FAPA

System for testing IR FPA sensors

Fig. 1. CONIR universal controller for control of IR FPA sensors

Fig. 2. FAPA-N system for response/noise tests of IR FPAs/camera cores

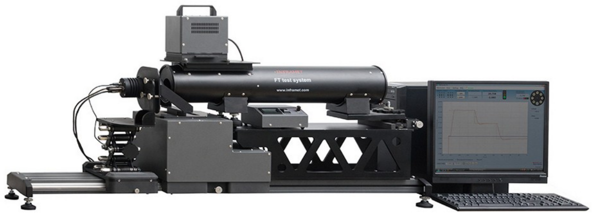

Fig. 3. FAPA-I system for image quality tests of IR FPAs/camera cores

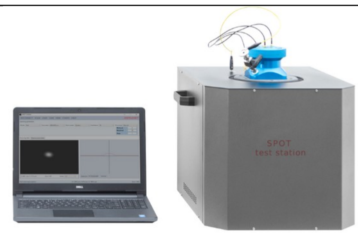

Fig. 4. FAPA-C system for spatial responsivity tests of of raw IR FPAs

Fig. 5. FAPA-S system for spectral tests f IR FPAs/camera cores

1 Introduction

The term IR FPA sensors (focal plane array) means array of detectors sensitive to IR light that can potentially generate electronic two dimensional image when located at focal plane of an IR objective. However, in detail the term IR FPA sensors typically describe image sensors sensitive to thermal radiation in spectral range from about 3μm to about 15μm. Further on, on criterion of spectral band the IR FPA sensors are divided into two groups: 1)MWIR FPAs (middle wavelenght infrared FPAs) of spectral band typically not wider than 3μm to 5μm; 2)LWIR FPAs (long wavelenght infrared FPAs) of spectral band not wider than 7.5μm to 14μm. In addition, on criterion of work temperature IR FPA sensors are divided into two groups: 1)cooled FPAs (both MWIR and LWIR sensors) and non cooled IR FPAs (almost always LWIR FPAs). Finally, it should be noted, that the term IR FPA typically does not cover FPAs sensors of spectral band located below 3μm that are considered as a separate group (SWIR FPA sensors).

From desing point of view IR FPA sensors offered commercially on the market are built by combining array of IR detectors (raw IR FPA sensor) with read out electronic system.

IR FPA image sensors are the most important block of thermal imagers. The latter systems can be built using two main ways: 1)to purchase IR FPA sensor integrated with a miniaturized control/image processing electronics (thermal camera core) capable to generate standard electronic video image and later to combine it with optical objective, optional cooler, and mechanical case; 2) to purchase IR FPA sensor, to develop suitable miniaturized control/image processing electronics, and later to combine created thermal camera core with optical objective, optional cooler, and mechanical case. In both cases IR FPA sensor is the crucial starting point for design process of thermal imagers.

Technology of IR FPA sensors is very difficult and has been mastered only by not more than a dozen of manufacturers worldwide. However, there are dozens of scientific institutes/companies that carry out work on development of new IR FPA sensors. Both manufacturers and research institutes need scientific apparatus to control/characterize IR FPA sensors that they manufacture or develop.

Testing IR FPA sensors is not standardized. However, IR FPA sensors are typically characterized using a set of parameters used to characterize thermal imagers. There are three main groups of parameters: 1)noise/sensitivity parameters, 2)image quality parameters, 3)spectral parameters. In spite of similarity of characterization parameters, the systems for testing IR FPA sensors differ a lot from systems for testing thermal imagers due to two reasons. First, universal control electronics capable to control IR FPAs of different ROIC architecture is needed to generate images in one of standards of electronic video image. Second, some optical blocks are needed to simulate optical objectives used in thermal imagers. There are also some other minor differences.

2 What is FAPA?

FAPA is a quasi universal system for expanded control/testing IR FPA sensors optimized for use by scientific institutes that carry our research on development of such image sensors. It is intended mainly for testing complete IR FPA sensors (array of detectors integrated with readout electronics) and thermal cameras cores but some critical parameters of raw IR FPA sensors (before integration with ROIC) can be measured, too. Further on, FAPA can be also optionally used for testing complete thermal imagers. In this way FAPA can be a valuable tool for evaluation of IR PFA sensor at any stage of its life time:raw IR FPA sensor, IR FPA sensor, thermal camera core, thermal imager.

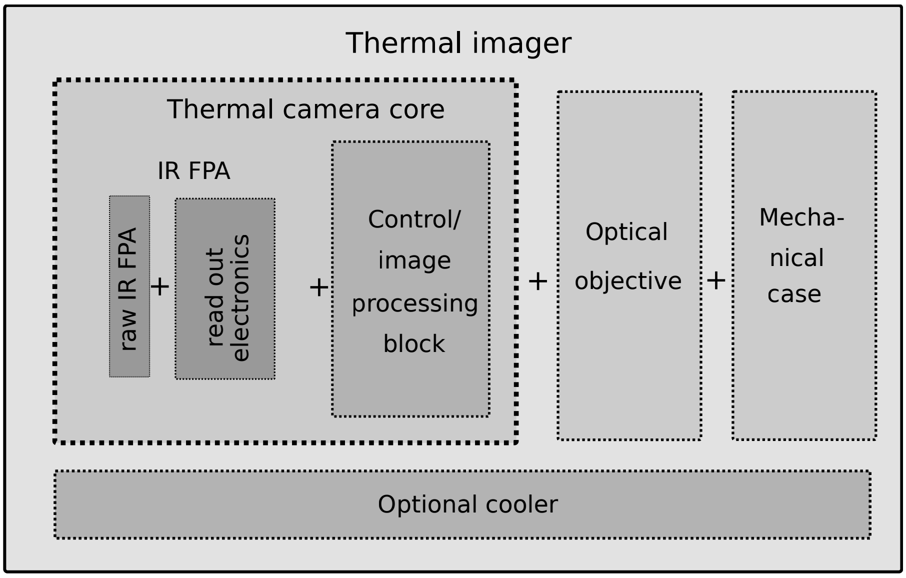

Fig. 6.Stages of design of thermal imagers

In detail, FAPA is a turnkey system that generates IR radiation of precisely controlled spatial and temporal distribution to the input plane of tested IR FPA, controls the tested IR FPA; and finally carries out semi-automatic analysis of the output signal necessary to perform characterization of the tested IR FPA sensors (or a thermal camera core). The system enables measurement of all important parameters (noise/sensitivity, image quality, and spectral parameters) of raw IR FPA sensors, IR FPA sensors and camera cores. Sensors of different spectral bands (LWIR or MWIR), cooled or non cooled can be tested.

3 General concept of FAPA

FAPA is a modular system built from a series of modules that can be configured to create a series of different sub-systems intended for measurement of different groups of parameters. However, basically all modules of FAPA can be divided into three groups (blocks):

1. Radiometric tools,
2. Sensor control/image processing tools,
3. Image acquisition/computing tools.

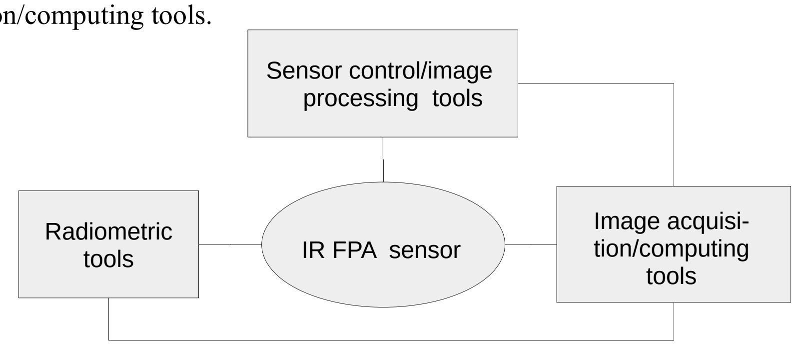

Fig. 7.Groups of tools used by FAPA system

The first group includes modules that generate necessary radiometric stimulus to input of tested IR FPA sensor. This stimulus can be in different forms: large uniform image, or edge/line/pinhole image. This group includes such modules like blackbodies, IR sources, collimators, optics, mechanical stages, optical integrators, optical projectors, monochromators.

The second group includes a series of electronic tools that form a quasi universal electronic controller system for control of complete IR FPA sensors. This system (coded as CONIR) enables three main functions:

1)to provide input electronics signals to the tested IR FPA sensor needed to make sensor to generate output signals

2)carry out basic signal processing,

3)conversion of sensor output signals into a electronic video image in one of standards of electronic video image.

The third group (coded as COMP) is practically a PC set with two types of accessories:1)frame grabbers to enable acquisition by PC of electronic video image from the CONIR sensor controller, 2)set of specialized computer programs for image processing and calculation of parameters of tested IR FPA sensor on basic of captured images. Different versions of COMP block are needed to support measurement of different groups of parameters of IR FPA sensor/cores.

It should be noted that the second block (coded as CONIR sensor controller) is strictly needed when testing IR FPA sensors. It is not needed when testing thermal camera cores having their own miniaturized sensor controllers. However, in spite of being optional CONIR sensor controller is the most important block of FAPA system.

4 CONIR sensor controller

CONIR is an universal controller of IRFPA sensors capable to control of great majority of IR FPA sensors offered on the market and due to its universality can be a very useful tool for R/D projects. The controller enables image processing up to 4096 pixels per line and up to 4096 lines, depending on the available memory. It is a delivered as a set of electronic cards (pattern generator, bias generator, analog digital converter, digital acquisition card, and preamplifiers modules), PC set, and software package. The hardware components are delivered in the form of several electronic cards enclosed in a 19” x 3U rack housing.

In other words, CONIR is a complete set of tools to run virtually any IR FPA sensor offered on market. In detail, CONIR supports control of FPAs and ROICs from such manufacturers as Lynred, Hamamatsu, IRay, Andanta, Mikro-Tasarim and many others.

Detail technical specifications of CONIR sensor controller is presented in a separate CONIR data sheet.

5 Configurations of FAPA system

FAPA test system can be configured into four semi independent subsystems:

1. FAPA-N system for measurement of noise/responsivity parameters of IR FPA sensors or thermal camera cores,
2. FAPA-I system for measurement of image quality parameters of IR FPA sensors or thermal camera cores,
3. FAPA-C system for measurement of spatial responsivity of raw IR FPA sensors (before integration with ROIC),
4. FAPA-S system for measurement of spectral parameters of IR FPA sensors or thermal camera cores.

All four combined subsystems offer expanded testing of raw IR FPAs, complete IR FPAs, and thermal cameras cores. These four FAPA subsystems shall be discussed in detail in next sections.

6 FAPA-N system

The aim of FAPA-N system (see photo at Fig. 2) is to enable noise/responsivity tests of IR PFA sensors and thermal camera cores. In detail, the FAPA-N system performs three functions:

1. Quasi uniform irradiation of tested IR FPA sensor. In detail, it is simulated situation when tested sensor located at focal plane of optical objective see a large blackbody target of known temperature. The target is large enough to fill FOV of set sensor – objective. This function is carried out by a set of modules that form a block coded as BIRAD (blackbody irradiator) that shall be discussed in detail in this section.
2. Electronic control of tested IR FPA sensor by delivery of proper bias voltages and clocking. This function is carried out by CONIR controller presented in Section 4. Attention: this function is not needed when testing camera cores.
3. Remote control of BIRAD modules and image acquisition/processing/computing of video images generated by CONIR block. This function is carried out by COMP-N block defined in Section 3.

Therefore it can be said that FAPA-N is built form three main blocks: BIRAD blackbody irradiator, CONIR controller, COMP-N computing system.

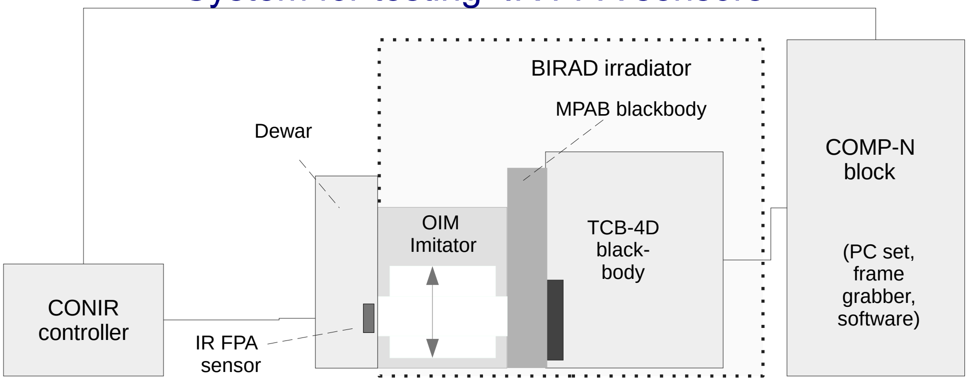

Fig. 8.Block diagram of FAPA-N station

Detail design as below:
BIRAD blackbody irradiator is built from following modules: TCB-4D blackbody, MPAB movable blackbody, set of exchangeable four OIM optics imitators, and BP base platform as shown in Fig. 8.
BIRAD blackbody irradiator is the critical block of FAPA-N station. It enables uniform irradiation of tested IR FPA sensor at high dynamic in both thermometric and radiometric calibration. It is based on concept of two blackbodies: TCB-4D and MPAB blackbody separated from tested IR FPA sensor by OIM optics imitator. The latter block enables to simulates all types of typical IR optical objectives used in real thermal imagers.
Due to use of MPAB movable blackbody it is possible to achieve very fast change of irradiance of the IR FPA sensor needed during NUC tests.
Detail performance parameters of BIRAD irradiator are presented in Table 1.
CONIR controller is the same block as presented in Section 4.
COMP-N computtin block is built from following modules: PC set, LVDS frame grabber, and control/test software (TCB Control program, TAS-FPA program).

Tab. 1. Performance parameters of FAPA-N station

Parameter	Value
Simulated optics	
Transmission	1
Spectral band	At least 3 to 14μm
F-number of simulated optics	Step variable: from 1 to 4 (1,2,3, 4) F1 recommended for non cooled LWIR sensors F2 recommended for cooled LWIR sensors F4 or F2 recommended for cooled MWIR sensors
Irradiance non-uniformity	The same as for real optics of specified F-number
Thermometric mode	
Absolute temperature of simulated large target	At least from 0 ºC to 100ºC
Differential temperature of simulated large target	At least from 0 ºC to 80ºC (at ambient temperature 20ºC
Emissivity of simulated large target	0.98±0.005
Resolution of temperature regulation	1mK
Temporal stability	±3mK
Radiometric mode	
Absolute irradiance at sensor plane *	3-5μm band: 40.2 to 1016 μW/cm^2 (for F1 optics) 8-12μm band: 1492 to 6388 μW/cm^2 (for F1 optics)
Differential irradiance at sensor plane*	3-5μm band: 0 to 926 μW/cm^2 (for F1 optics) 8-12μm band: 0 to 4236 μW/cm^2 (for F1 optics)
Resolution of iadiance regulation	3-5μm band: 0.0034 μW/cm^2 (for F1 optics) 8-12μm band: 0.037 μW/cm^2 (for F1 optics)

*Attention: approximate values. Effective irradiances do depend on details of spectral band of tested IR FPA sensor.

FAPA-N enables measurement of following parameters:

1. Thermometric response parameters: thermometric response function TRF, signal transfer function SiTF, dynamic range (relationship between output image brightness in digital levels dL and input sensor irradiation in thermometric units: mK),
2. Radiometric response parameters: radiometric response function RRF, responsivity, linearity, dynamic range (relationship between output image brightness in digital levels dL and input sensor irradiation in radiometric units: W/cm^2. Attention: information on spectral sensitivity is needed.
3. Electric noise parameters: temporal noise, high frequency spatial noise, low frequency spatial noise (rms of different types of noise present in image generated by the sensor in electric unit: mV
4. Noise related parameters: NETD, FPN, NEP, D* (sensor performance parameters calculated on basis of measured response parameters and electric noise parameters,
5. Two point NUC parameters: Gain/offset correction factors
6. Bad pixels (determined using different criteria: responsivity, electric noise parameters, pixel NETD, pixel D*, pixel gain, pixel offset),
7. 3D noise model, NPSD, quantum efficiency (option)

Measurements can be carried out for total area, selected area of tested IR FPA sensor, total area minus bad pixels, selected area minus bad pixels.

7 FAPA-I system

The aim of FAPA-I system (see photo at Fig. 3 and block diagram at Fig. 9) is to enable image quality tests of IR PFA sensors/ thermal camera cores. In detail, the FAPA-I system performs four functions:

1. Projection of images of exchangeable reference targets on surface of tested IR FPA sensor. The sensor creates image of the reference target. Analysis of quality of this image delivers information on image quality parameters of the sensor.
2. Precision movement of image of the reference target at any desirable location within area of the tested IR FPA sensor.
3. Electronic control of tested IR FPA sensor by delivery of proper bias voltages and clocking (the same fuction of CONIR block as in FAPA-N station).
4. Control of radiation source and mechanical stage resposible for position of projected image,
5. Acquisition of video images generated by tested IR FPA sensor, image processing and calculation of image quality parameters.

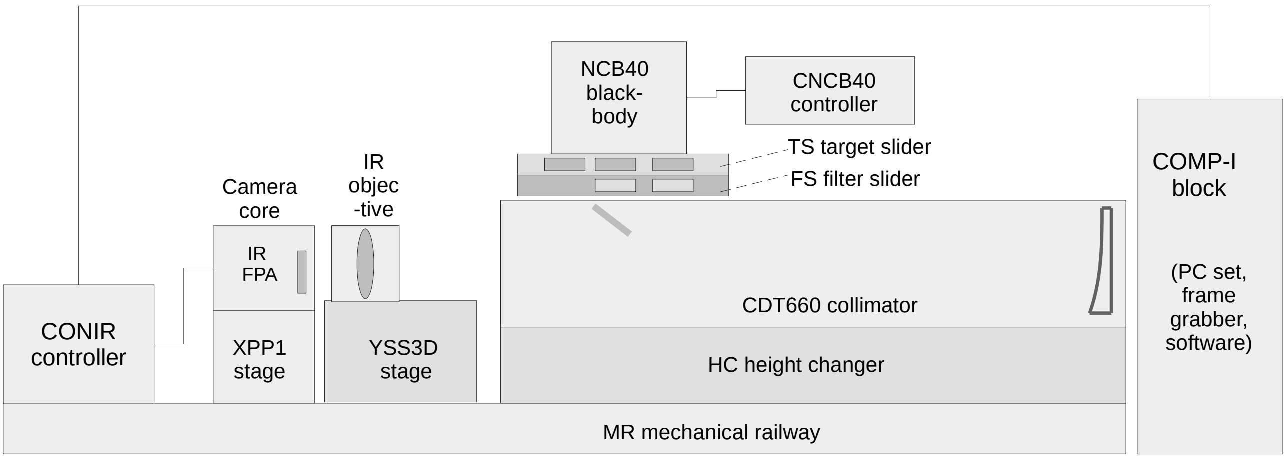

Fig. 9.Block diagram of FAPA-I station

From desing point of view FAPA-I is built from following blocks

1. CDT760 HR collimator: reflective optical projector,
2. NCB40 blackbody: broadband radiation source,
3. TS target slider - to enable easy exchange of targets,
4. Set of IR targets - set of five targets (vertical slanted edge, horizontal slanted edge, slit, pinhole 1, pinhole 2)
5. FS filter slider - to enable easy exchange of spectral filters
6. Set of spectral filters - set of two spectral shortwave filters used to change spectrum of radiation of image to be projected by collimator
7. Set of reference IR optical objectives - to create image projected by the collimator on the surface of IR FPA sensor

8. YSS3 computerized x-y-z stage - ultra precision x-y-z stage that enables regulation of position of reference IR objective and position of image created by this objective
9. XPP1 platform -manual vertical platform for rough vertical position of tested IR FPA sensor/camera core,
10. CONIR controller – for control of IR FPA sensors (not needed when testing camera cores).
11. XMR mechanical rail – to enable mechanical movement of XPP1 stage, YSS3D stage along optical axis of the collimator,
12. HC heigh changer – mechanical block that increase height of optical axis of the CDT760 collimator to be equal to optical axis of the IR objective (needed due to mechanical constraints generated by YSS3D stage).
13. COMP-I block built form PC set, LVDS frame grabber, control/test software (ROB Control program, TAS-FI program).

FAPA-I enables measurement of following parameters:

1. MTF modulation transfer function (measured using slanted edge method)
2. Cross-talk (1-calculated on basis of measured MTF, 2)measured directly using spot projection method)
3. Spot scan (scanning sensor total area with spot light in search for significantly non perfections).

Tab. 2. Performance parameters of FAPA-I station

Parameter	Value
Image projection	
Type of projected images	vertical slanted edge, horizontal slanted edge, slit, pinhole 1, pinhole 2
Spectral band	At least 1-15µm
De-magnification ratio	At least 12 times
Non perfection of edge image	Below 1 µm
F-number of reference optical objectives	F1 for LWIR objective F2 for MWIR objective
Aberrations of reference optical objectives	Much below diffraction effect of the objectives
Mechanical scanning	
XY scanning area	At least 15x15 mm
Scanning resolution	Two modes: 1)rough movement – 5 um; 2)precision movement: 1 um
Focusing range	At least 14 mm
Focusing resolution	At least 2.5 um
Control	From PC via USB

8 FAPA-C system

FAPA-C (photo at Fig. 4) is an exceptional sub-system of FAPA system. It it the only subsystem that enables testing raw IR FPA sensors before integration with ROIC electronics. It enables spatial responsivity tests (mainly measurement of crosstalk) of such raw sensor.

FAPA-C system looks apparently as non important because basically cross talk of IR PFA sensors can be also measured using FAPA-I presented in previous section. However, there are two main differences:

1. FAPA-C enables direct measurement of cross-talk of raw IR FPA sensors when FAPA-I enables typically indirect (via measurement of MTF) measurement of cross-talk of a set: raw IR FPA sensor and ROIC electronics,
2. FAPA-C enables ultra accurate measurement of cross-talk of raw IR FPA sensors (including weak cross talk between far away pinholes) when FAPA-I enables only measurement of strong crosstalk between neighbor pixels. Practical experiments have shown that weak crosstalk between active pixel and hundreds of far away pixels can be as important as strong crosstalk between active pinhole and its neighbor pinholes. The prime example is situation when image of aircraft located on cold sky background becomes distorted due to influence of warm large ground targets and warm clouds.

In such a situation FAPA-C is a very valuable tool that help to optimize manufacturing of raw IR PFA sensors and to develop sensors having very small cross talk and near perfect MTF (both parameters are related).

It should be noted that FAPA-C is based on a special spot projection system capable to project image of spot below 8 um. It it a level that competing systems cannot achieve.

Due to big design and application differences FAPA-C is offered commercially in two forms:

1. subsystem of bigger FAPA system,

2. independent test system coded as SPOT.

Technically both forms are the same. Technical details of FAPA-C (SPOT) are presented at https://www.inframet.com/Data_sheets/Spot.pdf

9 FAPA-S system

The aim of FAPA-S system (photo at Fig. 5) is to enable spectral tests of IR PFA sensors/camera cores. In detail, FAPA-S is used to measure relative spectral sensitivity. Measurement of this parameters appears to be of limited value because relative spectral sensitivity of commercially available IR FPA sensors is typically approximately determined by transmission of coated optical windows integrated with these sensors. Transmission of the windows can be accurately measured much more easily than relative spectral sensitivity of the IR FPA sensors. However, relative spectral sensitivity of IR FPA sensor measured in two main forms (average relative spectral sensitivity of total sensor, standard deviation of relative spectral sensitivity of pixels of the sensor) measured on sensor before integration with the coated window deliver valuable information on performance of IR wafer used to manufacture IR FPA sensor.

Attention: standard deviation of relative spectral sensitivity of pixels of the sensor cannot be accurately measured in case of non cooled LWIR sensors due to too low responsivity.

FAPAT-S station is a system that that irradiate tested IR FPA sensor, measure reactions of the sensor to this radiation and calculates spectral parameters of this sensor.

In detail, the FAPA-S system performs three functions:

1. Irradiation of a part of tested IR FPA sensor using radiation of variable wavelength and of known intensity (SPECTR irradiator),
2. Electronic control of tested IR FPA sensor by delivery of proper bias voltages and clocking (this function is done by typical CONIR block) .
3. Remote control of modules of SPECTR, image acquisition, computing of video images generated by tested sensor, calculation of spectral parameters. This function is carried out by COMP-S block defined in Section 3.

Therefore it can be said that FAPA-I is built form three main blocks: SPECTR variable wavelength irradiator, CONIR controller, and COMP-S computing system.

The first task to irradiate uniformly IR FPA sensor of tested camera core using light beam of variable precisely known wavelength and of specified known intensity level looks to be simple: just to buy a blackbody and a monochromator and to use it. Practically this task is a technical challenge and there are very few vendors of equipment suitable for such task.

Total list of modules is as below:

1. SPECTR irradiator
   1. BLAM blackbody
   2. OP1 optical projector - to project image of emitter of BLAM blackbody to input slit of the monochromator and to optimize incoming beam to monochromator optics,
   3. AT attenuator
   4. FC filter changer - to enable easy exchange of edge filters needed to eliminate problems with harmonics of main wavelength to be transmitted,
   5. Set of 3 edge filters ,
   6. SH shutter - to enable simulation of low temperature background,
   7. M250BB monochromator - to work as variable wavelength narrow band filter of regulated wavelength,
   8. OP2 optical projector - to project image of monochromator slit to plane of IR FPA sensor of tested camera core,
2. CONIR
3. COMP-S
   1. set of two frame grabbers (analog video and CameraLink)
   2. PC set
   3. WAVE Control program - to control M250BB monochromator, SH shutter, and FC filter changer,
   4. SPECTEST program to support measurement of spectral parameters
   5. API WAVE program to allow customer software to control BLAM blackbody, SH shutter, FC filter changer, M250BB monochromator (option)

Tab. 3. Parameters of SPECTR irradiator

Parameter	Value
Spectral band	At least 3-14μm
Resolution of regulation of wavelength	30nm at MWIR 60 nm at LWIR
Dynamic of regulation of radiation intensity	At least 100 times

PC control	USB 2.0

10 Customer responsibilities

There are two main resposibilities of user of FAPA:

1. User is expected to deliver simple user board that work as a buffer between CONIR and sensor. Development of such user boards is much simpler than development of the specialized control electronics. Tinframet delivers detail guidelines to develop required user board.
2. User is expected to deliver cooler (typically dewar) to cool IR FPA sensor to be tested. Inframet can deliver some guidelines for optimal dewar but does not deliver any cooler to be a part of FAPA system.

11 Desing optimization

The main application of FAPA is characterization of IR FPAs at different stages of integration with other blocks: raw IR FPA sensor, complete IR FPA sensor, thermal camera core and optionally complete thermal imagers. Finally, it should be noted that FAPA enables not only measurement of parameters of IR FPA sensors. In fact it can be used for design optimization of both raw IR PFA sensors, complete IR PFA sensors, and thermal camera cores.

1. FAPA-C enables directly ultra precision measurement of crosstalk of raw IR FPA sensor. These measurement results enable indirectly optimization of properties of wafer used to manufacture this raw IR FPA sensor.
2. FAPA-I station combined with CONIR controller enable directly measurement of MTF/cross talk of complete IR FPA sensors. However, in contrast to typical specialized control electronic blocks CONIR enables flexible regulation of bias voltages supplied to tested IR FPA sensor. In this way it is possible to find optimal combination of bias voltages that enables to obtain best MTF of the IF FPA sensor. This new set of bias voltages can be later used for guidelines to develop specialized control electronics for IR FPA sensors used by thermal imagers.
3. Similar optimization is possible in case of FAPA-N station combined with CONIR controller. They enable directly measurement of noise/sensitivity of complete IR FPA sensors. However, they enable also to find optimal combination of bias voltages that enables to obtain minimal noise and maximal resposivity the IF FPA sensor.
4. FAPA-N enables directly two point non uniformity correction. However, it means that it can be used to optimized image processing used to reduce spatial noise of IR FPA sensor.

12 Versions

FAPA is a modular test system can be delivered in different versions of different design, different test capabilities and at different price level. The version can be precisely determined using the five digit code as shown in the table below.

Tab. 4. Versions of FAPA test system

Subsystem	YES	NO
CONIR	1	0
FAPA-N	1	0
FAPA-I	1	0
FAPA-C	1	0
FAPA-S	1	0

Code FAPA 11111 means FAPA system that includes CONIR controller and all four FAPA subsystems: N, I, C and S. Such test system can be used for testing both complete IR FPA sensor, raw IR FPA sensors (crosstalk, MTF) and camera cores.

Code FAPA 01111 means FAPA system of potentially can measure the same number of parameters of complete IR FPA sensor, raw IR FPA sensors (crosstalk, MTF) and camera cores but CONIR is not included and customer must have its own controller of IR FPA sensors.

Code FAPA 11000 means FAPA system in most typical FAPA-N configuration (including CONIR) capable to control IR FPA sensors and do noise/responsitivity tests.

13 Options

Inframet can optionally deliver

1. AT optical table to be used as platform for FAPA system.
2. Additional DT system for testing complete thermal imagers (coded as FAPA-DT)
3. EL customized test station to enable powering and basic electrical tests of cooled thermal camera cores using Stirling coolers. EL is to enable following functions:

1. Power supply and measurement of power consumption of cooler of tested cooled thermal camera core (max voltage 60V, max current 20A)
2. Measurement of cool down time of tested IR FPA sensor (DT-670 temperature sensor or 2N2222 transistor).

14 Requirements on customer

FAPA is a potentially universal control/test system. However, there are some requirements on customer:

1. Customer is responsible to deliver dewar or other cooling system.
2. Customer is responsible to power cooler system in case of Stirling coolers.
3. Customer is responsible to deliver optical table where FAPA system can be located.
4. Inframet can accept window at side wall or bottom of dewar but must know details in advance to optimize design.
5. Window flatness must be not worse than P-V L/2 at L=630nm in order to avoid effect when the window degrade transmitted image,
6. Distance from front mechanical wall of dewar to sensor plane is to be not more than 10mm (it can be optionally increased).
7. It is recommended if customer could share with Inframet data sheets of sensors to be tested using FAPA system.
8. It is preferable (not strictly needed) if customer could send to Inframet a sample sensor to be tested.

*specifications are subject to change without prior notice

Data sheet version 8.1

CONTACT:

Tel: +48 604061817 Fax: +48 22 3987244 Email : info@inframet.com