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Target Acquisition System for Antitank Guided Missile Systems

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ABSTRACT

A brief summary of the state-of-the-art antitank guided missile systems (ATGMs), their target acquisition system and guidance have been presented. Historical developments of thermal imagers used in such weapons systems have been outlined, bringing out their limitations and technological bottlenecks. Status of an indigenously designed and developed state-of-the-art thermal sighting system for antitank missile system which has given excellent performance in terms of range and picture quality, is discussed in details. An overview of the emerging and futuristic trends in imaging technologies has also been covered.

NOMENCLATURE

f/n_0	Systems effective f/no
T_o	Optics transmission
C_1	Number of detectors in series in each row of elements
D^*	Average detectivity (cm $Hz^{1/2}/W$)
$A_d^{1/2}$	Detector linear dimension for square elements
dN/dT	Radiation contrast which is $0.615 \times 10^{-4} W cm^{-2} Sr^{-1} K^{-1}$ at 300°K in 8-12 μm band
n_c	Total number of scan lines
n_h	Number of picture elements in each scan line
η	Scan efficiency
C_2	Number of detector channels in parallel
f	Target spatial frequency (cycles/mrad)
$w^{1/2}$	IFOV of the system (mrad)
$\dot{F}$	Frame rate (25 frames/s)
T_e	Eye integration time
MRTD	Minimum resolvable temperature difference
NETD	Noise equivalent temperature difference
MTF	Modulation transfer function
ΔT_o	Inherent temperature difference of target *w.r.t* background
ΔT_c	Critical temperature difference
R_o	Target range, and
$\tau(R_o)$	Atmospheric transmission

1. INTRODUCTION

Night surveillance and acquisition of targets on the battle field has been a necessity for the military ever since the World War-II; and this requirement has become much more complex and demanding in the present day context due to induction of smart and brilliant sensors. A lot of attention is currently devoted to infrared sensors and guidance because of their passive nature, better penetration through mist and fog, immunisation against countermeasures and necessity of extending wars during dark hours.

The first and second generation antitank guided missiles (ATGMs) have been in use during day time up to a range of 2 to 2.5 km with a few exceptions wherein their range is extended up to 4 km. During mid seventies, a number of thermal imaging systems, were coupled with launchers to enhance the capability of these missiles for operation during night time. However, because of the technological bottlenecks, these sights were restricted to a range of 1 to 2 km only. As the threat from main battle tanks increased, attempts have been made to improve the warhead design to cope with multilayer reactive type armour on one hand and better target acquisition systems to go beyond 2 km on the other hand. In the late 80's, attempts were made to exploit

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Table 1. Summary of present day ATGM

ope	USA	Israel	Russia	India
Up to 2.5 km				
MILAN	DRAGON		AT-7 SAXHORN	MILAN
ARIES	JAVELINE (m)		AT-4 SPIGOT	FAGOT
RAS 56 BILL	TOW-2A, 2B		FAGOT	
TRIGOT (MR)				
Up to 4.5 km				
HOT	TANK BREAKER	MAPATS	AT-3 SAGGER	NA
TRIGOT (LR)	MAVERICK	-	AT-5 SPANDREL	
	LOSAT		AT-6 SPIRAL	
	AAWS-M		KONKURS	

the top of the tank which is the most vulnerable portion. This led to the development of fire & forget, top attack and lock on before launch (LOBL) missiles. A summary of present day representative ATGMs is given in Table 1.

The target acquisition system (TAS) for the third generation, fire and forget, top attack missile system comprises a high performance long range thermal imager, integrated with a CCD camera and a laser range finder (LRF). The development of such sophisticated devices as thermal imagers with an expected deployment life time of about one-and-a-half decades involves considerable development efforts and time. Worldwide, the thermal imagers have been under development since mid-seventies and have nearly matured in technology by now. Most of the designers of thermal imagers have either employed a large number of linear array detectors in parallel scan with or without interlace (US common module) and/or a short array in serial parallel scan (UK common module). Based on the US common module using 60, 100, 120 and 180 elements with 4:1 to 2:1 interlace, the US, Germany, Holland, Israel, Spain and India have made a number of sights.

The UK common modules (Class A,B,C) have been adopted by the UK, France, Sweden and a number of other smaller companies in Eurosia. Not much information is forthcoming regarding developments in Russia, China and Japan. A comparison of parallel and serial scans is given in Table 2.

All the common modules are working in the 8-12 μm band and employ an optomechanical scanner with focal plan arrays having less than 180 detector elements and are of direct view/indirect view types. Almost all systems built so far have recognition ranges of 2 to 2.5 km for A and B type vehicles. A comparative performance of thermal sights presently being used by various countries is given in Tables 3 and 4. But recent applications in third generation antitank missiles need ranges much beyond the capability of present day thermal imagers.

Table 2. Comparison of parallel and serial scans

	Parallel scan	Serial scan
Temperature discrimination	High	Low
Scanning system	Relatively quiet	Noisy
Scanning efficiency	Low	High
Mechanical scanning	Simple	High
Number of detectors	Large	Low
Cost	High	Low

2. SYSTEM PARAMETERS

Before going into the details of thermal sight, it is essential to discuss the performance parameters and design methodology. Performance of a thermal imager is governed by its thermal sensitivity and spatial resolution. Thermal sensitivity is defined as target to background temperature difference for large area target which produces a peak signal-to-rms noise ratio of unity in the video output of the detector. In terms of sensor parameters it is expressed as[1,2].

$$NETD = \frac{4(f/n_o)^2}{\pi A_d^{1/2} C_1^{1/2} D^* \, T_o \, dN/dT} \left[\frac{\pi n_e n_b F}{4\eta c_2}\right]^{1/2}$$

Spatial resolution is defined in terms of modulation transfer function (MTF) which is a function of spatial frequency (f). For a typical thermal imager, the total MTF is given by:

Table 3. Thermal sights comparative performance

System Parameters	MIRA (FRANCE)	BARR & STROUD (U.K)	THORN (EMI) (U.K.)	TEXAS/FFV (U.S.A)
System type	Serial Parallel	Parallel (Steps)	Serial Parallel	Parallel 2:1 Interlace
Optics	100 mm, f/2	140 mm, f/2	120 mm, f/2	76 mm, f/2.6
FOV				
WFOV	6° × 3°	11.8° × 8°	12.9° × 7.9°	4.6° × 6.1°
(IFOV, mrad)	(0.175)	(0.54)	(0.64)	(0.25)
NFOV		4° × 2.7°	4.9° × 3.2°	
(IFOV, mrad)		(0.18)	(0.25)	
Detector				
No. of elements	30	8 Sprite	23	60
MRTD (°C)	0.16	0.35	0.3	–
Range				
detection (km)	2.0	2.0	3.0	1.9
Recongnition (km)	1.5	1.1	2.2	0.7

Table 4. Thermal sights comparative performance

System Parameters	IRDE	SAAB Proposed for Helicopter Version	OLDELFT (Holland)	ELOP-MLFS (Israel)
Optics FOV	240 mm, f/2	250 mm	110 mm	150 mm, f/1.2
WFOV	5.2° × 2.8°	6.4° × 4°	10.8° × 4.2°	24.3° × 18.7°
(IFOV mrad)	(0.25)	(0.18)		
MFOV				7.1° × 5.4°
NFOV	1.5° × 0.8°	2.4° × 1.6°	3.6° × 1.4°	2.0° × 1.5°
(IFOY mrad)	(0.07)			
Detector	MCT	MCT	MCT	MCT
No. of elements	100, Linear	8, Sprite	60, Linear	120, Linear
Element size (μm)	35 × 35	62.5 × 700	34 × 48	12 × 20
Spacing (μm)	35	12.5		20
$D^*_{\lambda p}$ (cmHz$^{1/2}$/W)	6×10^{10}	11×10^{10}	6×10^{10}	6×10^{10}
MRTD (°C)				
At 1.7 Cy/mrad	0.03	0.17	0.06	0.25 (4 Cy/mrad)
At 5.2 Cy/mrad	0.22	0.24		0.65
At 7 Cy/mrao	0.49			0.8
Recognition Range (km) (ΔT:2°C, 2.3 m × 2.3m α : 0.37/ km T : 27°C, RH : 85%)	4.0	4.0	2.5	2.7

$$MTF_{total}(f) \quad MTF_{optics}(f) \times MTF_{detector}(f)$$
$$MTF_{electronics}(f) \times MTF_{display}(f)$$

Both NETD and MTF parameters put together give minimum resolvable temperature difference (MRTD) which is defined as minimum target to background temperature difference in four bar pattern of 7:1 aspect ratio which can just be resolved by an observer viewing the target through the imager. MRTD is expressed as[1,2]:

$$MRTD(f) \quad 6\sqrt{1/\pi F T_e} \quad w \quad NETD/MTF(f)$$

MRTD is used to predict the detection and recognition capability of the system. Range performance methodology is depicted in nomogram given in Fig. 1. A target of critical dimension, H and temperature difference, ΔT_0 is at range, R_0. After transmission through the atmosphere, it is reduced to $\Delta T_c = \Delta T_o \times \tau R_o$. The limiting resolving capability of system looking at ΔT_c is frequency, f_o (cycles/mrad). Multiplying it by the angular substance of the target, H/R_o by f_o, we get the number of resolvable cycles N_o across the target. Probability of detection and recognition is related to N_o through empirically derived set of curves. Hence probability of detection and recognition as a function of range can be calculated. A representative of MRTD plot *vs* target frequency for a thermal imager is given in Fig. 2.

By using the above formulae and MRTD curve, the basic system parameters, like spatial resolution, f-number, optics aperture and field of view for a selected

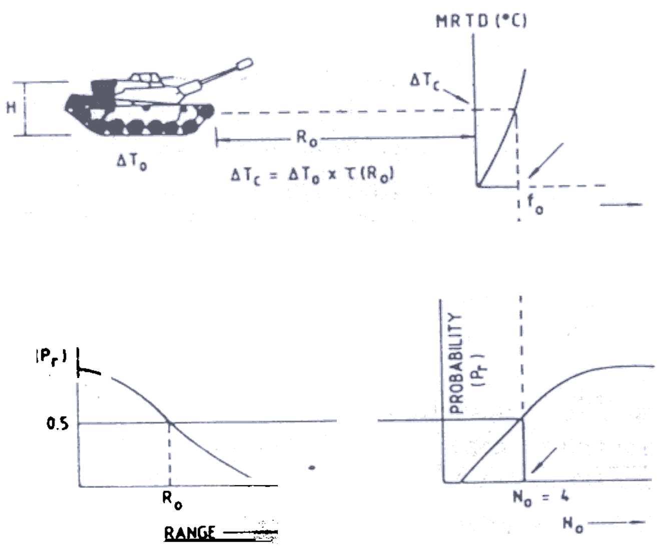

Figure Schematic of range performance methodology.

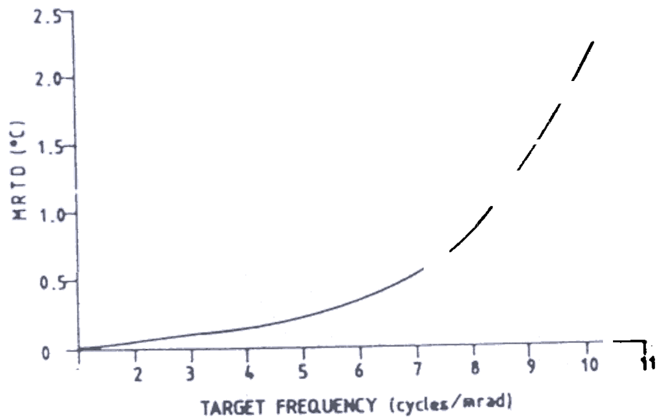

Figure 2. Plot of MRTD *vs* target spatial frequency.

detector array can be worked out to meet the required range.

3. SYSTEM DETAILS

The Instruments Research & Development Establishment (IRDE) at Dehra Dun (India), has designed and developed a target acquisition system consisting of a thermal sight, a CCD camera and a *Nd-YAG* LRF for acquiring target for the third generation ATGM missile. It has given recognition capability of more than 4 km against tank type of target.

The layout of the thermal sight is shown in Fig. 3 and its performance specifications are included in Table 4. The front end of the thermal sight is an afocal telescope with dual field of view capability. The scanner operates in parallel beam in between telescope and the final image forming detector lens system. The wide field of view (5.25° × 2.8°) with medium resolution of 250 μrad is used for target search whereas the narrow field of view (1.5° × 0.8°) with higher resolution of 72 μrad helps target recognition for engagements.

The afocal system designed and fabricated at IRDE has a reflective objective for NFOV and a refractive lens objective in WFOV. The reflective objective is an RC system employing a primary hyperbolic mirror of 240 mm aperture and a secondary hyperboloid mirror of 100 mm aperture. Both these objectives have been designed to give diffraction limited performance. The modulation transfer function curves for both WFOV and NFOV objectives are given in Figs 4 and 5. There is a common eyepiece for both the objectives. Changeover from WFOV to NFOV or vice-versa is achieved through electrically-driven flapping mirror mechanism suitably located in the optical path. The

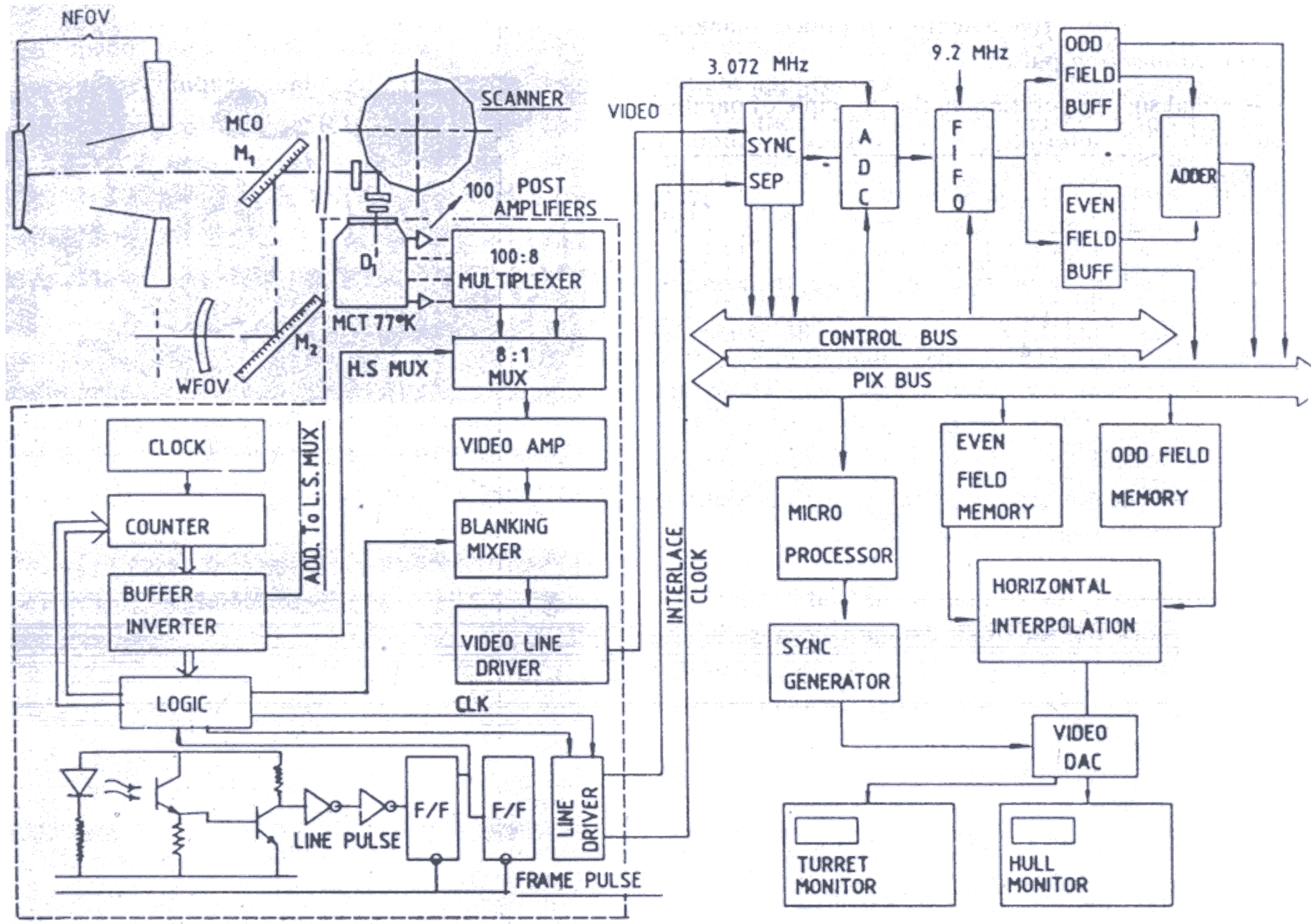

Figure 3. Layout of thermal sight (TS).

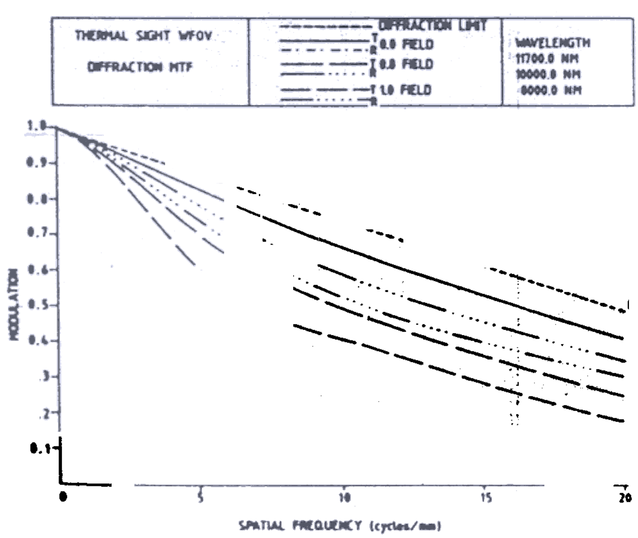

Figure 4. MTF curve for WFOV objective.

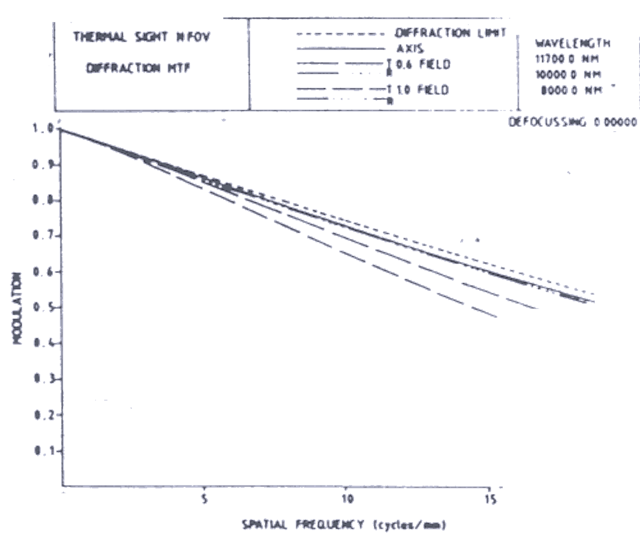

Figure 5. MTF curve for NFOV objective.

sub-systems like scanner, imaging optics, signal processing and CRT displays are common for the two channels. A precision 12 sided polygon scanner having alternate facets tilted by 4′ 12″ wrt normal facets has been designed and used. An optical encoder having a resolution of 512 cycles per revolution linked to the shaft of the scanner drive assembly, produces blanking and synchronisation pulses.

Thermal sight, operating on the principle of parallel scan with 2:1 interlace, is configured around a 100-element linear MCT array cooled to liquid N_2 temperature using stirling engine cooler. The 100-element array covers FOV in elevation direction; and with a rotation of two facet of scanner, the azimuth FOV is covered. Therefore in one rotation of the scanner, six frames are covered. Signal outputs from the detector elements are of nanovolts. These are amplified using 100 preamplifiers located in close proximity of the detector followed by postamplifiers to limit the bandwidth and compensate for responsivity variations from channel to channel.

Unfortunately, the format of thermal imager does not match with the CCIR-B standard because of the vertical readout in the present case as against horizontal one in CCIR-B, and the number of pixels in the frame also is different. Therefore, a digital scan conversion technique has been evolved and used wherein the nonstandard analog data from the normal and tilted facets of the polygon is digitized and stored in the odd and even memory. The data is interpolated in both X and Y directions to enlarge the image-format from 200 × 350 pixels to 400 × 700 pixels. The digital data from the memory is converted into analog format and is mixed with sync pulses to generate composite video for presentation to the observer through a CRT monitor.

A CCD camera is also integrated with thermal sight for day time surveillance and is having the recognition capability of better than 4 km against tank type targets. A Nd-YAG LRF having range capability of 5 km has also been integrated with thermal sight to estimate the range of the targets.

Thermal sight and CCD camera images are displayed on a single monitor through a select switch. Two such monitors alongwith controls are located inside the turret and in the hull for the operator and the commander, respectively. The total system has been integrated and harmonised. It has been field-evaluated at various places and has given excellent results in terms of range and picture quality. Photographs of target acquisition system along with thermal image of a tank are given in Figs 6 and 7.

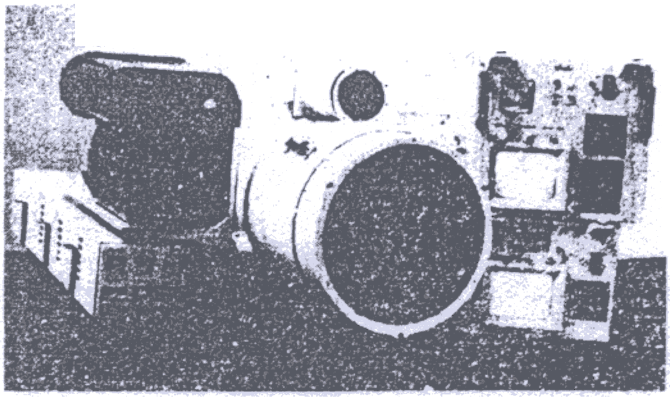

Figure 6. Target acquisition system (TS, CCD camera and LRF).

Figure 7. Thermal image of a tank at 1 km.

The following are the special technologies required in the design of such thermal systems till such time second generation linear/staring focal plane arrays become commercially viable:

* Large aperture, high magnification infrared zoom telescope (design, fabrication, assembly and testing)
* Fast wide FOV infrared imaging optics
* High efficiency, high precision scanners
* High efficiency, broad band, multilayer and DLC coatings

- High speed multiplexing and low level signal processing techniques, and
- Multifunctional coloured CRT display.

4. SECOND GENERATION THERMAL IMAGERS

Present day, state-of-the-art thermal imagers utilise arrays of discrete detector elements which call for 2-D scanning for coverage of the total FOV and require large number of preamplifiers and postamplifiers to process the signal before being displayed on CRT. Thus they are large in size and weight. With recent advances in focal plane detector technology, thermal imaging using second generation scanning focal plane arrays (FPAs) are a promising approach to realise higher performance. Unfortunately, they suffer from a peculiar noise pattern called fixed pattern noise (FPN). Still they are finding niche in the development of second generation thermal imager using linear FPAs (48 × 4 and 288×4 elements) requiring one-dimensional scanning.

These detectors because of time delay and integration (TDI) effect, have D* one order of magnitude higher than linear mercury cadmium telluride (MCT) arrays. Since, the requirement of signal processing for linear FPAs and that of staring FPAs will be almost identical, so by the time staring FPAs mature, the use of these interim linear FPAs-based system will get perfected. Currently at IRDE, a similar programme is in progress using 288 × 4 LFPAs for aerial and light weight applications.

Another breakthrough expected in this field is the development of staring FLIR's operating at room temperature using tantalate pyroelectric FPAs as sensors. Once fully developed, they may find application in helmet-mounted infrared goggles, rifle sights, missile launch detectors and threat warning systems, all operating in 8-12 μm band. All these equipment require WFOV, low cost and light-weight design.

Futuristic systems may also employ multisensors on a single platform together with automatic target recognition capability.

5. CONCLUSION

Present day thermal system based on linear array detectors are well proven for ATGM roles. However, futuristic thermal sighting system will be based on linear/staring FPAs giving the equivalent or better performance and will be much smaller in size/weight.

REFERENCES

Ratches, J.A. Static performance model for thermal imaging systems. *Opt. Engg.*, 1976, **15**, 525-30.

Lloyd, J.M. Thermal imaging systems. 5.3, 5.8 Plenum Press New York, 1975. pp. 166-90.