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A New Technique for Infrared Remote Sensing Of Solar Induced Fluorescence and Reflectance from Vegetation Covers

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Abstract

A new technique of remote sensing of solar-induced fluorescence and reflectance from vegetation covers has been developed, radiant calibrated, and applied to investigate solar-induced infrared fluorescence (680-730 nm) and reflectance (750-1000 nm) from some tropical plants within the tropical peak summer period (in August) in Nigeria, for five days, taking readings at sun rise, midday and sunset , each day. The IR device used electronic filters and Fresnel lens to attenuate signals outside the spectral bands. The radiometric detection parameters of the device stood at; Responsivity of 1.5 x 10^{31} V/W, Noise Equivalent Power NEP of 6.48 x 10^{-34} W, and Detectivity of 1.54 x 10^{33} /W at 780 nm; Responsivity of 2.2 x 10^{37} V/W, Noise Equivalent Power NEP of 4.45 x 10^{-40} W, and Detectivity of 2.0 x 10^{39} /W at 680 nm. The infrared fluorescence/reflectance for each plant canopy varied consistently with solar irradiance.

Keywords: Radiometry, Solar-Induced Fluorescence (SIF), Reflectance (SIR)

1. Introduction

Chlorophyll Fluorescence is light that has been re-emitted after being absorbed by chlorophyll pigment of plant leaves. Measurement of the intensity and nature of this fluorescence enables the investigation of plant Eco physiology. Solar induced fluorescence, SIF is chlorophyll fluorescence brought about by direct absorption of visible portion of the solar radiation. SIF increases with decreased chlorophyll content. Thus, SIF vary indirectly with photosynthesis activity and by implication, carbon dioxide drawdown by vegetation canopy increases with decreased fluorescence. Infrared sensing of SIF therefore, provides a rapid non-destructive means of studying photosynthesis and other physiological processes as stress of plants under yield conditions. This is quite beneficial to the environmental and agricultural business community. Ability to measure SIF from space with ease by remote sensing will therefore be a significant contribution. At room temperature, chlorophyll a emits fluorescence in the red and near infrared spectral region between 650 and 800nm in two broad band's with peaks between 684 and 695nm and 730 and 740nm (Lichtenthaler and Rinderle, 1988 ; Franck et al, 2002). The peak at shorter wavelengths is attributed to PSII (Dekkel et al, 1995) while that at longer wavelength originated from antenna Chlorophyll of PSI and PSII (Agati et al, 2000 and Buschmann, 2007). The introduction of the Pulse Amplitude Modulation (PAM) Fluorometer allowed the non-imaging outdoor measurements of chlorophyll fluorescence in broad daylight (Schreber et al, 1986). Fluorescence imaging introduced by Omasa et al, 1987 was modified for field survey in the 1990s (Cecci et al, 1994; Nedbal et al 2000). Laser pulses were later used to discriminate from static and panchromatic background light to elicit fluorescence transients (Corp et al, 2006). Planck and Gabriel (1975) demonstrated that

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passive remote sensing techniques could be used to accurately separate Solar Induced Fluorescence signals from reflectance measurements inside and near to the Solar Fraunhoffer and atmospheric absorption lines. This procedure, Fraunhoffer Line Discrimination, FLD techniques was used to measure Chlorophyll fluorescence emissions (F685nm and F740nm) in O_2-B (687nm) and O_2-A (760nm) atmospheric absorption lines (Moya et al, 2004; Louis et al, 2005). A scientific team from the Laboratoire de Météorologie Dynamique in Paris developed a passive airborne Solar induced Fluorescence ,SIF, recording instrument called AIRFLEX that was successfully tested for the first time during the SEN2FLEX campaign and then employed in combination with extensive ground and airborne supportive measurements during the CEFLES2 campaign (Rascher *et al.*, unpublished results). The sensor outputs proved that vegetation fluorescence could be measured from a flying platform in both oxygen absorption lines. AIRFLEX represents the aerial predecessor of the Fluorescence Explorer (FLEX) satellite, proposed originally to ESA as one of the 7th Earth Explorer candidate missions (Rascher *et al.*, 2008). The FLEX imaging Fluorometer was expected to acquire narrow SIF bands (bandwidth of 0.13 nm) located in individual Fraunhoffer and atmospheric absorption lines between 480–760 nm. It was originally proposed to accompany a passive fluorescence system with a multi-angle imaging spectrometer (spectral range of 400–2400 nm) and a thermal infrared imaging system (three thermal bands between 8.8–12.0μm) as supportive systems facilitating fluorescence signal interpretation. Although the FLEX concept was not approved as a future ESA Earth Explorer mission, its continuation is anticipated as a scientific technological experiment within the ESA Technology Research Programme.

The plant research community is expected to play an important role in extending our understanding of the steady-state solar-induced fluorescence signal under natural conditions, which is required for unambiguous interpretation of remotely sensed data and developing advanced air- and space-borne fluorescence detectors achieving a high signal-to-noise ratio in relevant spectral bands (**Zbyněk Malenovský et al, 2009**).

This work reports the development of a new technique for remote sensing of Solar-Induced reflectance, SIR from vegetation canopy and also Solar-Induced Fluorescence, SIF signals under natural conditions, using a refractor optical segment and band pass electronics filters. Fresnel's lens and electronics band pass filters were used to ensure that solar induced infrared reflectance is appropriately sensed within the infrared band.

2. Research Methods

Photodiodes and Phototransistors were chosen to sense infrared reflectance and fluorescence directly from targeted plants leaves. Photodiode was considered most suitable to detect fluorescence signal as its response coincides with actual fluorescence excitation response time. The output of the diode/transistors was very small. Use of active amplifying and filtering circuits became necessary. The various circuits for each segment of the work were first designed on the Multism-8 Electronics Workbench Software and simulated for workability before the selection of the electronic components and bread boarding. Series of Multi Feedback band pass filters MFBP's, were selected and adopted for the band pass filtering circuits to allow only infrared reflectance i.e. Figure 2 (near IR 750nm-3000nm) and IR fluorescence i.e. Figure 3, (far red 680 nm- near IR 730 nm) from vegetation to pass through while attenuating all other signals below or above the reflectance and fluorescence bandwidths. The Block Diagram of the setup is as shown on Figure 1. Standard soldering techniques were employed for the connection of components on the Vero boards. For the ICs, sockets were employed to avoid excessive heat during soldering which could damaged the ICs. Interconnecting leads were used to join 'legs'of the ICs with other components and with the power supply.

The dc power supply was mounted on a separate board with its output sent to other stages in the circuit. The detectors were extruded for the incidence of the irradiance of interest could, on their junctions but well shielded, to screen-off unwanted signals. So, only the irradiance under observation is incident onto the respective detector at any time. The power supply unit for the infrared radiometer was constructed using standard techniques.. A battery recharging circuit was incorporated. The power supply circuit was designed for both mains and d. c. supplies for field work. Diode D_1 was used to connect the output from the battery to the circuit to prevent back e.m.f that could damage the battery.

For portability and safety, a plastic sheet of dimension: 28cm x 10cm x 6cm was used for the casing. The circuits for both IR reflectance and fluorescence were combined together in the same housing, using same power supply and display. This made the device dual-band. The IR fluorescence sensing phototransistor was protruded outwards the casing on one side, and IR reflectance sensing photodiode was protruded outside the casing on the opposite side, placed in the Fresnel lens. An extraneous radiation-screen was provided for the IR reflectance sensing phototransistor.. Necessary openings were made for the insertion of the recording and control units. Slight gaps were left at the top for ventilation and cooling purposes. Cognisance was taken, as much as possible, on the aesthetics aspect. The instrument–user interface friendliness was ensured as much as practicable with much simplicity.

2.1 Operation of the Device

When electromagnetic radiation is incident on the Fresnel lens (in IR reflectance measurements), the lens filters the radiation and allow only infrared signals to be focused on the sensor. The IR signals fall on the photodiode/transistor and released electrons into the sensor's lattice, leading to current flow as the response to the measured signal. The output of the sensor is fed into the negative terminal of an op-amp for amplification. The three op-amps used are for three-stage amplification. The signal is filtered sequentially by the low band pass and high band pass filters according to the bandwidth, based on the parameters of the design. The filtered output from the MFBP is fed into the comparator and then into the output circuit..The display unit is a seven segment liquid crystal display, LCD console.

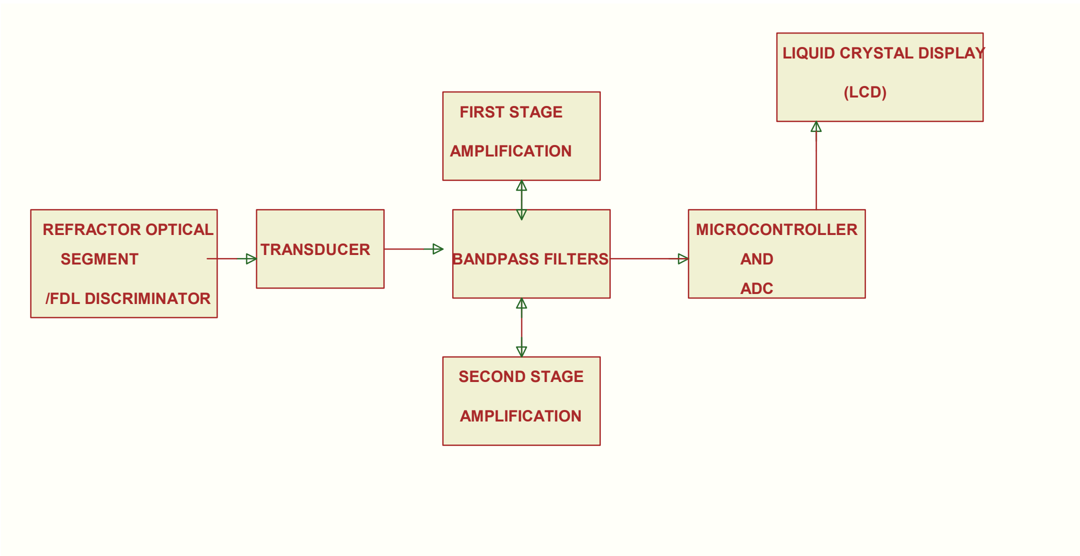

Figure1. Block Diagram of the Device: Schematics

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2.2 Calibration of the Device

The infrared detectors are assumed to have linear response to infrared radiation and were calibrated according to the procedure outlined in Menzel [2002], where the target voltage is given by

$$V_t = R_\lambda R_t + V_n \qquad \text{[1]}$$

Where, R_t is the target input radiance, R_λ is the radiometer's Responsivity, and V_n is the system's offset voltage. The calibration consists of determining R_λ and V_n. This is accomplished by exposing the device to two different radiation targets of known radiance. A blackbody of known temperature and space (assume to emit no measurable radiation) are often used as the two references. If z refers to space, bb the blackbody, the calibration can be written as

$$V_Z = R_\lambda R_Z + V_n \qquad \text{[2]}$$

$$V_{bb} = R_\lambda R_{bb} + V_n \qquad \text{[3]}$$

where,

$$R_\lambda = \frac{V_{bb} - V_Z}{V_{BB} - R_Z} \qquad \text{[4]}$$

$$V_n = \frac{R_{bb} V_Z - R_Z V_{bb}}{R_{bb} - R_Z} \qquad \text{[5]}$$

Setting $R_z = 0$ in Equation 21 yields,

$$R_t = \frac{R_{bb}(V_t - V_Z)}{V_{bb} - V_Z} \qquad \text{[6]}$$

From the radiometric parameters of the device,

Responsivity R_λ = 2.2×10^{37} V / W [680 nm]
and, = 1.5×10^{31} V/W [780 nm]
Offset voltage V_n = 0.01 volts.

Therefore, from Equation 1,

$$V_t = 1.5 \times 10^{31} (V/W) R_t + 0.01V$$

or,

$$R_T = \frac{V_t + 0.01}{1.5 \times 10^{31}} W \qquad \text{[at 780 nm]}, \qquad \text{[7]}$$

for infrared reflectance and

$$R_T = \frac{V_t + 0.01}{2.2 \times 10^{37}} W \qquad \text{[680nm]}, \qquad \text{[8]}$$

for infrared fluorescence. R_T is the radiance from the target (canopy/leaf) when the instrument reading is V_t volts.

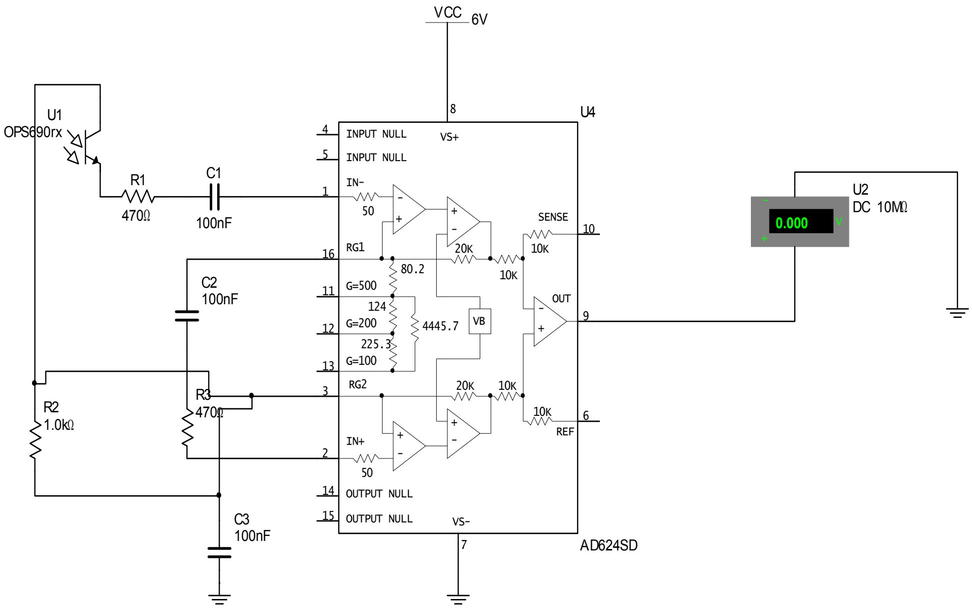


Figure 2. Infrared Reflectance Sensing Circuit

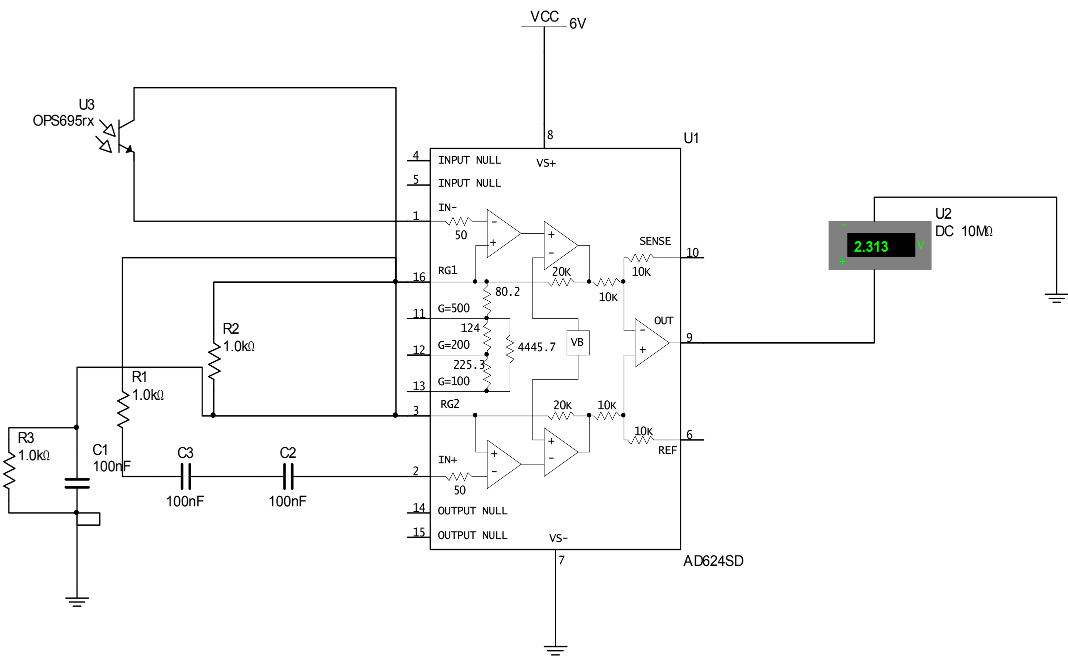


Figure3.

Infrared Fluorescence Sensing Circuit

2. 3 Testing

The components as arranged on the device circuits were first tested for continuity to ensure proper connection before casing. The device, after radiant calibration was tested for the detection and measurement of infrared fluorescence and reflectance from selected plant leaves. Thereafter, it was then used to observe the solar-induced IR fluorescence and reflectance from selected plants', tree canopies and detached leaves.

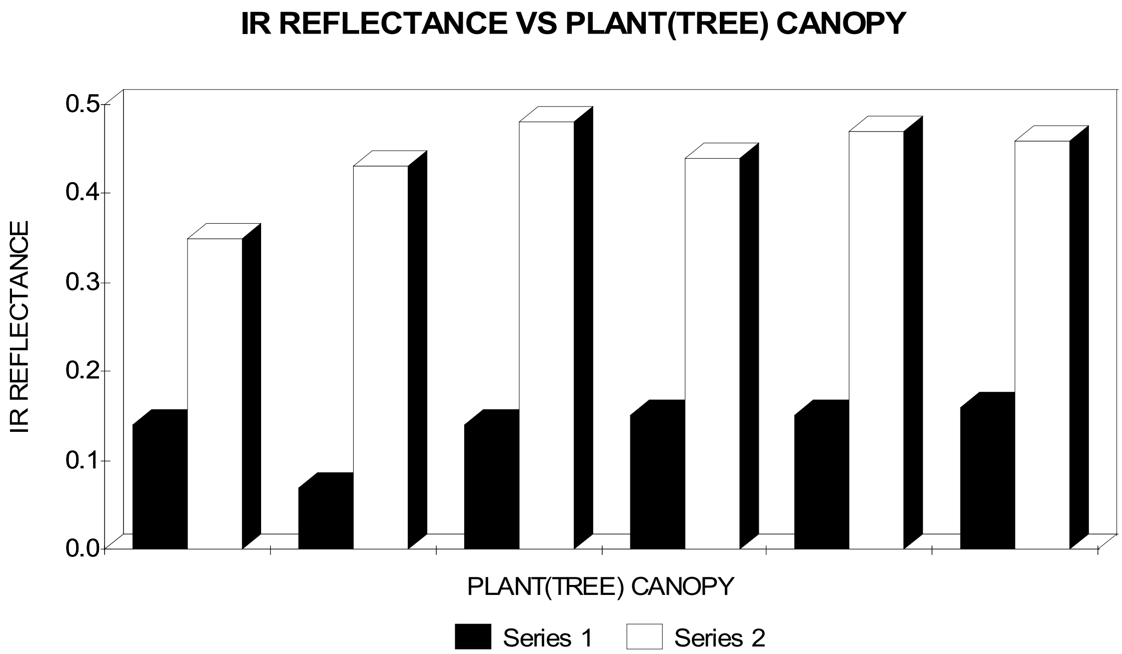
Plate 1. The Complete Instrument (With Telescope)

3. Results and Discussion

The following characteristic radiometric parameters were obtained for the device; Responsivity of 1.5 x 10^{31} V/W, Noise Equivalent Power NEP of 6.48 x 10^{-34} W, and Detectivity of 1.54 x 10^{33} /W at 780 nm; Responsivity of 2.2 x 10^{37} V/W, Noise Equivalent Power NEP of 4.45 x 10^{-40} W, and Detectivity of 2.0 x 10^{39} /W at 680 nm. These values are much improvements over the results obtained in an earlier work (Edaogbogun, 2008, unpublished): R_λ = 7.30 x 10^{21} v/W; NEP= 8.219 x 10^{-21} W; SNR = 11dB and; D = 1.2 x 10^{-21}/W at 0.6 μm. This may not be unconnected with the use of digital readouts and better MFBP filters employed in this study. The results are commensurate with expectations in the literature (Wyatt, 1987).

The instrument distinguished infrared fluorescence and reflectance signals for each plant's and tree canopy and detached leaf as shown on Figures 4, 5 and 6. It should be noted that suitable amplification and band pass filtering made the normally weak chlorophyll fluorescence signals more measurable. The results as shown on Figures 4 and 5 further illuminates the interplay between infrared reflectance and fluorescence signals from plants and tree canopy: Infrared reflectance signals appeared to be more intense from tree than plant canopy whereas fluorescence signals appeared to be more intense in plants than tree canopy. Ability to show these salient observations is peculiar to this study. This means that we have more photosynthetic activities/ yield in trees than plants canopy. Although, reflectance appeared to somewhat vary directly with photosynthesis activity, as generally held, then intense reflectance signals from tree canopy also confirmed that less photosynthesis activity actually take place in plants than tree canopy. This deduction is actually more laborious from reflectance data, but simply deduced here.

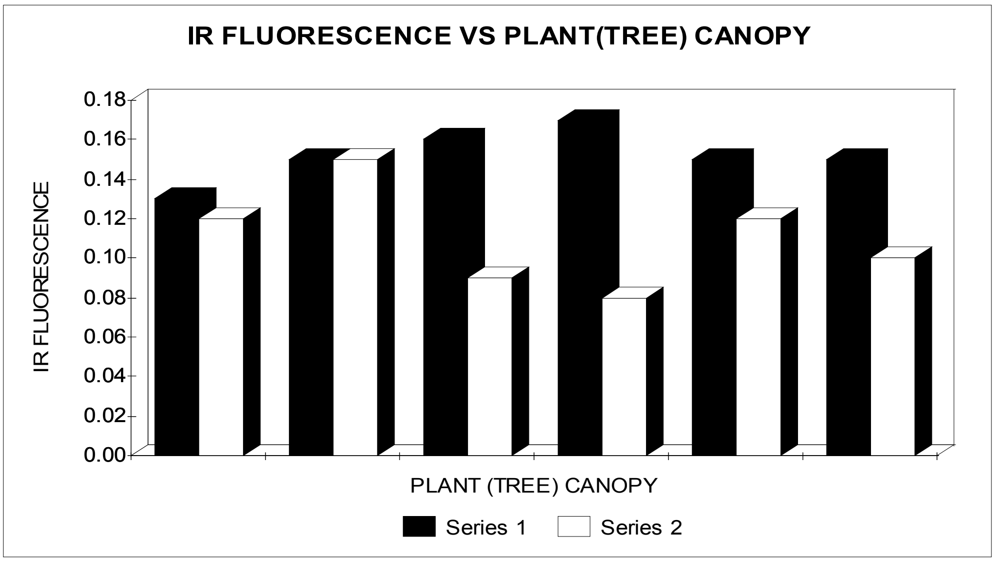
Meanwhile the results as shown on Figure 6 indicated that response of the fluorescence signals appeared to be out of phase with reflectance signals



I II III IV V VI

Series 1 – Plant canopies I – VI ; Series 2 – Tree canopies I –VI

Figure 4: Infrared Reflectance from Plants (Series 1) and Trees (Series 2) Vs canopies I, II, III, IV, V, VI



I II III IV V VI

Series 1 – Plant canopies I -VI ; Series 2 – Tree canopies I – VI

Figure 5: Infrared Fluorescence from Plants (Series 1) and Trees Series 2) Vs canopies I, II, III, IV, V, VI a

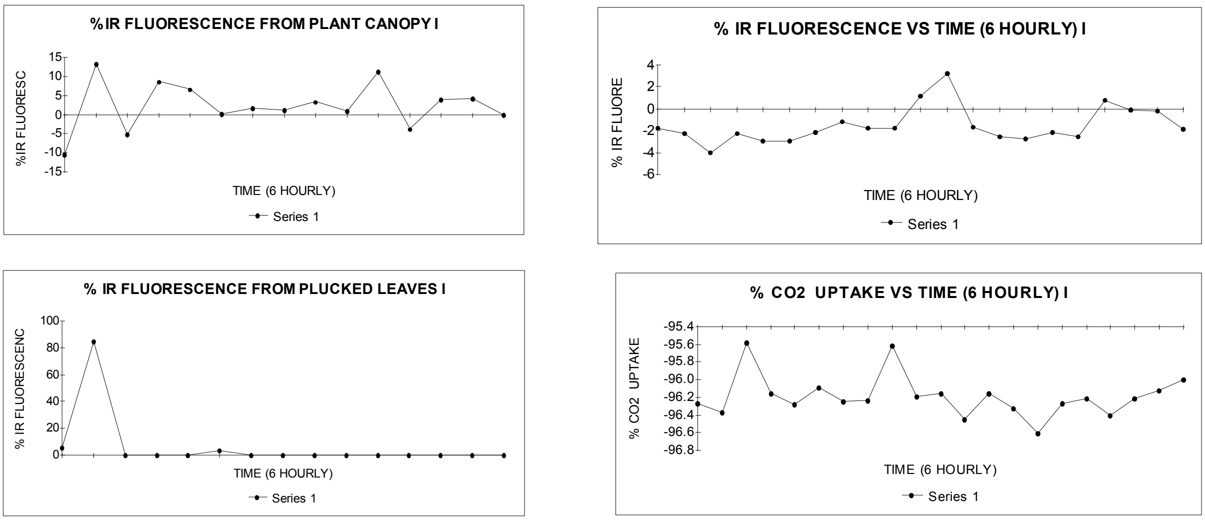


Figure 6. % IR Fluorescence Vs Time (6 hourly) i.e. Sunrise, Midday, Sunset each day for 5 days.: Plant Canopy , Detached Leaf Tree Canopy and CO_2 drawdown by Tree Canop

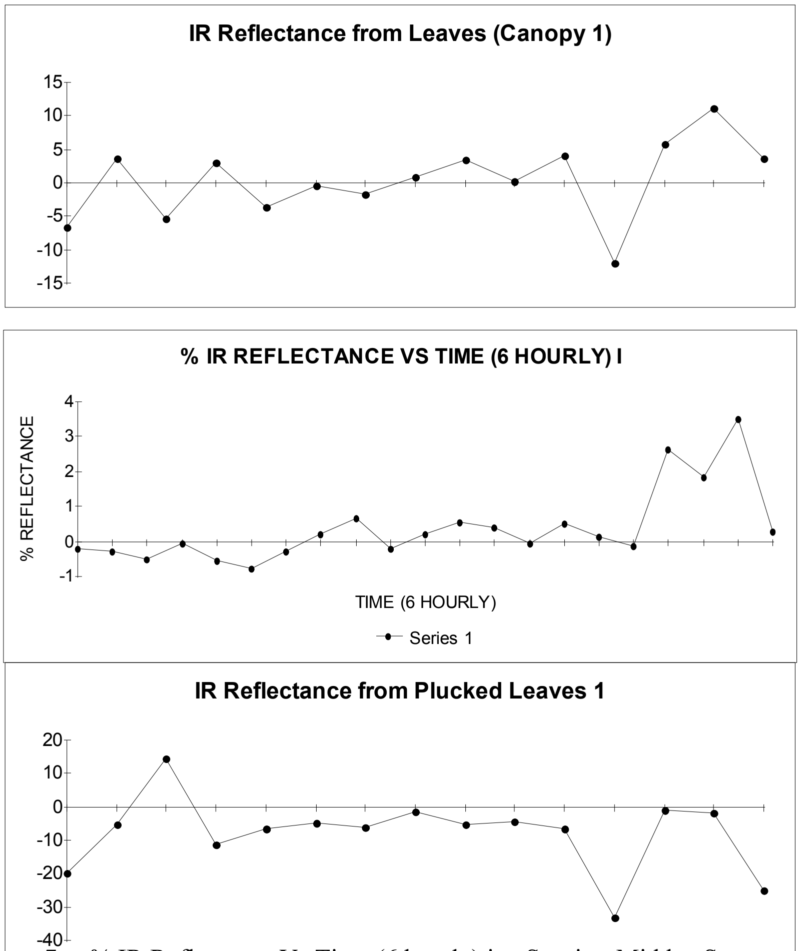


Figure 7. % IR Reflectance Vs Time (6 hourly) i.e. Sunrise, Midday Sunset each day for 5 days : Plant canopy ,Detached Leaf and Tree Canopy

(3)

4. Conclusion

This study developed a novel but simple technique for remote sensing of solar induced chlorophyll fluorescence and reflectance of intact vegetation covers under natural conditions using electronic filtering circuits and a refractor telescope. Its radiometric detector and optical parameters compared favorably with expectation in the literature. The device could therefore be used to remotely detect weak Solar Induced Fluorescence signals, SIF superimposed on infrared reflectance SIR from vegetation covers.

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