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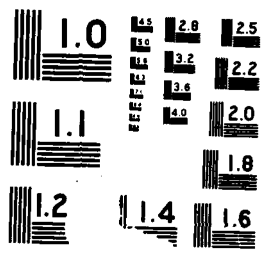
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TECHNICAL REPORT

ERL-0428-TR

RADIOMETRY USING THERMAL IMAGES
PART II - TECHNICAL DETAILS

R.J. OERMANN

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R.J. Oermann

S U M M A R Y

All parameters describing the Model 782 AGA Thermovision SWB and LWB systems that are necessary for their radiometric calibration have been measured. Quantitative use of both systems as broad-band imaging radiometers is now possible.

DSTO SALISBURY

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Box 2151, GPO, Adelaide, South Australia, 5001.

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1. INTRODUCTION

In the first part of this report (ref.1) the general operating procedures and system description of the AGA Model 782 Thermovision were outlined. The calibration of the system to determine the relationship between the Thermal value (an empirical quantity related to the energy received) and temperature was described in detail.

To enable the radiometric use of these thermal imagers, characteristics such as Field of View, Spectral Response and Irradiance Sensitivity had to be measured in order to validate the manufacturer's supplied specifications. The increased emphasis on the need to enhance the digitised images using image processing techniques has demanded the precise measurement of both the horizontal and vertical Modulation Transfer Functions in order to ascertain optimum sampling rates in both dimensions.

This report will describe the techniques used to measure each of the necessary performance characteristics, detail all performance specifications of the Short Waveband (SWB) and Long Waveband (LWB) Model 782 Thermovisions in use in IOC Group in all hardware configurations and describe the optical path, scanning principle and video format produced by the systems. (Australia).

2. OPTICAL LAYOUT

2.1 General

Both the LWB and SWB 782 Scanners utilise completely transmissive optical systems which comprise vertical and horizontal octagonal scanning prisms, collimating lens, aperture and filter wheels, focussing lens and an infrared detector. The detector in the SWB system is an InSb model J10 Judson infrared detector and in the LWB system is a CMT model G-2092 Infrared Associates Inc infrared detector. A schematic illustrating the optical path is given in figure 1. Attached to the front of the scanner is a focussing telescope which determines the Field of View of the instrument. The three telescopes, with focal lengths 33 mm, 99 mm and 191 mm, for both SWB and LWB systems are all rated as f/1.8 systems. Extension rings can be fitted between the lens and scanner to alter the minimum focussing distance without altering the f number of the system even though distortion at the edges of the image is observed.

2.2 Field of View

The Field of View offered by each lens in each waveband was measured by mounting the scanner with lens attached to a motorised pan and tilt head with angular read out to an accuracy of ±.5' of arc (±0.145 mrad). A high temperature black-body source with an aperture selected so as to appear as a point source (smaller than the geometrical resolution limit of the system) was placed at a distance dependent upon the lens being tested. The test layout is illustrated in figure 2.

The output from the thermal imager was continuously digitised and displayed. It was decided that, since all analysis of the data from these instruments is performed using digitised images, the Field of View as presented digitally is the most important to consider. Previous tests have shown that the Field of View as presented digitally is 6% larger in the horizontal direction than that displayed on the monitor.

Scans across the field were measured in three positions in each direction. The horizontal Field of View was measured at the top, middle and bottom of the field and the vertical Field of View was measured at the left, centre and right side of the field. The results of measurements of each lens in each waveband and including those obtained while using selected combinations of extension rings are given in Table 1.

3. SCANNING PRINCIPLE

3.1 Scanning of the Field of View

The principle of scanning the Field of View is identical for both SWB and LWB systems. The video signal thus produced by the SWB system has the same format as that produced by the LWB system. As previously mentioned the Field of View is scanned by two rotating Germanium polygons.

The foremost octagonal prism rotates about a horizontal axis. As each face of the prism passes the entrance aperture (see figure 3), the scene is scanned once in the vertical direction. Synchronised with this prism is the rearmost octagonal prism, rotating about a vertical axis 100 times faster than the forward prism. As each face of this prism passes near the first prism one line is scanned by the same mechanism as illustrated in figure 3 but in the horizontal direction.

The scanning mechanism produces 25 fields/s and, due to slightly different angles of the faces of the first (vertical scanning) prism, four different field types are produced which interlace the lines of the field. The second prism causes 100¼ lines/field to be scanned (see figure 4). With 25 fields/s being produced, one for each face of the vertically scanning prism, it can be seen that this prism rotates 25/8 or 3 1/8 rev/s (187.5 rev/min). Since the second (horizontally scanning) prism is synchronised to rotate at precisely 100 times this speed, its rotation rate is 18,750 rev/min.

The scanning rate of the 782 scanner can be adjusted from 25 field/s to 16 fields/s to enable compatibility with former models that scanned slower. The adjustment of one resistor (R112) on the ME board of the scanner can adjust this scan rate.

3.2 Video format

As a consequence of the scanning principal outlined above the format of the video signal produced by the system in no way resembles any standard television format. The signal can be characterised as a 25 Hz video signal with 100 lines/field and a 4:1 interlace.

It is possible to convert this video signal to standard TV signal (50 Hz, 625 line/field) using the AGA Discon unit. This scan converter uses a four (4) bit, video speed digitiser, to digitise field types 1 and 3 of the Thermovision video signal. Two memory banks hold the digitised image data and read circuitry (operating at twice the speed of the writing circuitry) together with a digital to analogue converter reconstitutes the image after the addition of certain padding information.

4. HORIZONTAL AND VERTICAL SPATIAL RESOLUTION

4.1 Horizontal Modulation Transfer Function (MTF)

The horizontal line spread function (LSF) was measured using a 0.1 mm (or 1 mm in the case of 33 mm focal length lens) wide slit at the focus of a 1.7 m focal length reflective collimator (figure 5). Using a sampling instrument developed in IOC Group, that enables triggering from any point in the thermal image, and a Data Precision D6000 digital waveform analyser samples through the LSF were taken at intervals of 40 ns and stored for subsequent analysis. Since the facility existed, the opportunity was taken to average the LSF from consecutive fields in order to get an indication of the possible improvement to signal quality by temporal filtering.

In this manner, LSF's were measured in the centre of the Field of View of each of the three lenses and for both wavebands. The resulting LSF's are given in figures 6 and 7. After Fourier transformation of these LSF's and dividing by the Fourier Transform of the slit, in order to remove the convolved effect of the slit, the MTF for all six configurations was obtained and are illustrated in figures 8 and 9.

4.2 Optimum horizontal sampling rate for digital analysis

The time taken for the optics to scan one line is 300 μs. The AGA Datalink takes 128 samples across one line which corresponds to a sampling rate of 2.1 samples/mrad in the case of the 191 mm SWB lens (426 kHz) and 1.58 samples/mrad for LWB. The sampling rate for lenses with differing Fields of View can be determined by applying a conversion factor.

From the MTF of the SWB system (figure 8) it can be seen that the response becomes negligible to spatial frequencies beyond 1.0 cycles/mrad for the 191 mm focal length SWB lens. Thus by applying the Nyquist criterion, of sampling at twice this maximum spatial frequency, it can be seen that the 2.1 samples/mrad sampling rate of the AGA Datalink is adequate for the SWB system.

However, the MTF of the LWB system (figure 9) indicates that the response to spatial frequencies greater than 0.9 cycles/mrad is negligible for the 191 mm focal length LWB lens. This implies a sampling rate of 1.8 samples/mrad would be necessary, which, with the 81 mrad horizontal Field of View of the 191 mm focal length lens, would result in 146 samples/line.

4.3 Vertical Modulation Transfer Function

Although not as straightforward as the measurement of a LSF in the direction of the scan, the vertical line spread function was determined by measuring the response profile of one scanned line in the vertical direction. One line of the same field type was selected using logic circuitry that ANDed a pulse produced by the thermovision monitor at the occurrence of every second field type 1 (every revolution of the vertical scan prism) with the triggering pulse for one line from the sampling instrument used to measure the horizontal line spread function (see Section 4.1).

A high temperature black-body calibration source was fitted with 0.3175 mm diameter aperture and placed at a distance of 4 m. In this position the aperture geometrically occupied 1/70th of the width of one scan line. This "point-source" was caused to scan through three consecutive lines by mounting the scanner onto a pan and tilt head ani rotating it vertically in increments of 5' of arc.

The three resulting vertical LSF's were averaged and, after Fourier transformation, corrected for the slit function as described in Section 4.1. The scanning mechanism scans a vertical Field of View of 303 mrad (in the case of the 33 mm focal length SWB lens) by 64 active image lines. This implies a vertical sampling rate of 0.21 samples/mrad. The 4:1 interlace of the scanning mechanism can, however, increase this vertical sampling rate four fold to 0.84 samples/mrad.

The vertical MTF (figure 11) shows that the system can resolve spatial frequencies up to 0.18 cycles/mrad for the 33 mm focal length SWB lens.

4.4 Optimum Vertical Sampling for Digital Analysis

Interestingly the sampling rate of 2 x 0.18 samples/mrad required to meet Nyquist criterion explained in 4.2 is obtainable by only using two of the four field types. This is to say that suitable merging of field types 1 and 3 or 2 and 4 raises the vertical sampling rate to 0.42 samples/mrad which more than adequately satisfies the necessary criterion.

5. SPECTRAL RESPONSE

5.1 Radiometer Spectral Response measuring facility

The Spectral Response of the two systems with all filters was measured using the radiometer Spectral Response measuring facility(ref 2), set up in IOC Group. This facility incorporates an Oriel Globar source, an Oriel Model 7240 Monochromator, a Golay Cell with synchronous detection and order sorting filters.

The Thermal Imager was positioned to image the output slit of the monochromator and readings sampled from this portion of the image were recorded as the monochromator performed its spectral scan. Figure 12 illustrates the set up used for this test.

5.2 Factors affecting Spectral Response

The Spectral Response of each system with no spectral filter was determined with each of the three focal length lenses available. The Spectral Responses thus obtained indicated that there was no difference, in total system response, between each lens type. The only system component that obviously affected the Spectral Response was the spectral filter. The filter wheel has 8 positions of which position 0 is reserved for no filter. The filters are circular elements 9 mm in diameter and can be up to 2 mm thick.

5.3 Summary of Spectral Responses

Figures 13 and 14 show the Spectral Responses of the total system for each of the spectral filters. These indicate that the unfiltered response of the SWB system is actually 3.3 μm to 5.5 μm with some response down to 2.6 μm. The unfiltered Spectral Response of the LWB system indicates response down to 4.5 μm and extending up to 13 μm. The use of the Long Pass filter in position 1 of the LWB system removes the shorter wavelength "tail" of the response and cuts the response down to 6.5 μm to 13 μm.

6. CONCLUSION

Important radiometric parameters of the Short Waveband and Long Waveband AGA Thermovision systems have been determined. Spectral Responses of the total system with each of the supplied filters have been measured. These indicate that the unfiltered response of the short waveband system covers the near IR region from 2.5 μm to 6.0 μm although main response is from 3.4 μm to 5.6 μm. The unfiltered response of the LWB system extends from 4.5 μm to 13 μm with short waveband "tail" able to be removed by use of a long pass filter (position no. 1) which cuts on at 6.2 μm.

Details of the spatial resolution of the system have also been measured indicating that the long waveband system has better spatial resolution than the short waveband system and thus requires a greater sampling rate for digitising. Vertical spatial resolution measurements indicate that the digitising of alternate fields and appropriate digital interlacing is all that is required to meet the vertical sampling criteria.

Precise Fields of View measurements have indicated slight differences between the stated and actual Fields of View of the standard lenses supplied. These measurements have also indicated a 6% larger horizontal Field of View on the digitised image than is seen on the analogue image displayed on the monitor.

7. ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of Dr Shane Brunker in the setting up of the Spectral Response measurement facility and Mr Fred Buttignol for the design and construction of the video sampling instrument.

The author would also like to acknowledge the assistance of Mr Robert Caprari in the measurement of horizontal line spread functions and Mr George Poropat in the calculation and interpretation of the Modulation Transfer functions.

TABLE 1. MEASURED FIELDS OF VIEW (FOV)

Waveband	Lens	Horizontal FOV	Vertical FOV
SWB	191 mm ($3\frac{1}{2}°$)	3° 29' ± 1' (60.8 ± 0.3 mrad)	2° 58' ± 2' (51.8 ± 0.6 mrad)
	99 mm (7°)	6° 50' ± 3' (119.26 ± 0.8 mrad)	5° 41' ± 2' (99.19 ± 0.6 mrad)
	33 mm (20°)	20° 10' ± 10' (351 ± 3 mrad)	17° 20' ± 10' (303 ± 3 mrad)
LWB	191 mm ($3\frac{1}{2}°$)	4° 38' ± 3' (80.87 ± 0.9 mrad)	3° 5' ± 2' (53.8 ± 0.6 mrad)
	99 mm (7°)	7° 8' ± 2' (124.5 ± 0.6 mrad)	6° 21' ± 2' (105.3 ± 0.6 mrad)
	33 mm (20°)	21° 20' ± 10' (372.3 mrad)	18° 40' ± 10' (325.8 mrad)

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2	Oermann, R.J. and Brunker, S.A	"A Facility for the Measurement of Radiometer Spectral Responses". ERL-0420-TM, July 1987
3	Lloyd, J.M.	"Thermal Imaging Systems". (Plenum Press), Chapter 7, 1975

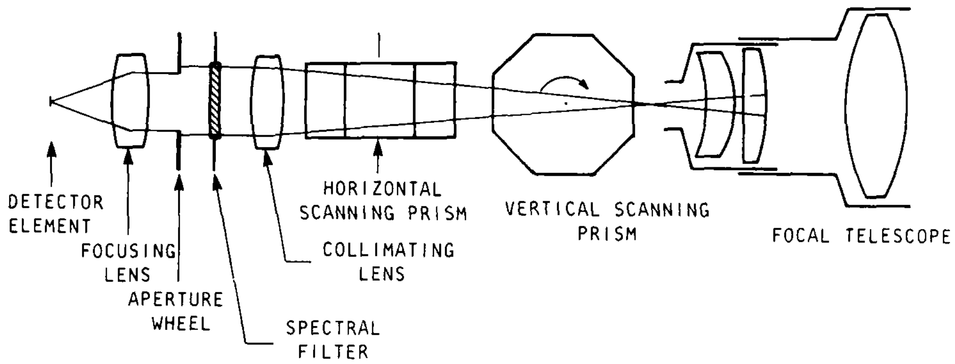

Figure 1. Optical path of 782 Scanner

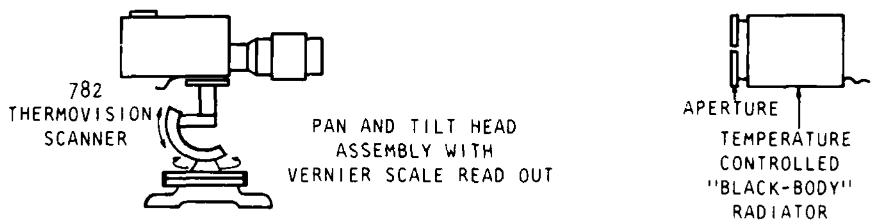

Figure 2. Test layout for Field of View determination

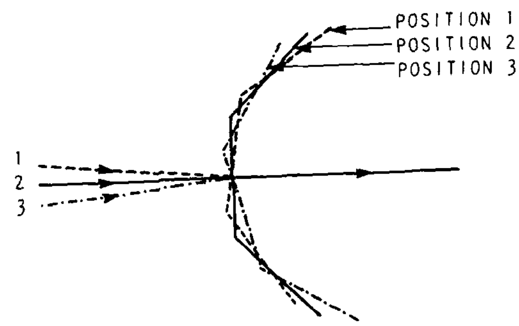

Figure 3. Scanning principle of refracting polygon

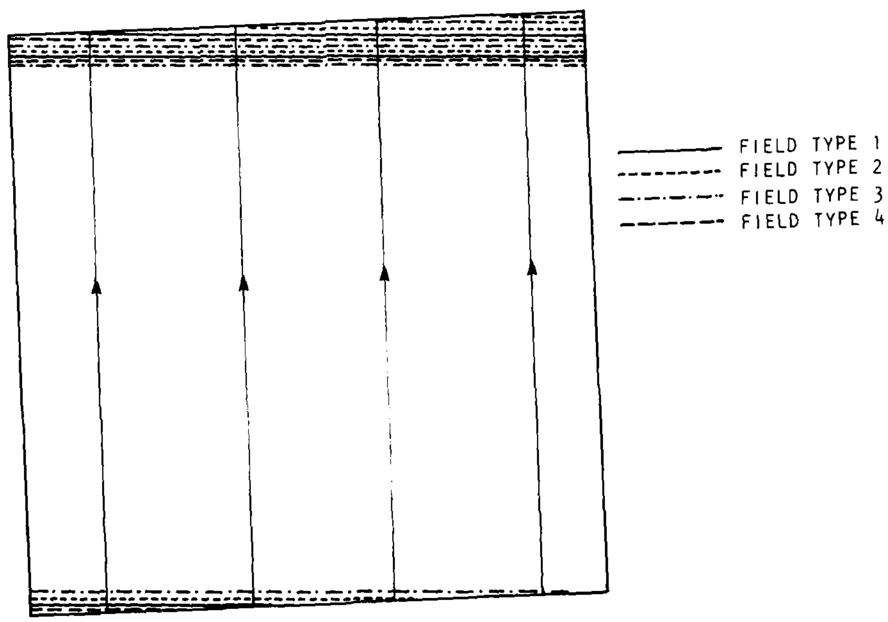

Figure 4. Field interlace

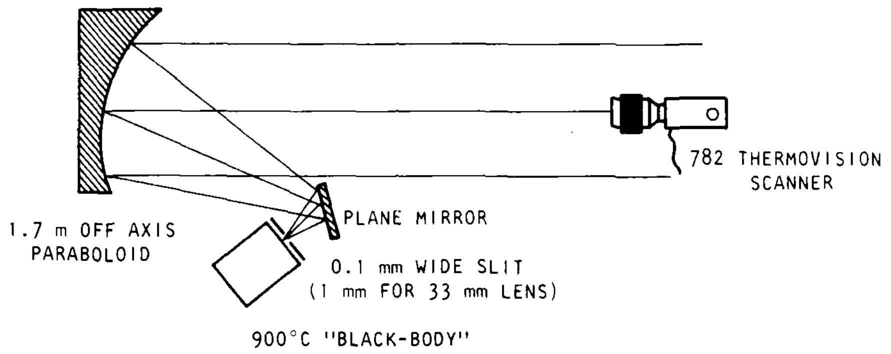

Figure 5. Set up for horizontal LSF measurement

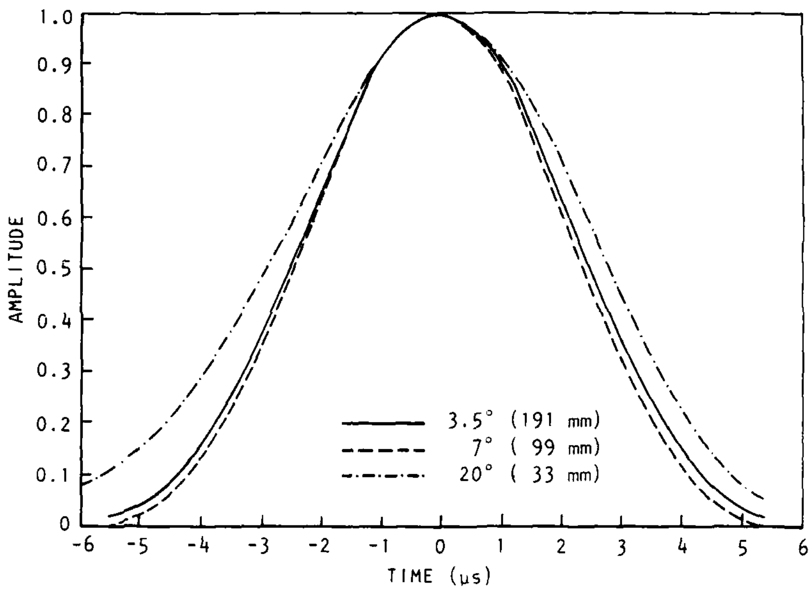

Figure 6. LSF of SWB for 3 lenses

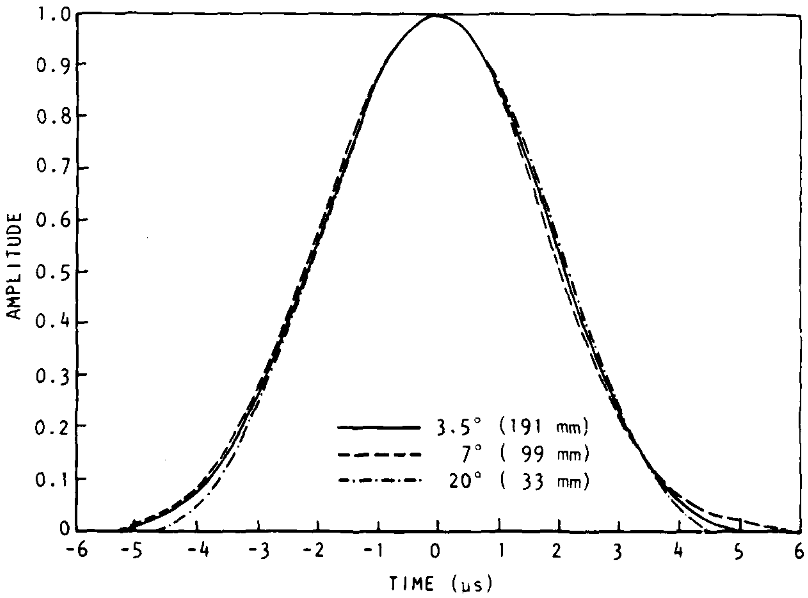

Figure 7. LSF of LWB for 3 lenses

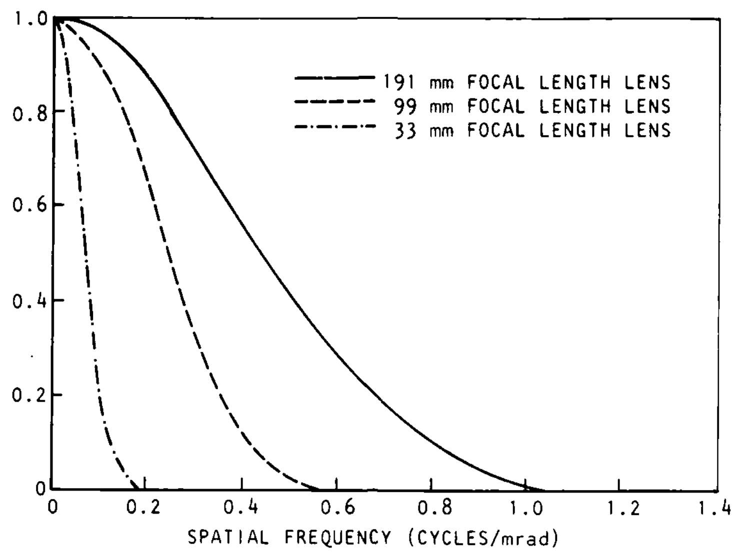

Figure 8. SWB MTF

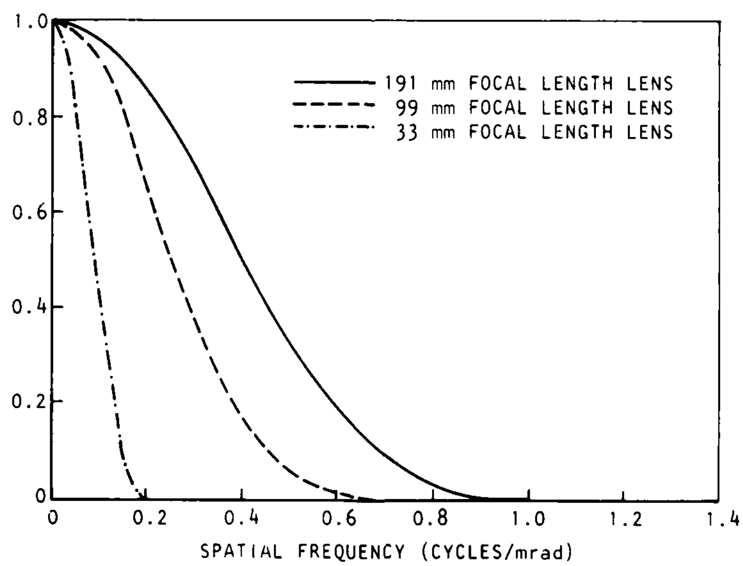

Figure 9. LWB MTF

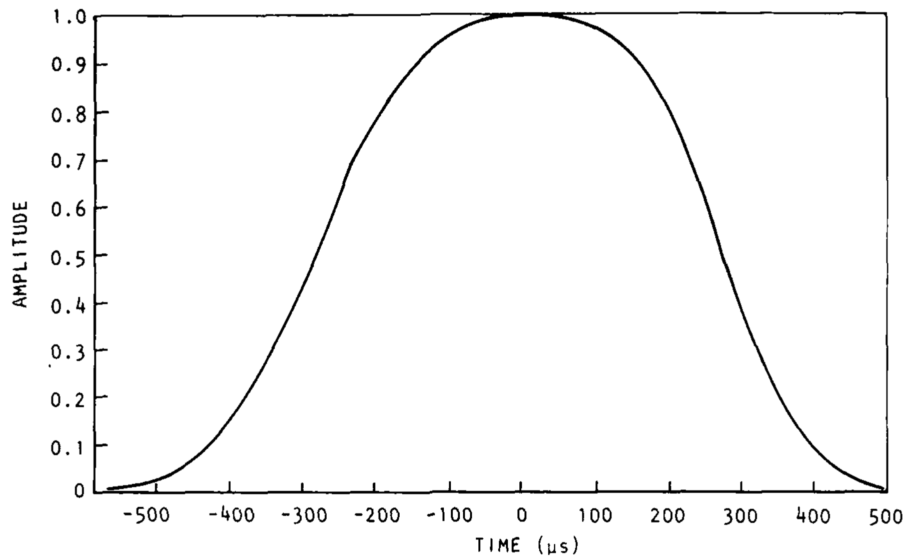

Figure 10. Vertical LSF of SWB with 33 mm focal length lens

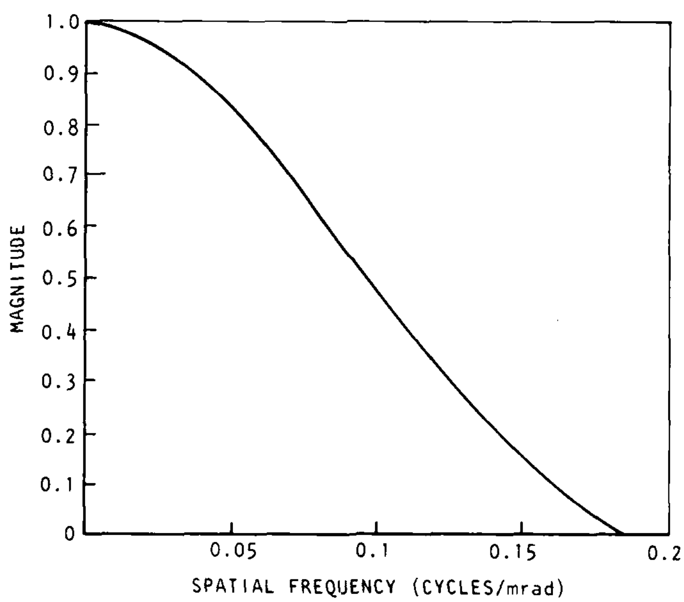

Figure 11. Vertical MTF of SWB 33 mm focal length lens

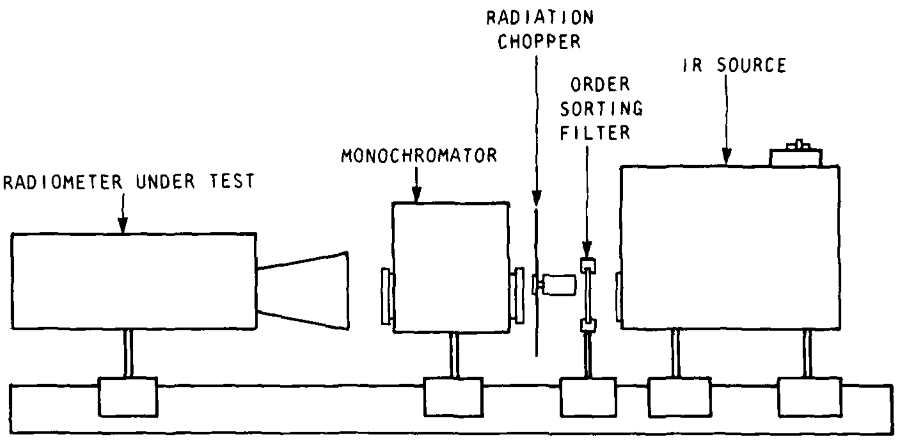

Figure 12. Set up for Spectral Response Measurement

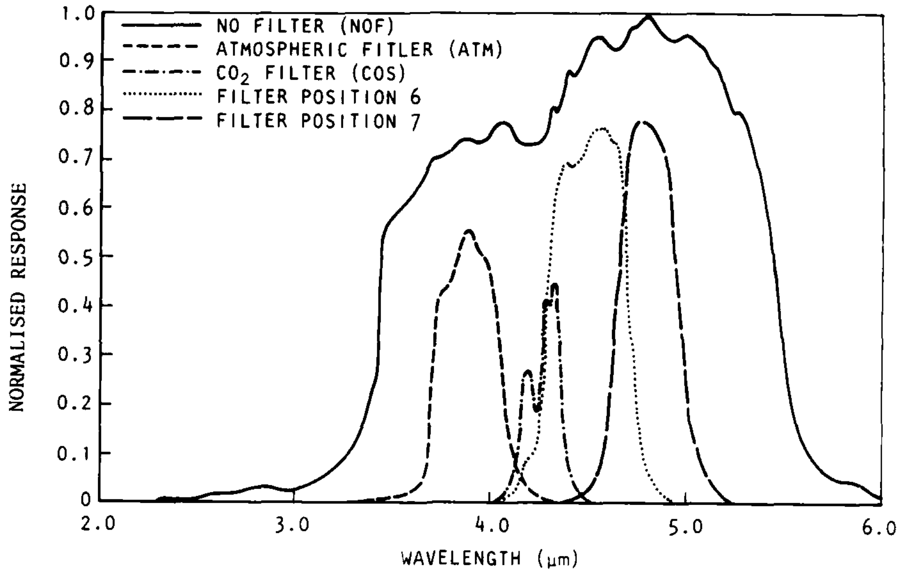

Figure 13. Spectral Response of SWB system with all filters

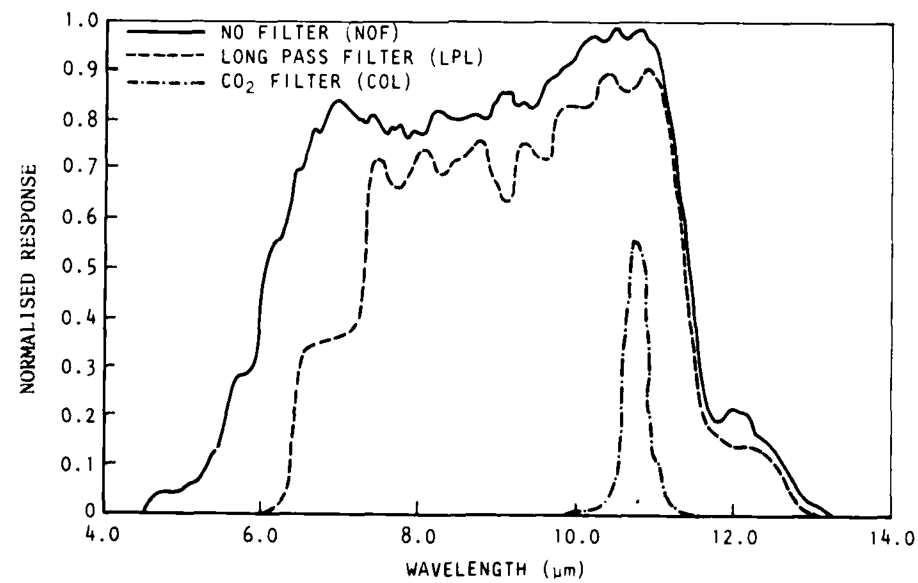

Figure 14. Spectral Response of LWB system with all filters

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