Low-noise, Large-active-area, Wide-band InGaAs Photoreceivers

〇和泉究，福邉健次（JAXA 宇宙科学研究所），小林雅人，岡坂洋輝（法政大）
(Kiwamu Izumi, Kenji Fukunabe, (ISAS/JAXA), Masato Kobayashi and Hiroki Okasaka (Hosei Univ.))

概要(Abstract)

Space laser interferometry will play a key role in the coming decades for performing advanced astronomical observations in space. LISA is an international gravitational-wave observation mission requiring space laser interferometry. We report on our current activities on the development of the most critical device, namely, photoreceivers with the use of an InGaAs photodiode, for LISA.

1. Photoreceivers and their requirements

The photoreciever is a device which receives laser light and subsequently converts the photo current into voltage signals. The photoreceivers are indispensable in LISA in order to detect gravitational waves that modulate the optical phase of the laser light (see Figure 1 for the phase sensitive photo-detection). The photoreceivers for LISA must meet a set of challenging requirements as summarized in table 1. The wavelength of the lasers for LISA is 1064 nm, which makes InGaAs the most suitable optical element because of the high quantum efficiency.

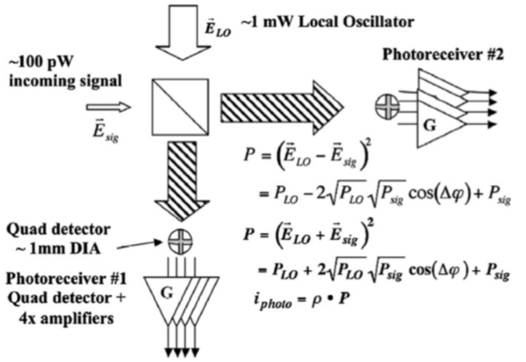

Figure 1: A schematic view of the heterodyne setup for LISA. Figure taken from [1]

2. The development of InGaAs photodiodes

In order to achieve a low noise design, one has to take a special care on the noise contribution via the junction capacitance of the InGaAs photodiode. In terms of the input-referred current noise, it contributes to the input referred noise through the following function form.

Parameter	Required value
Input referred current noise	2 pA/Hz$^{1/2}$
Frequency response	5-25 MHz (Flat in magnitude)
Power consumption	200 mW / unit
Operating Temperature	Room temperature
Size of active area	1 mm or larger in diameter

Table 1: Major requirements

$$i_n = 2\pi f\ C_d\ e_n,$$

where f is frequency of the signals, C_d is the junction capacitance, and e_n is input voltage noise of the amplifier that is connected to the photodiode.

Assuming voltage noise of 1 nV/Hz$^{1/2}$, a reasonably good value for commercially available op-amps, at f = 30 MHz, one can find that the junction capacitance C_d has to be as small as 10 pF per segment or smaller in order to bring current noise below 2 pA/Hz$^{1/2}$. On the other hand, achieving a small value in C_d is not trivial for those with a large active-area because the capacitance generally scales with the size of the active area. In fact, commercial InGaAs photodies with 1-mm diameter typically exhibit a junction capacitance of as high as 15 pF per segment. In order to tackle this challenge, we have been collaborating with Hamamatsu Photonics K.K. for producing a set of customized InGaAs photodiodes. A batch of the first customized InGaAs photodiodes were already delivered and they are currently being stuffed on a prototype circuit. See section 4 for more details.

3. The development of transimpedance amplifier

Another critical part is the transimpedance amplifier. The transimpedance amplifier receivers the photo current from the photodiode and converts it into voltage signals with an amplification gain. The amplifier has to be designed such that it maintains a good noise performance across the frequency band in 5-25 MHz while maintaining a flat frequency response in the frequency band.

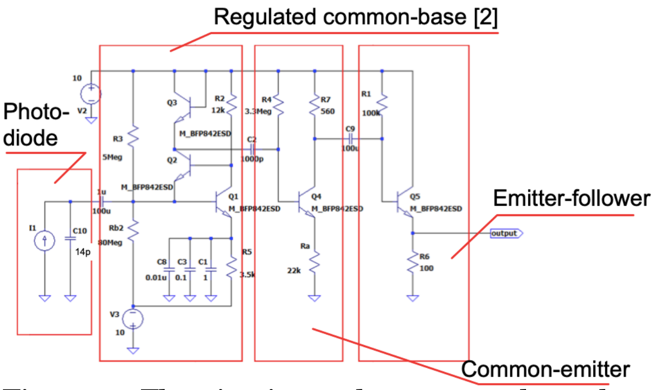

Figure 2: The circuit topology currently under study.

We have chosen the regulated common-base (RCB) configuration [2] for the first amplification stage because the RCB allows us for designing a wide bandwidth independently from the junction capacitance by isolating the junction capacitance from the amplifier. A candidate circuit topology is shown in figure 2. We selected BFP842ESDs from Infineon [3] for the transistors. They have been proven to be superior in the noise performance at frequencies we are interested [4].

4. Current status and future plans

We are currently evaluating a prototype circuit based on the latest circuit topology (Figure 2) with a customized InGaAs photodiode from Hamamatsu stuffed. According to a factory measurement, the customized InGaAs photodiodes have a junction capacitance of 14 pF. The circuit is implemented on a printed-circuit board or PCB. Our simulation

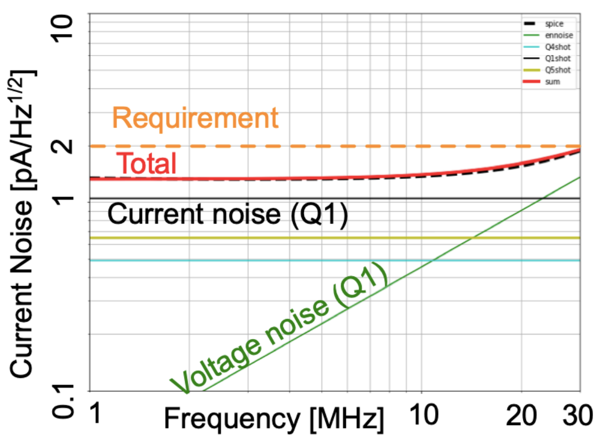

Figure 3: Simulated noise in terms of input referred current noise.

study to date suggests that it achieves a good bandwidth with a highest cut-off frequency of as high as 25 MHz as well as input referred current noise of 1.9 pA/$Hz^{1/2}$ at 30 MHz as shown in Figure 3.

Our next step is to experimentally determine the noise performance and frequency response. In addition, we are currently discussing with Hamamatsu to see if they can implement the method of inserting an additional intrisic layer between the P- and N-layers [5]. If such an improvement is successful, the junction capacitance should be further reduced and therefore the photoreceivers will be able to achieve a lower noise level.

Acknowledgements

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