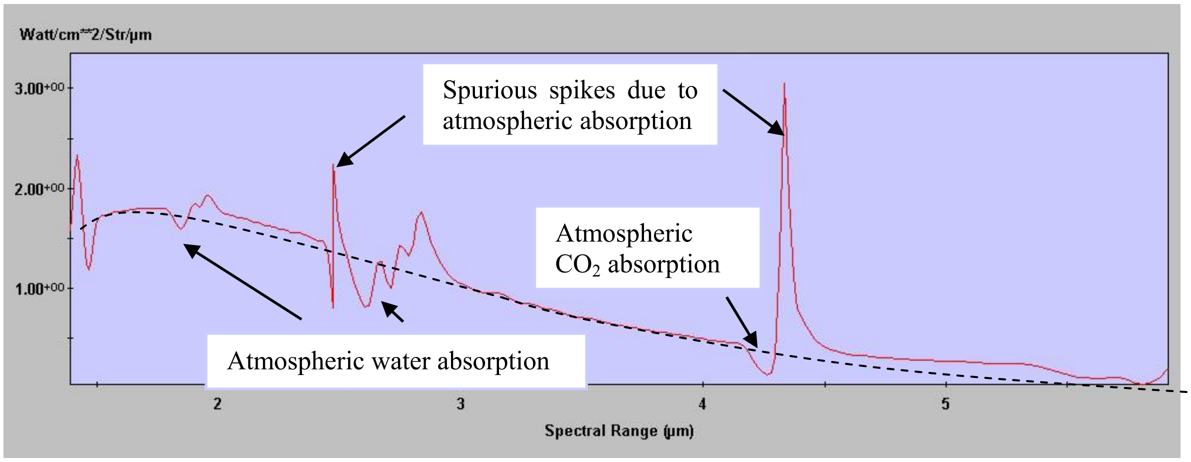

Figure 7: Calibrated spectral radiance of the IRTS emittance (typical). The spikes at 2.5 and 4.3 µ are spurious, and are due to loss of significant figures in the calibration algorithm because of high atmospheric absorption at those wavelengths. The maximum of the dashed curve at approximately 1.7 µ shows an equivalent blackbody temperature for the filament of 1700 Kelvin.

Figure 8 shows the time behavior of the calibrated radiometric signal at maximum opening-closing speed of the VBS, also measured with the SR 5000 spectroradiometer.

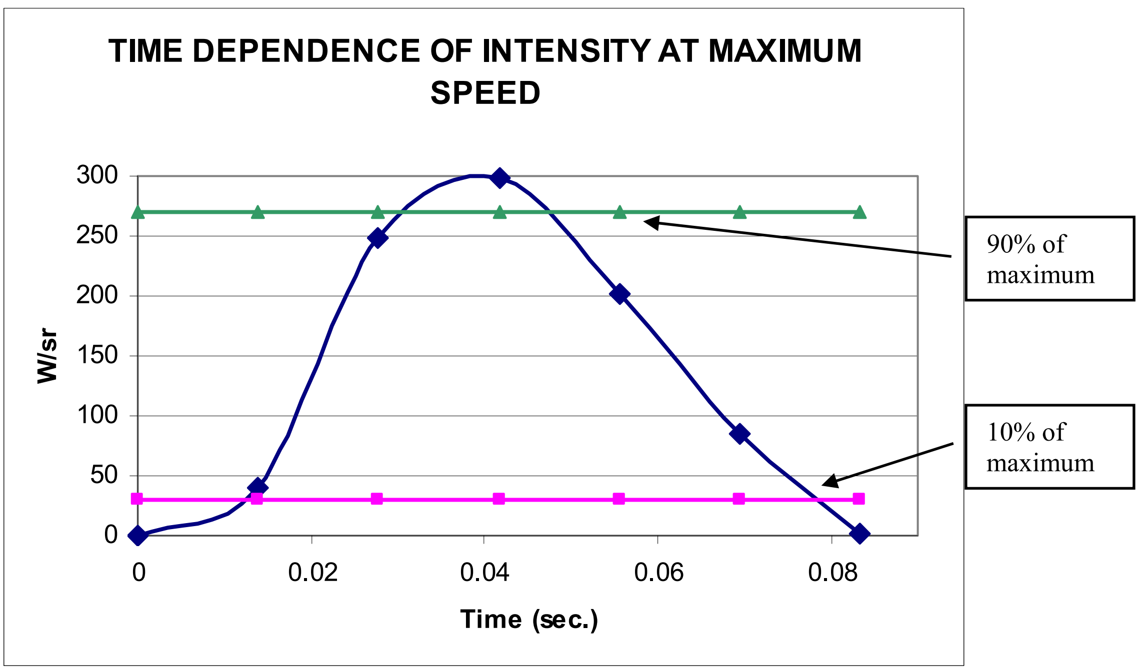

Figure 8: Time dependence of the radiometric intensity signal for full close to open and open to close settings, measured with the SR 5000 spectroradiometer. The measurement is done with internal chopping and synchronous detection filtered at 300 Hz.

The times between 10% and 90% of maximum signal are seen in figure 8 to be about 15 msec. for the rising side and 30 msec. for the decaying side. We are working on decreasing these times to 10 msec. The 300 Hz filtering of the measuring radiometer used, only contributes a small fraction of the total measured time VBS constant.

Figure 9 shows the IRTS projecting three different intensities at three different positions of the Venetian Blind Shutter.

(a) (b) (c)

Figure 9: (a) VBS closed: minimum intensity, (b) VBS partially open: Intermediate intensity, (c) VBS open: Maximum intensity.

Figure 10 shows the IRTS emission as seen by an MWS FLIR, mounted on a flying helicopter. The IRTS is mounted like in figure 1 in the field on the slope of a hill, so the image shows the natural background similar to a typical battlefield.

(a) (b)

Figure 10: IRTS emission as seen by an MWS FLIR mounted on a helicopter in flight: (a) IRTS source off, (b) IRTS source on.

1.4. Other features

Following are other important features of the IRTS/JBR source:

- Ranges between 200 m. and 5 Km. can be simulated,
- A software tool is provided for the user to build his complete scenario for different missiles,
- Atmospheric transmittance can also be taken into account when building the simulation scenario, by using MODTRAN,
- Prepare and run a sequence of profiles by batch file,
- Synchronize a number of IRTS heads and have them operate in unison or sequence, by a provided GPS,
- Simulate different missiles,
- Simulate dual or multiple color emissions.

2. THE JAM BEAM RADIOMETER (JBR)

The integration of the IRTS source with the JBR sensor in one system allows the efficient testing of the whole MWS/countermeasure suite by one single test system. In this way, for example, as soon as the IRTS source has been detected and recognized as a threat, the JBR measures the intensity and time dependence of the activated countermeasure. One important parameter that can be measured is the maximum distance at which the countermeasure is effective, if the threshold intensity for successful defense is known. Therefore, the JBR measures and tests the performance and well functioning of the defensive reaction, represented by a DIRCM (Directional IR Countermeasure) and other or similar means of missile deflection or destruction, in the field, immediately after the stimulation of the MWS. The JBR is mounted on the same pedestal as the projection optics and tracking CCD (see figures 1, 3 and 4). CI has developed two JBR configurations: single and dual band. The former measures only one wavelength band and has a cost and size advantage, while the latter measures two wavelength bands simultaneously with the same boresighted fields of view and therefore has a spectral discrimination advantage.

Figure 11 shows the optical head of the single band JBR version. In front of the field IR lens, it is possible to mount a bandpass filter and a neutral density filter, at the user's discretion. The system includes a dedicated CCD for autonomous alignment on the target to be measured.

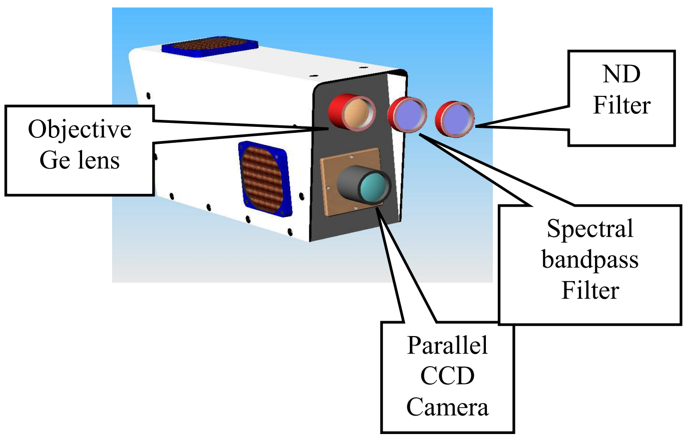

Figure 11: Single band JBR, showing the dedicated CCD, the neutral density and bandpass filters.

Figure 12 shows a schematic optical diagram of the single band radiometer shown in figure 11.

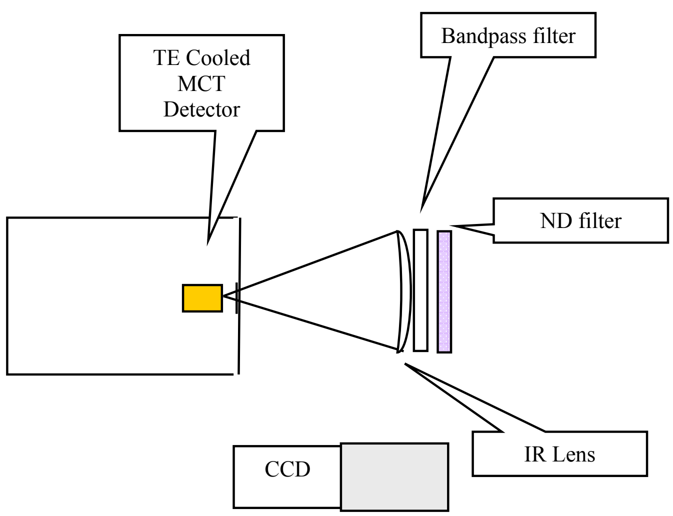

Figure 12: Optical diagram of the single band JBR.

Figure 13 shows the dual band JBR with the cover removed.

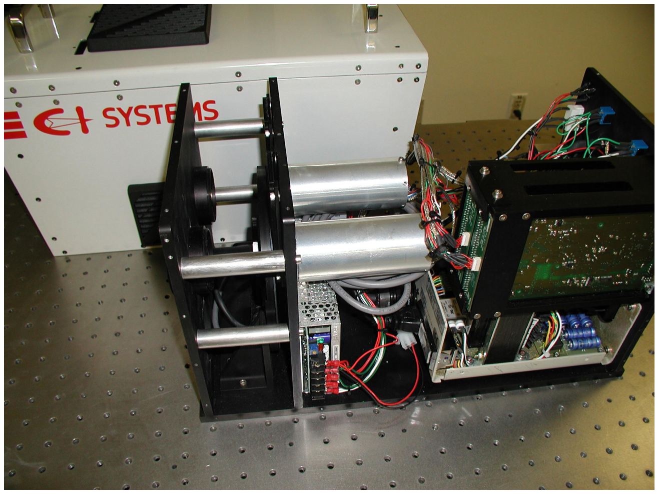

Figure 13: Dual band JBR, showing the interior of the optical head, and in the center, the two cooled detectors.

Figure 14 shows a schematic optical diagram of each detection channel of the dual band JBR.

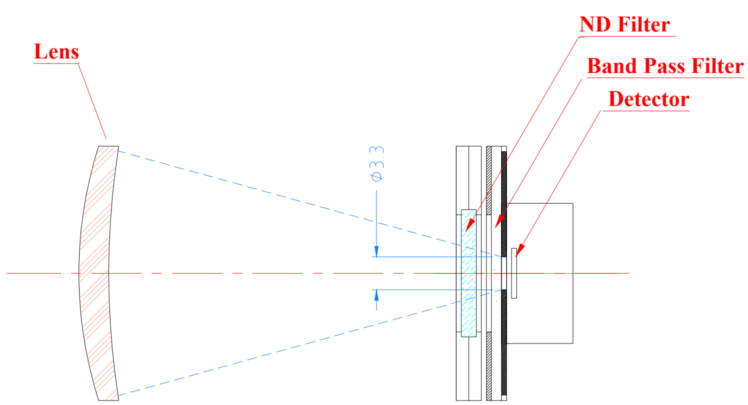

Figure 14: Optical diagram of each of the dual band JBR detection channels.

The dual band JBR has the advantage of measuring in two wavelength ranges simultaneously. This is important if the countermeasure to be tested is designed to emit radiation in the two bands in a predetermined ratio.

The following table summarizes the specifications of the two versions of the JBR.

Parameter	**Single band JBR**	**Dual band JBR**
Detector(s)	TE cooled MCT	Both TE cooled PbSe
Field of View	40 mrad.	35 mrad.
Focal length	25 mm.	76.2 mm.

Clear aperture	11.3 mm.	48.4 mm.
Modes of operation	DC coupled with frequency response to 60 kHz	DC or AC coupled, user selectable
NEI DC mode	N/A	$2\cdot10^{-9}$ W/cm^2, measured at 3 msec integration time. $5\cdot10^{-10}$ W/cm^2, measured at 10 msec integration time.
NEI AC mode	8 10^{-9} at 100kHz	8 10^{-8}
Size of the optical head	30x30x20 cm.	22.5x22.5x46.1 cm.
Weight	< 5 Kg.	< 10 Kg.

Table 1: Most important specifications for the single and dual band JBR's.

The main control screen of the JBR in both single and dual band versions is shown in figure 15.

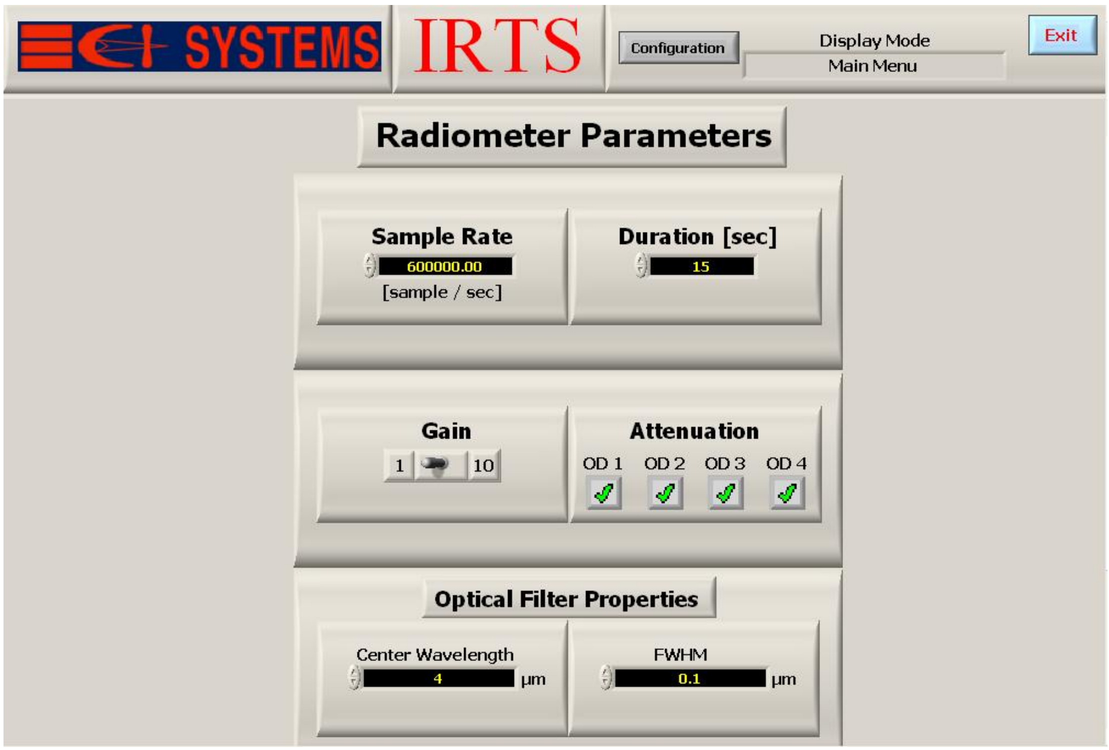

Figure 15: Control screen of the JBR radiometer.

From figure 15 it is possible to see how the radiometer parameters are set through interface buttons: i) the sampling rate, which is up to 600 kHz, ii) the measurement duration for a maximum of 15 seconds, iii) a dual position electronic gain, iv) the presence of up to 4 neutral density filters, and v) the presence of an optical filter for calibration and display of the measured radiation in absolute units of W/sr.

Figure 16 shows the signal screen with an example of countermeasure signal.

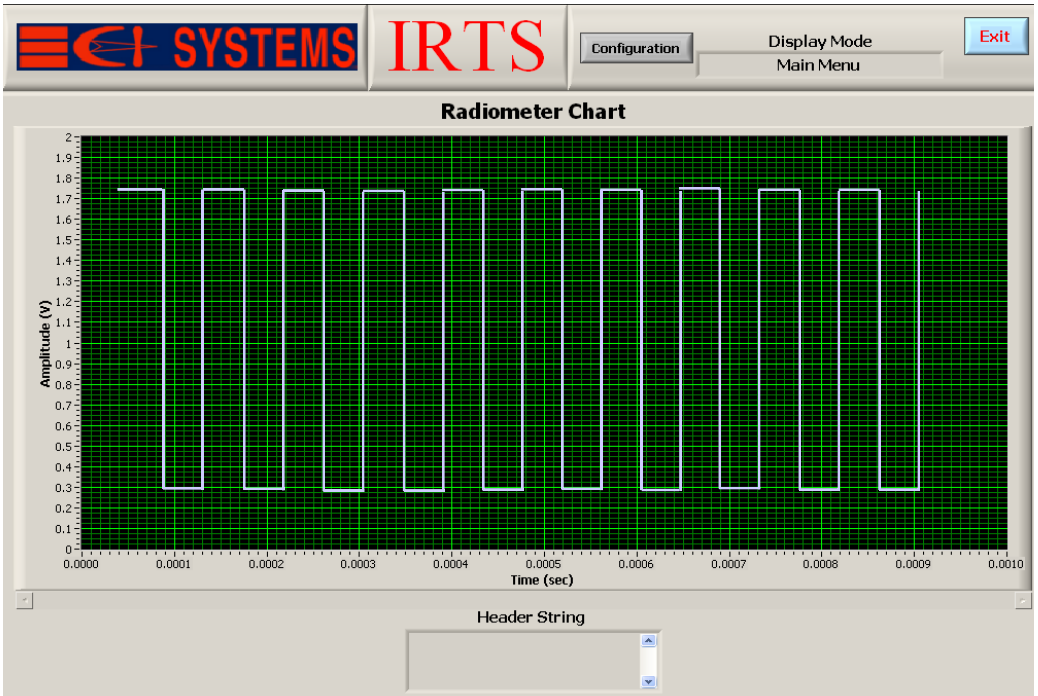

Figure 16: Signal screen of the JBR radiometer, showing an example of countermeasure signal.

3. SUMMARY

We have shown in this paper the implementation of the so called IRTS system (IR Threat Stimulator), developed to test the response and well functioning of IR Missile Warning Systems (MSW) in the field, when mounted on an aircraft, and of the subsequent operation of a defensive IR countermeasure. The system is composed of a strong IR source in the focus of a large reflective optics for projection at a few kilometers distance, and of a dedicated Jam Beam Radiometer (JBR) to measure the emittance of the countermeasure, once the threat is detected and declared as such by the MWS. The projected intensity is controlled by a motor driven set of parallel slats, positioned in front of the optics, in the manner of a Venetian blind. The software allows the user to build intensity versus time scenarios with a characteristic minimum refresh time of 5 to 8 msec., for realistic representation of the initial missile burst at ejection, boost, and approach stages. The minimum time for transition from minimum to maximum projected intensity is 15 msec. and we are working to improve it to 10. The integrated radiometer (the JBR) is automatically operated at the start of the simulation scenario, and measures the IR emittance of the countermeasure in two modes: DC for measurements of continuous sources in a radiometric unit calibrated mode and AC for measurements of modulated sources as function of time.

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