Optimization of Detector Arrays and Circuits Targeted for Precision Calculation in Infrared Laser Interferometer

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***Abstract*—A low noise transimpedance amplifier (TIA) is used in a wide band PIN (Positive Intrinsic Negative) laser detector arrays to transform the photo current produced by an infrared interfering laser power to an output voltage with a specified amplitude and frequency response. In this paper we consider the specifications of a PIN detector array coupled with a TIA circuit. Then the following issues that influence high precision calculation results will be investigated: low noise performance of the detector array and TIA pre-amplifier; fluctuation effects of amplitude caused by frequency modulation interfering signal; photosensitive area (PA) of the detector and physical distance between detectors.**

We find that noise performance related with signal to noise ratio (SNR) defines the minimum calculation error. And PA related with sensitivity has influence on junction capacitance and amplitude fluctuation. Meanwhile bias circuit mode related with dark current also influence amplitude response. Based on these issues, a PIN detector array pair is constructed of five sensors arranged in cross. The center response wavelength of the detector array is around 850 nm according to the requirement of the referential laser interferometer.

I. INTRODUCTION

Fourier Transform Infrared Spectrometer (FTIRS) is a main load in the next generation geostationary meteorological satellite. In a FTIRS with traditional structure, laser beams reached orthogonal placed detector arrays in Fig 1 [1]. Photocurrent responses from detector arrays are then amplified and transformed into voltage signal through the TIAs. Tilts of moving mirror appeared in scan motion will exist a dynamic phase difference between the voltage signals on sensors, e.g. HL and HR, or HL' and HR', see EQ (1) to EQ (4).

$$T_{HL} = I_{fm} + I_{sm} + 2*M(\alpha)*\sqrt{I_{fm} + I_{sm}}* \cos(2*\pi*v_{OPD}*t/\lambda + \theta_{\delta HL} + \Delta\theta(\alpha)) \quad (1)$$

$$T_{HR} = I_{fm} + I_{sm} + 2*M(\alpha)*\sqrt{I_{fm} + I_{sm}}* \cos(2*\pi*v_{OPD}*t/\lambda + \theta_{\delta HR} - \Delta\theta(\alpha)) \quad (2)$$

$$R_{HL} = I_{fm'} + I_{sm'} + 2*M(\alpha)*\sqrt{I_{fm'} * I_{sm'}}* \sin(2*\pi*v_{OPD}*t/\lambda + \theta'_{\delta HL} + \Delta\theta(\alpha)) \quad (3)$$

$$R_{HR} = I_{fm'} + I_{sm'} + 2*M(\alpha)*\sqrt{I_{fm'} + I_{sm'}}* \sin(2*\pi*v_{OPD}*t/\lambda + \theta'_{\delta HR} - \Delta\theta(\alpha)) \quad (4)$$

Where: I_{fm} represents the laser intensity (or laser power) from the reflection of fixed mirror; I_{sm} represents the laser intensity from the reflection of scanning mirror; $M(\alpha)$ represents the interference efficiency of the referential laser signal [2][1][3], λ represents the wavelength of the laser; $\theta_{\delta HL}$ represents the static phase difference from standard cosine laser signal; v_{OPD} represents the velocity of OPD (Optical Path Difference); $\Delta\theta(\alpha) = 4*\pi*d*\alpha/\lambda$ represents the dynamic phase error induced by the tilt angle(α) [4][5]; d represents distance between detectors in horizontal or vertical side.

With normalization and perpendicular compensation [5], $\Delta\theta(\alpha)$ is calculated through inverse trigonometric functions. By comparing the phase differences between $\Delta\theta(\alpha)$ s, the tilt α between fixed mirror and scanning mirror can be calculated, see EQ (7) .

$$\alpha = 4*d*\Delta\theta/\lambda \quad (7)$$

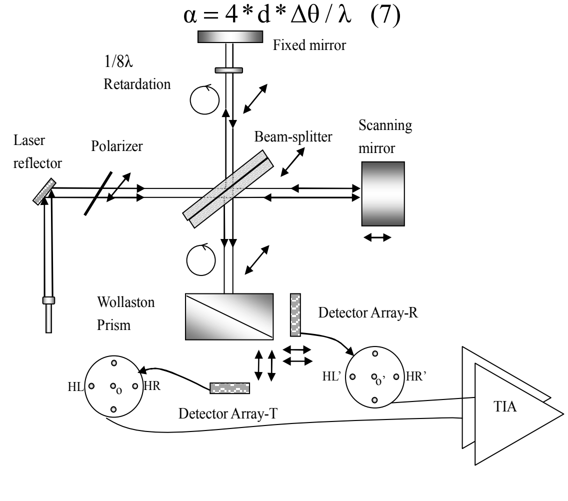

Fig. 1. Detectors and optic path of laser interferometer

II. Methodologies

A. *The requirement of SNR*

To simplify the circuit structure and cut down the difficulty for space based application, a common JFET amplifier (LF356) is used as the main TIA. Fig 2 is the TIA circuit coupled with the photodiode. Meanwhile the maximum measurable physical tilt angle α is limited by SNR of combination of detector and TIA, see EQ (6) [5]. When λ and d is fixed for system configuration, SNR defines the measurement dynamic range. Noise modeling of combination of photodiode and TIA is shown in Fig 3 [6]. Measurement of output noise is listed in table I.

$$\alpha_{max} = \lambda / (2 * d * SNR) \quad (6)$$

B. *The requirement ofamplitude fluctuation*

Normalization process of a trigonometric function is sensitive to signal amplitude variation. Yet it's a frequency modulation signal at detector side caused by interferometer specification. So fluctuation of signal is seen as noise when calculating tilt angle. Fig 4 is the fluctuation noise equivalent tilt angle. Hence the bandwidth of the detector defines the sensitivity of tilt measurement. Fig5 (a) and (b) is the comparison of voltage fluctuation between previous version and after optimization of detector and TIA.

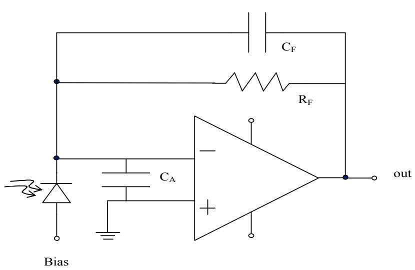

Fig. 2. Scheme of detector and TIA

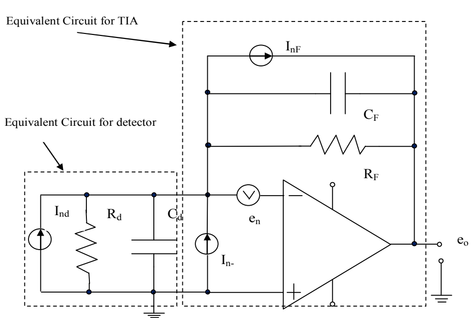

Fig. 3. Noise model of detector and TIA

TABLE I

Measurement Of Output Noise

RMS noise (µV) / Detector No.	Detector & TIA	Sampling System	TIA	Detector	3dB BW (kHz)
T_{HL}	751.6	145	56	735.4	745
T_{HR}	731.4	145	56	714.7	682
R_{HL}	661.8	145	56	643.3	856
R_{HR}	753.6	145	56	737.4	623

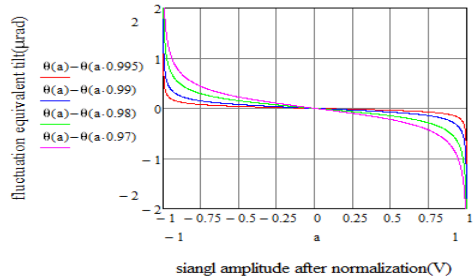

Fig. 4. Voltage equivalent tilt angle

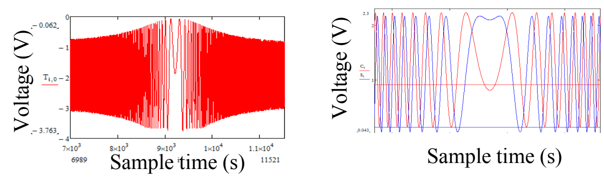

Fig. 5. Voltage fluctuation VS time variable modulation signal

III. Conclusions

This paper proposes a five element PIN detector array with cross ranged placement. The detector array is fabricated with common anode process and biased properly. Through analysis of direct noise caused by detectors and circuits, calculation noise caused by amplitude fluctuation, an optimized combination of parameter for photosensitive area, distance between detectors, transimpedance resistor and capacitor is derived. With a familiar JFET worked as TIA to suppress the dark current noise, the tilt measurement accuracy reached infra one micro-radian.

Acknowledgement

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