LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T1900596-v3	*LIGO A+*	June 2020

A+ BOSEM IR LED
Screening Procedures

J.L Bryant, D Hoyland

Distribution of this document:
Inform aligo_sus

School of Physics and Astronomy
University of Birmingham
Phone +44 (0) 121 414 6447
Fax +44 (0) 121 414 3722
E-mail av@star.sr.bham.ac.uk

http://www.ligo.caltech.edu/

http://www.physics.gla.ac.uk/igr/sus/

http://www.sr.bham.ac.uk/gwgroup/index.php

1 Introduction and Scope

This document describes the rationale and procedure for screening of IRLEDs for use in BOSEM production for the LIGO A+ upgrade. It begins by outlining the screening which was introduced for AdLIGO BOSEMs. The reasons for its introduction are documented in reference [2]. Screening process enhancements which aim to ensure compatibility of new devices with the installed units are described.

This document also includes characterization tests procedures for completed BOSEM assemblies.

1.1 Version History

Rev. v1 - Initial release. Sept 2019 (DMH, JLB)

Rev. v2 – Update following review. Added missing part labels in fig 5.2.2. Update figure 5.3.3. Updated burn-in (section 6.1) to include monitoring of power before and after test per RODA (reference [8]) to ensure rejection of potential early failure devices. Additional screening step added to identify devices which exhibit lowest noise, for installation in BOSEMs which can be used in critical locations.

Rev. v3 – Added appendix with more details on software operation. The software has also been revised, and these updates have been reflected in the text.

1.2 Acronym List

ATE	Automatic Test Equipment
DSA	Dynamic Signal Analyzer
DMM	Digital Multi-Meter
DUT	Device Under Test
IRLED	Infra-Red LED
PSU	Power Supply Unit

1.3 References

(1) T060233-04-K BOSEM Assembly Specification

(2) T0900496-v4 Advanced LIGO BOSEM Noise Measurement Report

(3) T050111-06-K BOSEM Design Document & Test Report

(4) G1100856-v5 BOSEM Satellite Amp Saturation

(5) E1100767-v1 UK Satellite Amp Rev 2 Upgrade

(6) T050111-06-K BOSEM Design Document

(7) T1900423-v2 Proposed IR Emitter Failure Analysis

(8) M1900038 RODA BOSEM replacement IRLED.

2 IRLED Screening for Advanced LIGO BOSEM Assembly

To derive screening parameters for A+ we start by examining the screening used for AdLIGO. This is described below:

The screening procedure used in AdLIGO BOSEM production is given in Appendix A of reference [2]. It uses a simple 'open light' test rig which positions each DUT on the optical axis of a BPX65 photodiode. The LED is driven, and the Photocurrent read using a satellite box unit. An SR560 Preamplifier converts the satellite box output from differential to single ended AC coupled format for the Agilent 35670 DSA. DC output amplitude is measured on a DMM. There is no flag assembly and the photocurrent output ***approximates*** to the maximum achievable output of the BOSEM.

The process aimed to select (TSTS7100) devices of a pre-determined **minimum** light output, and noise which is based on the BOSEM requirement defined in reference [3] as:

- Worst Case Noise (1-10Hz) = 3×10^{-10}m/√Hz
- Worst Case Noise (10-20Hz) = 1×10^{-10}m/√Hz

The noise was the critical parameter in this procedure and devices were selected by testing (with margin) at a spot frequency of 10Hz. Conversion to V/√Hz is achieved as follows:

$$V = N_{limit\_10Hz} \times 2K \times M$$

This gives a spot frequency limit of 3uV/√Hz (-110dBV/√Hz) at 10Hz.

K = 25000V/m and is the conversion constant for the BOSEM based on a dynamic range of 0.8mm and maximum BOSEM/satellite amplifier differential output of 20v.

The factor 2 accounts for the fact that the test rig has no flag and so the output is at the top of its dynamic range rather than the mid-point.

M = 0.6 is the applied margin for the test. This is an empirically determined factor which ensures adequate pass margin over the entire 1-20Hz range.

The light output screening portion of the process resulted in a photocurrent output distribution for the completed batch of AdLIGO BOSEMs as shown in figure 53 of reference 2. The photocurrent represents the maximum output (ie flag fully retracted), and shows a range of $45uA \le I_{photo} \le 80uA$.

3 Satellite Box Transimpedance and Drive Current

The AdLIGO satellite box design originally had channel transimpedance of 160KΩ (with differential output giving and additional factor 2 ie 320KΩ). The IRLED drive current was 35mA.

Subsequently, see ref [4] and [5], it was found necessary to reduce the transimpedance from 160KΩ to 121KΩ in order to prevent some of the BOSEM units overdriving the transimpedance amplifier and/or data acquisition.

4 Requirements for Screening IRLEDs for A+ BOSEMs

To ensure direct compatibility with existing BOSEM and Satellite amplifier units, the requirements for screening the IRLEDs must ensure completed BOSEM units:

1) Meet the noise requirement of
   - Worst Case Noise (1-10Hz) = 3×10^{-10}m/√Hz
   - Worst Case Noise (10-20Hz) = 1×10^{-10}m/√Hz

(Note: A further lower limit has been requested (see section 5.4 below) to identify devices with exceptional low noise which can be used in critical applications – we classify these as ‘enhanced’ devices in the following sections)

2) Have maximum open light photocurrent within the range
   - $45uA \le I_{photo} \le 80uA$

In addition, as with AdLIGO IR LEDs, a burn in stage will be incorporated prior to the screening in order to remove any devices likely to be ‘early failures’. The original AdLIGO devices were burned in for 50Hrs at the devices I_{max}. However during auditioning and testing of candidate devices for the IRLED, evidence was found of one specific device type (Hamamatsu L1915 – now a rejected candidate) exhibiting increased noise during initial (50) hours of operation (reference [7]). As a precaution, the burn period of all devices will be extended from 50 to 168Hrs (7 days) at I_{max}, to ensure such all devices are removed from the production flow.

5 Burn in and Screening Test Equipment

5.1 Burn in Jig

The burn in jig is identical to that used for AdLIGO IRLED processing (ref [3]), and is shown in figure 5.1.1 below. IRLEDs are plugged into DIL sockets on each Eurocard array containing 50 devices. The devices (plus a series resistor) are all connected in parallel across a suitable PSU, capable of delivering the required current, and the devices are left for 168Hrs. (Power output from each device is measured before and after the test, in order to identify and reject any potential ‘early failure’ devices). Forced-air cooling is used to ensure devices do not exceed their operational temperature limit. After the test, devices are removed from the array and stored in an ESD safe container ready for screening.

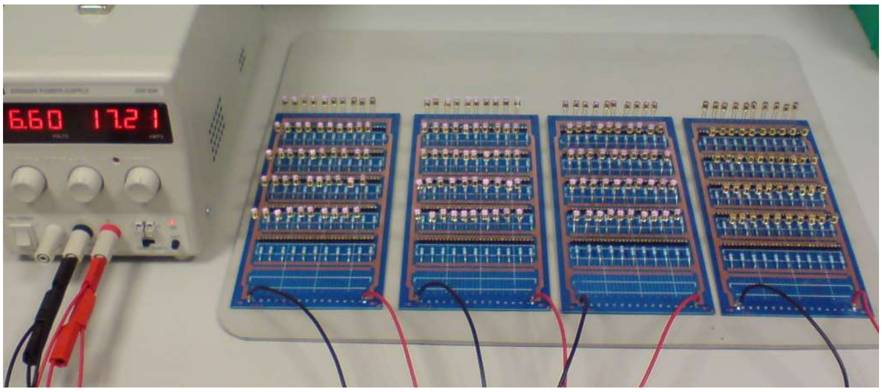

Fig 5.1.1 IRLED Burn In Jig

5.2 Optical Screening Jig

To measure the expected photocurrent that the IRLED creates in the completed BOSEM, the screening rig has been modified to incorporate the complete BOSEM PD assembly and IRLED assembly as shown in figure 5.2.1 and 5.2.2 below (from reference [6]). The assemblies are secured on optical mounts at separation identical to that in a complete BOSEM (5mm) as shown in figure 5.2.3. A light proof cover is also placed around the optical path to minimize stray light and 50/100Hz pickup from lighting.

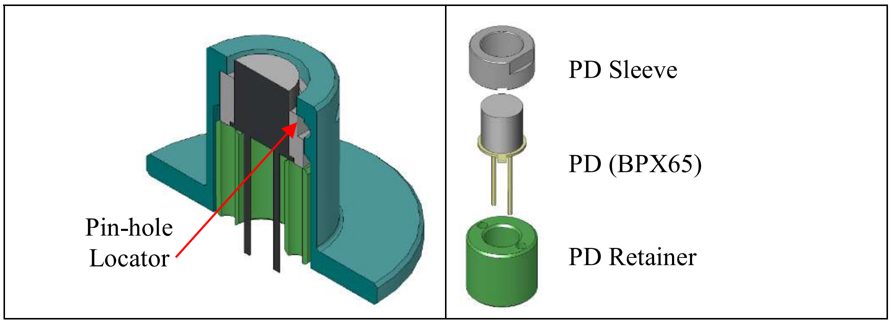

Fig 5.2.1 BOSEM PD Assembly

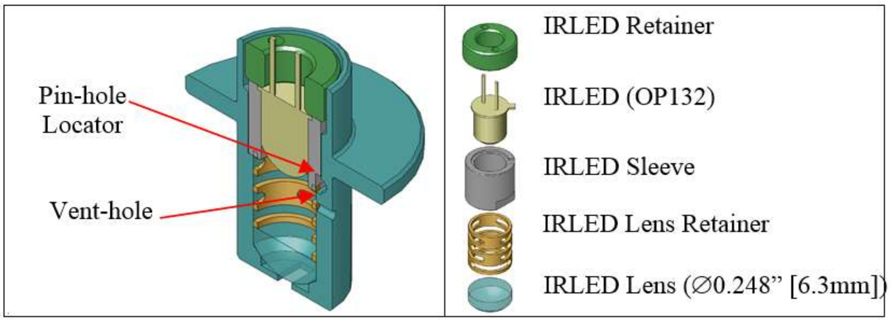

Fig 5.2.2 BOSEM IRLED Assembly

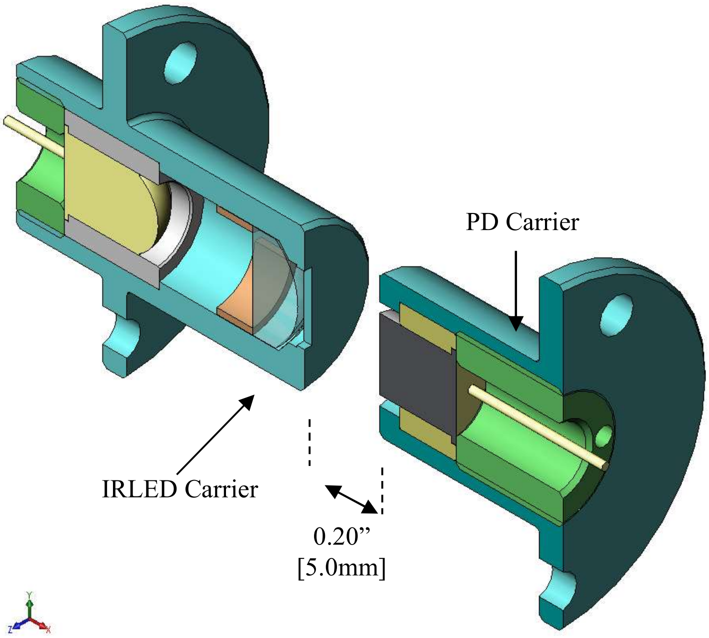

Fig 5.2.3 Section thro complete assembly

The complete jig is shown in figure 5.2.4 below

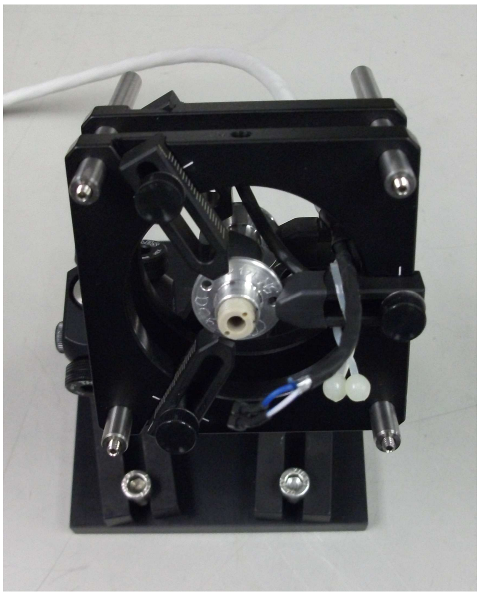

Figure 5.2.4 Completed Optical Screening Jig

5.3 Screening Readout Electronics

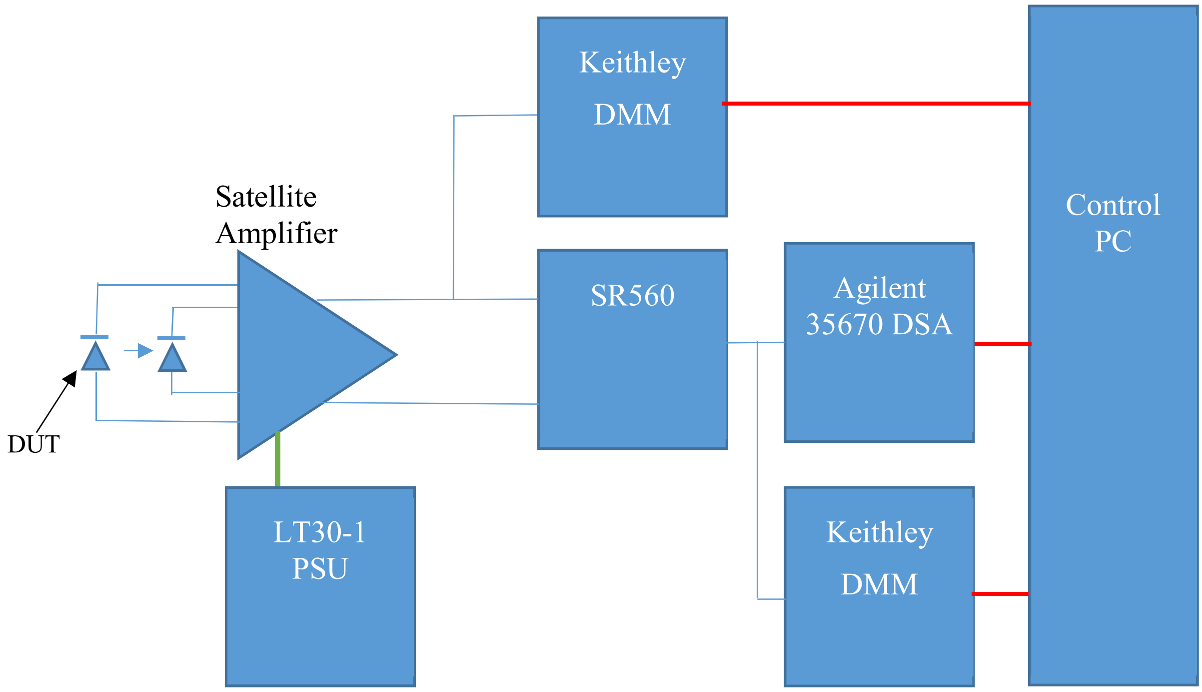

Figure 5.3.1 Readout electronics configuration

The readout electronics is shown in Fig 5.3.1 above, and comprises a production Satellite Amplifier unit modified per current in service units (reference [4] and [5]). Additionally, the whitening filter was also removed to prevent pre-distortion of the noise spectra measurements.

An SR560 Preamplifier is used to convert the satellite box output from differential to single ended AC coupled format for the Agilent 35670 DSA, with (single ended) DC voltage amplitude measured on a DMM.

The test process is automated using a Labview ATE application with GPIB control interface, which configures the instruments (see sections 5.3.1 and 5.3.2 below), conducts the test, and records the results. Devices are binned according to 'pass', 'enhanced pass' or 'fail' outcome. Note: the ATE also monitors the SR560 output with a second DVM, allowing it detect transients on the output when a new DUT is plugged into the rig, thus only allowing the test to commence when the output has settled.

Figure 5.3.2 below shows a screen shot of the Labview ATE application. Figure 5.3.3 gives an example of the results summary document output from it.

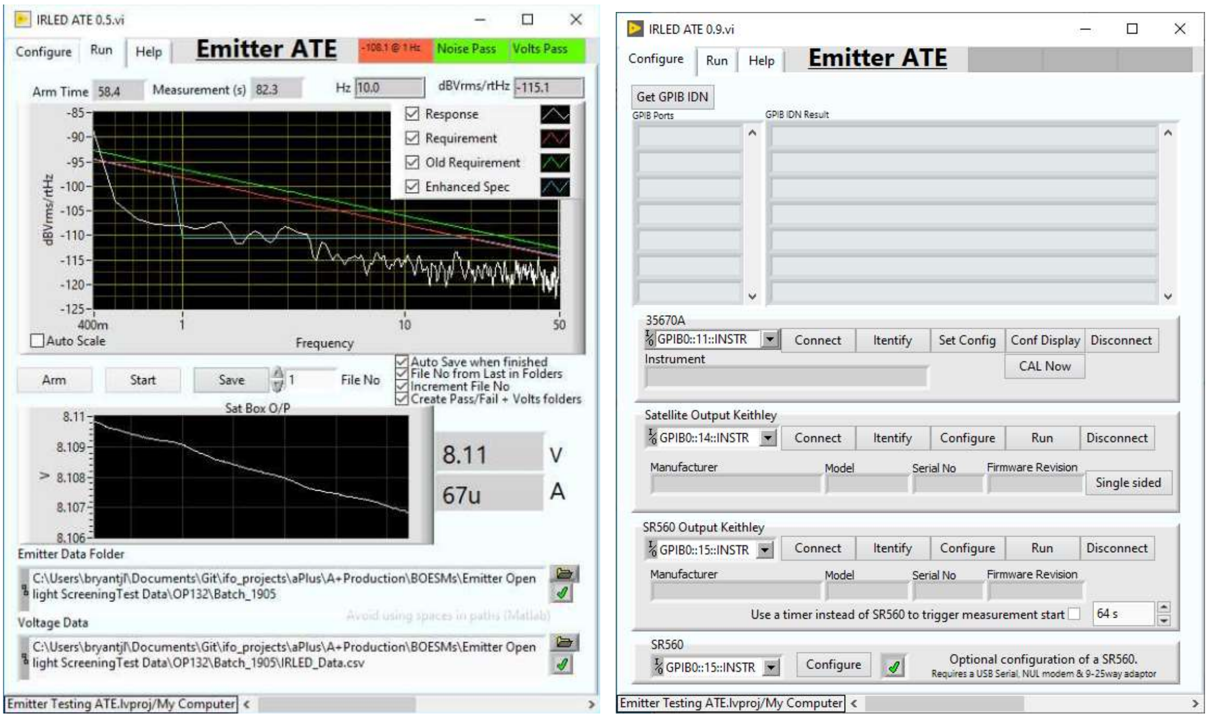

Figure 5.3.2 Labview ATE Software

	A	B	C	D	E	F	G
1	Date	Time	No	PD (V)	dBVrms/rtHz	PD (A)	
2	07/08/2019	13:49	31	7.366	-114.856	6.09E-05	
3	07/08/2019	13:53	32	5.357	-120.73	4.43E-05	
4	07/08/2019	13:56	33	7.862	-116.343	6.50E-05	
5	07/08/2019	14:01	34	8.186	-118.912	6.77E-05	
6	07/08/2019	14:06	35	7.814	-117.895	6.46E-05	
7	07/08/2019	14:31	36	6.326	-104.531	5.23E-05	
8	07/08/2019	14:36	37	7.356	-105.823	6.08E-05	
9	07/08/2019	14:40	38	7.654	-117.739	6.33E-05	
10	07/08/2019	14:44	39	7.303	-111.245	6.04E-05	
11	07/08/2019	14:47	40	6.159	-119.455	5.09E-05	
12	07/08/2019	14:52	41	7.58	-118.874	6.26E-05	
13	07/08/2019	14:56	42	7.548	-119.555	6.24E-05	
14	07/08/2019	14:59	43	6.82	-118.455	5.64E-05	
15	07/08/2019	15:03	44	7.41	-117.68	6.12E-05	
16	07/08/2019	15:06	45	5.937	-119.678	4.91E-05	
17	07/08/2019	15:10	46	7.737	-117.086	6.39E-05	
18	07/08/2019	15:13	47	7.15	-117.745	5.91E-05	
19	07/08/2019	15:16	48	5.773	-104.511	4.77E-05	
20	07/08/2019	16:29	49	6.87	-118.033	5.68E-05	
21	07/08/2019	15:45	50	6.773	-118.439	5.60E-05	
22							

Figure 5.3.3 ATE Output data

5.3.1 SR560 Configuration

Filter Cutoffs (Hz) = **DC,** Coupling = **AC,** Source = **A-B,**

Gain Mode = **Low-Noise,** Gain = **1,** Power = **Line**

5.3.2 Agilent 35670 Configuration

Measurement Type: Pwr Spectrum

Trace Coordinates: dB Magnitude, X: Hz, Y: V/√Hz

Frequency: Start: 0Hz, End: 50Hz

Averages: 10 (RMS average)

Overload Reject: On

Record Length: 400 (8s)

5.4 Test Limits

Since the screening test jig has now been updated, and satellite box modified (per in service units), the screening test limits as used in AdLIGO production require revision. Revised limits for A+ IRLED screening are detailed below:

5.4.1 Photocurrent

Upper Photocurrent limit measurement: 80uA×121K = 9.7V (ie 19.4v differential)

The lower photocurrent limit is 45uA. However empirical evidence suggests that if this is increased to ~54uA, in conjunction with the BOSEM representative optical setup, this helps ensure we select devices with beam profiles that are more accurately aligned on the optical axis. This improves the transfer function linearity for the BOSEM.

Lower Photocurrent limit: 54uA×121K= 6.5V. (ie 13v differential)

5.4.2 Noise

Using the same conversion as before

$$V = N_{limit\_10Hz} \times 2K \times M$$

The constant K is defined based on the expected **mean** value of the BOSEM maximum output rather than the **maximum** itself. In this case, the mean output will be (19.4+13)/2 = 16.2v. Therefore K=20250V/m.

The factor 2 (unchanged) accounts for the fact that the test rig has no flag and so the output is at the top of its dynamic range rather than the mid-point.

M = 0.6 (unchanged) is the applied margin for the test. This is an empirically determined factor which ensures adequate pass margin over the entire 1-20Hz range.

This gives a revised **spot frequency limit of 2.43uV/√Hz (-112dBV/√Hz) at 10Hz**.

5.4.3 Enhanced low noise

Devices which exhibit low noise at 1Hz will typically show low noise across the 1-20Hz band. A further test screens out devices (which meet the above limit and) exhibit 1Hz noise which is >4 times below the standard 1Hz requirement of 3×10^{-10}m/√Hz.

The enhanced limit is therefore

$$V = (N_{limit_{1Hz}}/4) \times 2K \times M$$

This gives an **enhanced noise spot frequency limit of 1.82uV/√Hz (-114.7dBV/√Hz) at 1Hz.**

6 IRLED Screening Test Procedure

All tests are performed in a static safe working environment.

6.1 Preparation – Burn In

Equipment:

- Thurlby Ex1910R Bench PSU
- Burn-in Eurocard Assembly (UoB internal design)
- Cooling Fan
- Thor labs PM100D Power meter with S145C integrating sphere
- Custom adaptor collar for above (to repeatably locate LED for measurement)

1. Insert IRLED(s) into DIL sockets on the Burn-in Eurocard. Each Eurocard will hold 50 devices. Ensure correct orientation (the anode of the device connects to the series resistor).
2. With the required number of devices mounted on the Eurocard, attach to Thurlby Ex1810R Bench PSU, switch on PSU and Cooling Fan. Ensure airflow is directed over the Eurocard.
3. With PSU in constant current mode, increase the current to ($n \times I_{max}$) where n is the number of devices, I_{max} is the maximum continuous forward current for the DUT (100mA for OP132).
4. Using power meter, ensure all devices are operating, and record output power of each device.
5. Burn the devices in for 168Hrs (7 days)
6. Repeat step 4 to ensure all devices are still illuminated. Reject any devices which show power drop of >TBC 20%, as potential early failures.
7. Switch off the PSU and fan.
8. Remove devices from the Burn-in Eurocard and store good devices in static safe bag ready for screening.

6.2 Noise Screening

Equipment:

- PC with Labview ATE application
- Keithley 2000 DMM (2 off)
- Agilent 35670 DSA
- Stanford Research SR560 Preamplifier
- Farnell LT30-1 PSU
- Satellite Box S/N 3202-020*
- Satellite Box I/O Cables, BNC Cables, BNC T adaptors as required
- Optical Test Jig
- GPIB and serial cables

* Modified per current in service units and whitening removed (See section 5.3 above)

1. Configure the Test Equipment per section 5.3 above
2. Switch off fluorescent lights, and other non-essential lab equipment (soldering irons etc).
3. Set PSU to provide +/-18v
4. Switch on PSU, DSA, DMMs, and SR560. Observe single red light (middle) illuminate on PSU and three green (power) lights illuminate on Satellite Box.
5. Configure the SR560 per section 5.3.1 above.
6. Start the ATE software application
7. Configure the hardware:
   (The following is a quick setup procedure. For full software details see Appendix 1)
   - Select ‘Config’ tab to identify the (GPIB) connected instruments
   - Select the Agilent 35670 DSA, click the ‘Connect’ button, then ‘Set Config’ to configure the device, and ‘Cal’ to trigger a calibration cycle.
   - Select each Kiethley DMM in turn and click the ‘Connect’ button, then ‘Configure’.
   - If the SR560 is connected to the PC, then press the ‘Configure’ button, otherwise configure manually per section 5.3.1
   - Select the ‘Run’ Tab.
   - Set the folder and file paths for saving of test data.
8. Allow equipment to thermalize for 15 minutes.
9. Select an IRLED from the Post burn-in batch.
10. Conduct visual inspection of the device and check batch number (if markings are visible)
11. Install the IRLED into the screening jig mount, with the package tab located in the slot in the macor sleeve. Secure it in position with the PEEK retainer.
12. Connect the IRLED to the satellite box input cable, ensuring correct polarity (OP132: Pin closest to tab is cathode). Correct polarity is confirmed by observing that the red fault light on the Satellite box has extinguished.
13. On the ATE software press the ‘Arm’ button to begin the test. (The test starts automatically when the photocurrent signal has settled).
14. After the test completes, remove the IRLED from the screening jig and place in the appropriate bin per the test outcome.
15. Repeat the test process from step 9 for all devices in the batch
16. On completion, store pass devices in a static safe bag ready for production. Store failed devices in a static safe bag and archive.

Appendix 1. Emitter ATE Software - Detailed Operation Guide

To assist with the testing and selection of IR LEDs for LIGO A+ this software was written to automate the test sequence and guide the operator to place the LED in the correct storage bin based on its response. Additionally, data files will be saved which describe the DUT performance for analysis later.

Multiple instances of this software can be running on the same PC, allowing more than one device to be tested simultaneously. However, each instrument 'cluster' (i.e. a spectrum analyser and one or more Keithley DVMs) must be connected to its own GPIB controller to ensure correct operation of each independent test process.

This software is no longer available as a 32bit application to eliminate 32/64bit compatibility with GPIB OPC.

A1.1 Instrument selection and configuration

After connecting the instruments as detailed in section 5.3 above, and starting the software, the following should display.

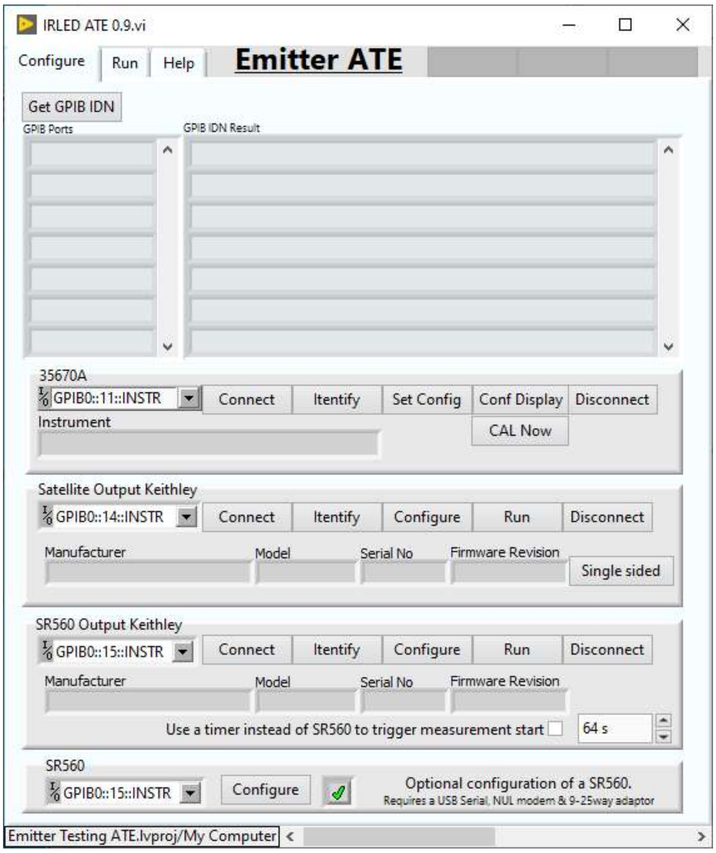

Fig A1-1

The GPIB information at the top should show the GPIB controller and each port, alongside the name of the identified instrument on that port (The number after 'GPIB' is the controller number).

In the '35670A' section of the tab select the port of the 35670A spectrum analyser, then:

- Press connect. If you have more than one 35670A connected, pressing ‘Identify’ will blank the screen of the instrument being configured. Don’t forget to stop identifying to un-blank the screen.
- Press ‘Set config’ to set the instrument configuration, this may take a few seconds to complete.
- Optionally press ‘Conf Display’ to configure the X axis to logarithmic scaling as per the usual graphing method for the data.
- Press ‘CAL Now’ to disable automatic instrument calibration and allow the software to control when to calibrate. This prevents automatic calibrations from interrupting data taking and adding noise.

In the ‘Satellite Output Keithley’ section of the tab:

- Select the GPIB port
- Press ‘Connect’ to open the instrument.
- Press ‘Identify’ to verify you are connecting to the correct Keithley. If you connect to the incorrect Keithley press ‘Disconnect’ and select the correct instrument.
- Press ‘Configure’ to set the instrument configuration.
- Press ‘Run’ to start acquisition.
- Verify how you have connected the instrument and make sure the remaining control is correctly set to ‘Single Sided’/’Differential’.

In the ‘SR560 Output Keithley’ section of the tab:

Note that the software uses this DVM to monitor transients on the SR560 output caused by insertion or disconnection of the DUT. This allows the software to automatically manage triggering of the start of a test. If a DVM is not used, the software can be configured to use a timer to allow for settling after a new device is inserted.

- If a Keithley DVM is used for this task, connect and configure as above.
- If there is no Keithley DVM for this task, check the use timer box. The default 64 seconds has proved to provide an adequate settling delay.

In the ‘SR560’ section of the tab:

Note that the software can be used to configure the SR560 if it is connected.

- If you have connected the SR560 to a serial port press the ‘Configure’ button.
- If the SR560 is not connected, then configure the instrument manually as detailed in section 5.3.1 above.

A1.2 Running the ATE

Select the Run tab

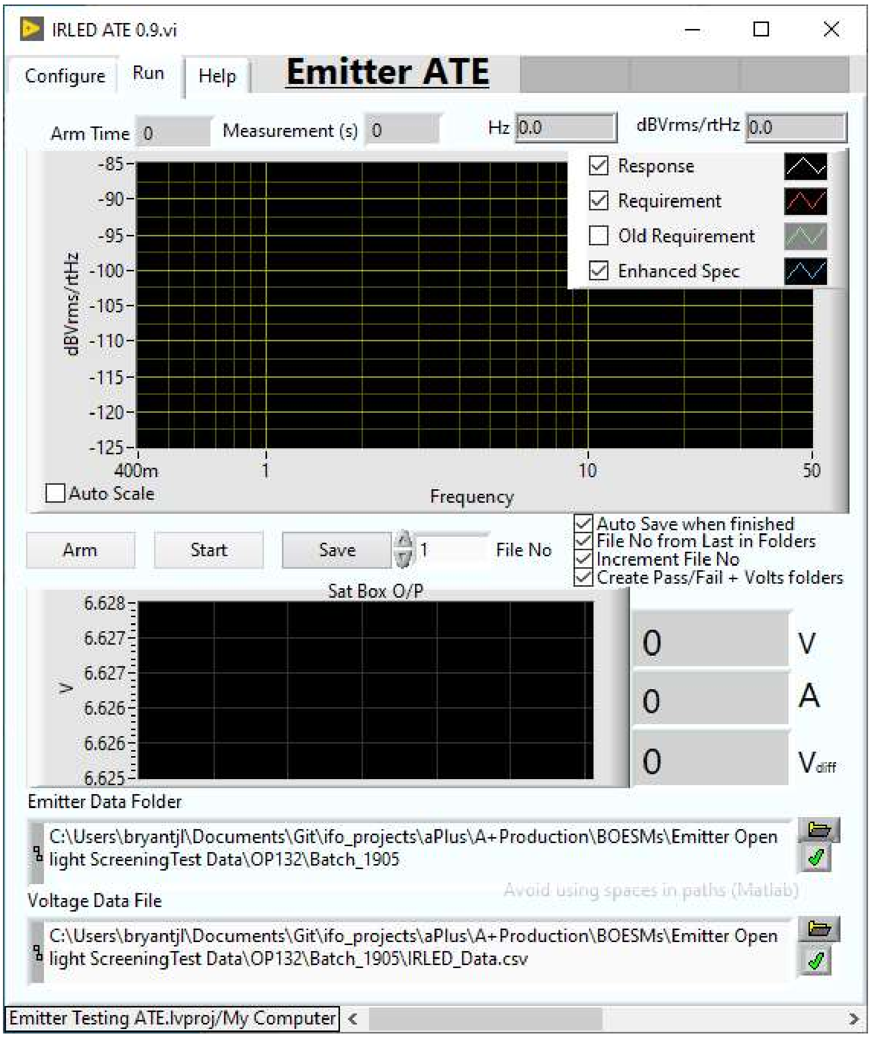

Fig A1-2

Configure 'Emitter Data Folder' at the bottom of the tab, then configure the location of the 'Voltage Data File'.

Observe the 4 tick boxes and 'File No' value box. If the 'File No from last in folders' is selected the 'File No' can be ignored and the value is chosen from the current contents of the 'Emitter Data Folder' and all of its sub folders.

When an LED is inserted in the test jig, immediately press the 'Arm' button. This will start a 35670A calibration cycle and get it ready to acquire.
When the voltage measured by the Keithley DVM on the SR560 output has reached a pre-set level (ie after the transient caused by insertion of the DUT has settled), or when the SR560 timer has expired, both Keithley DVMs will stop acquiring and the 35670A DSA will start acquiring. Data will plot on the top graph as it becomes available.

When the DSA acquisition has completed the data will be saved and the Keithley DVMs will restart acquiring.

The 'Start' and 'Save' buttons are manual controls for those functions and are not usually needed. The 'Start' button is occasionally useful if you forget to press arm, or don't press it in time. (ie the system does not see a transient).

At the top of the screen are three indicators to show if the DUT output level passes, and if the noise level passes, and if it meets the enhanced specification. These will aid in placing the device in one of the 5 output bins. The bins will be labelled as described in the table below, and selected in the same order as the table.

Label	**Criteria**
Noise Fail	All devices which fail to reach the noise requirement
Enhanced Pass	Devices meeting the enhanced noise and voltage specifications
Almost enhanced	Devices which meet the enhanced noise specification except for the low frequency test point when the graph is inspected, and that meet the voltage specification
Noise Pass	Devices which meet the standard noise and voltage specifications
Noise Pass Volts Low	Devices which meet the noise specification but with insufficient voltage (output amplitude).

Table A1-1

It should be noted that the devices in the 'Volts Low' bin and 'Almost Enhanced' bin will get stored to be used elsewhere later. Only devices that are in the 'Enhanced Pass' and 'Noise Pass' bins will be processed for A+ BOSEMs.

A1.3 Diagnostics Pages

By dragging the right hand window edge the diagnostics pages can be revealed.

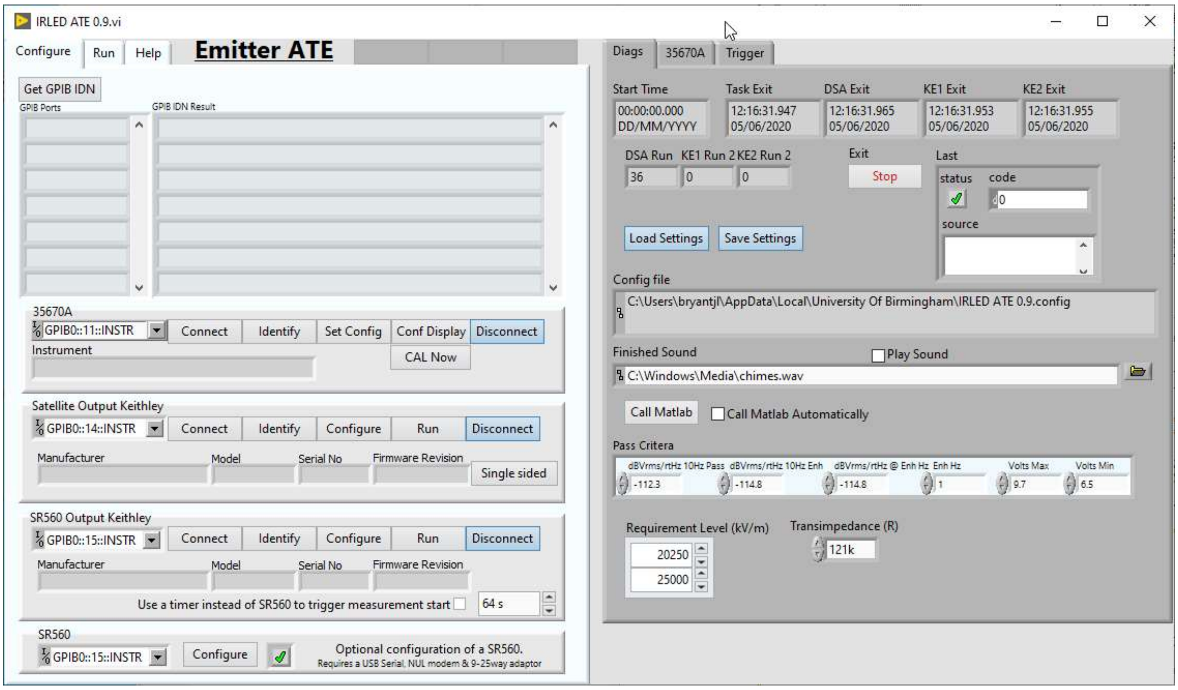

Fig A1-3

The diagnostics page is used for software development and testing. Details are not included in this document.