

## Design of low noise, high gain amplifier for the detection of shot noise

Jayarajalakshmi G<sup>1</sup>, Kumaran A<sup>2</sup>

<sup>1</sup>(Communication systems, Sri sairam engineering college / Anna University , India)

<sup>2</sup>(Electronic and Communication systems, Sri sairam engineering college/ AnnaUniversity,India)

---

**Abstract:** Profound advancements in quantum optics create necessity to analyse and detect correlated photon pairs. Technologies so far developed to support quantum optics is done mainly to offer new possibilities towards experimental tests dealing with basic principles of quantum mechanics. Dynamic range amplifier is designed for detection of shot noise current (in the range of several pico amperes or femto amperes) obtained due to squeezing or entanglement in laser. The amplification of the shot noise current (AC current) and DC current is done using this enhanced amplifier with the available input power. The performance of the system is notable from the significant increase in amplifier gain over a wide range of frequency. Therefore this design is tested for various input powers and it is concluded that it plays a very important role for a wide variety of applications, especially in weak signal detection.

**Keywords:** Transimpedance amplifier, DC amplifier, Impedance matching, JFET Buffer

---

### I. INTRODUCTION

The measurement of optical noise at the shot noise limit sensitivity with photo detector is an essential part of many quantum optics experiments, especially in non classical-light generation,[10], continuous variable (CV) quantum teleportation, and quantum information.[11] Quantum noise is usually measured through balanced homodyne detection (BHD) or heterodyne detection and could be typically compared with the shot-noise level of coherent light at the same power[10] The dark current of the photodiode, thermal noise of resistors, and the current and voltage noise in the op amps are the major contributors towards electronic noise when no light is incident on the photodiode, which sets a strong limitation to the measurement of quantum noise.[11].

Initially, a trans impedance ( photocurrent- to- voltage) amplifier was researched for use as the low-noise “front-end” electronics to a single photodiode-based shadow-sensor, with the shadow of the illuminated fibre falling over one vertically orientated edge of the rectangular sensor. In this way, a lateral vibration, or simple displacement, of the silica fibre’s shadow altered the photocurrent flowing through the photodiode (PD).

With modern solid-state devices and integrated circuits, it is possible to realize amplifiers that exhibit an extremely high voltage gain. Indeed, a gain of almost any desired magnitude can be obtained by cascading stages.[1] This might seem to imply that an arbitrarily small signal can be amplified to any desired level. This is not true because there is always a limit to the smallest signal that can be amplified. This limit is determined by electronic noise. If a signal is so small that it is masked by the noise in an amplifier, it is impossible to recover the signal by amplification.[3]

Noise is present in all electronic circuits. It is generated by the random motion of electrons in a resistive material, by the random recombination of holes and electrons in a semiconductor, and when holes and electrons diffuse through a potential barrier. The theoretical basis for the analysis of noise lies in the areas of semiconductor device physics and probability theory[1].

### II. THERMAL NOISE

A noise voltage called *thermal noise* is generated when thermal energy causes free electrons to move randomly in a resistive material. It is also referred to as *Johnson noise*. Nyquist used a thermodynamic argument to show that the open-circuit rms thermal noise voltage across a resistor is given by

$$V_t = \sqrt{4kTR\Delta f} \quad (1)$$

where  $k$  is Boltzmann's constant,  $T$  is the absolute temperature,  $R$  is the resistance, and  $\Delta f$  is the bandwidth in hertz over which the noise is measured.

The power in thermal noise is proportional to the square of  $V_t$  which is independent of frequency for a fixed bandwidth. The power between 100 and 200 Hz is the same as it is between 10100 and 10200 Hz. Such noise is said to have a **uniform or flat** power distribution and is called **white noise**[2]. It is called this by analogy to white light which also has a flat power distribution in the optical band.

Thermal noise is present in all circuit elements containing resistance. The noise is independent of the composition of the resistance. It is modeled the same way in discrete-circuit resistors and in integrated-circuit monolithic and thin-film resistors [9]. A carbon composition resistor generates the same amount of thermal noise as a metal film resistor of the same value. However, an additional noise component called flicker noise may be present in the carbon composition resistor. It results from the variable contact between the carbon particles of the resistive material. This noise is present only when a direct current flows in the resistor[2].

In any circuit containing resistors, capacitors, and inductors, only the resistors generate thermal noise. (The winding resistance of an inductor must be modeled as a separate resistor.)[2]. Let  $V_t$  be the complex impedance of a two-terminal network. The open-circuit rms thermal noise voltage generated by the network in the frequency band from  $f_1$  to  $f_2$  is given by

$$V_t = \left[ 4kT \int_{f_1}^{f_2} Re(Z) df \right]^{\frac{1}{2}} \quad (2)$$

### III. SCHEMATIC OF AMPLIFIER

A weak signal detection deals with major problem of electronic noise due to the presence of BJT and experience the thermal noise by very high feed back resistance. So, most of the applications where high SNR place a major role it is better to not use BJT. Its high input impedance, low input voltage noise density (0.8 nV/sqrt(Hz) at 100 kHz) with input capacitance around 9 pF in typical. Shot noise current to the OPAMP is estimated to be pico amperes. Non inverting node is grounded so its self biased voltage enter into this node is zero. Current from emitter resistor is enters the OPAMP. Feedback capacitor used to maintain stability. The value of capacitor depends on the total capacitance and feedback resistor is given by the equation.

$$C_f = \sqrt{\frac{C_T}{2\pi R_f (GBW)}} \quad (3)$$

Where  $C_f$  is feedback capacitance and  $C_T$  is the total capacitance.

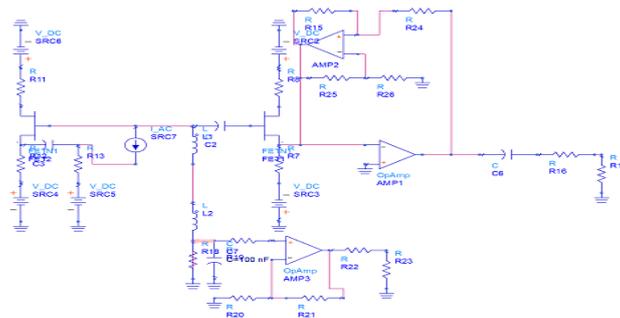


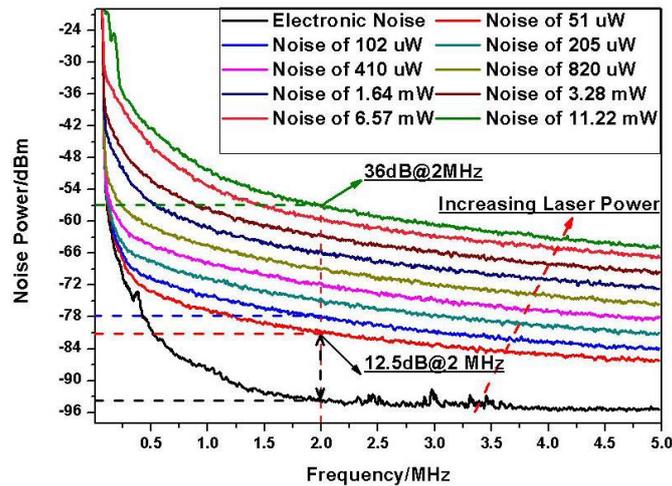
Fig 1: weak signal detection amplifier with low input noise signal (pico ampere range)

As mentioned above the feed back capacitance is used to stabilised the overall dynamic response of the amplifier. Without the feed back capacitance the circuit is not stabilised. The thermal noise is reduced by using low resistance with the opamp. The part of the output voltage is converted and given back as input to the opamp. The two opamps are connected back to back to increase the overall gain of the amplifier. When the given input signal is increased the output also increased in such a condition weak noise dominates electronic noise. In order to achieve the better amplification with low input there is trade between electronic noise and weak signal. Experimentally, the AC coupling capacitance C3 should be higher and a 100 nF was selected with less high frequency impedance appeared. Parasitic capacitances and inductances should be avoided and minimized under the criterion of high-frequency trans impedance amplifiers. The DC and audio frequency photocurrents travelled through

inductor L1 and resistor R15. The voltage generated across Rb was then amplified without oscillation to provide a DC voltage used for both alignment and phase locking.

#### IV. EXPERIMENTAL RESULT

From the graph given below it is observed that , when the input power given to the amplifier increase the electronic noise is difficult to split from the shot noise . However , the presence of thermal noise in the feedback resistance is replaced by back to back connection of opamp and overall stabilisation of amplifier is obtained. And measured noise voltages also indicate that total output noise voltages may be partially attenuated by the low pass effect of the feedback impedance at 2.0 MHz..



**Fig 2:** output graph obtained for various input power using ADS tool

#### V. CONCLUSION

In conclusion, we have designed a low-noise, high gain amplifier with low resistance feedback with low thermal noise and the combination of L-C (inductance and capacitance), which is suitable for measuring the shot noise from laser in the power range of microwatt. The designed photo detector had a large gain for the shot noise current without the influence of large DC current. When illuminated by 50  $\mu$ W input power, the electronic noise is easily distinguished from the available shot noise or white noise. The developed weak signal detection amplifier can be used as photo detector and input noise source should be replaced with photo diode and laser could be easily constructed using available components.

#### REFERENCES

- [1] H. J. Zhou, W. H. Yang, Z. X. Li, X. F. Li, and Y. H. Zheng, "A bootstrapped, low-noise, and high-gain photodetector for shot noise measurement," *Rev. Sci. Instrum.*, vol. 85, no. 1, pp. 013111-1–013111-5, Jan. 2014..
- [2] M. B. Gray, D. A. Shaddock, C. C. Harb, and H. Bachor, "Photo detector designs for low-noise, broadband, and high-power applications," *Rev. Sci. Instrum.*, vol. 69, no. 11, pp. 3755–3762, Nov. 1998.
- [3] D. Nordin and K. Hyypää, "Single-stage photodiode op-amp solutions suited for a self-mixing FMCW system," *IEEE Trans. Instrum. Meas.*, vol. 52, no. 6, pp. 1820–1824, Dec. 2003.
- [4] G. Giusi, F. Crupi, C. Pace, and P. Magnone, "Full model and characterization of noise in operational amplifier," *IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 56, no. 1, pp. 97–102, Jan. 2009.
- [5] *Design Considerations for a Transimpedance Amplifier*(SNOA515A–February 2008–Revised May 2013)
- [6] *Transimpedance Considerations for High-Speed Amplifiers*(SBOA122–November 2009)
- [7] T. Y. Lin, R. J. Green, and P. B. O'Connor, "A gain and bandwidth enhanced transimpedance preamplifier for Fourier-transform ion cyclotron resonance mass spectrometry," *Rev. Sci. Instrum.*, vol. 82, no. 12, pp. 124101–124108, Dec. 2011.
- [8] W. Marshall Leach, "Fundamentals of low noise circuit design ", IEEE, vol. 82. no. 10, october 1994..
- [9] P. R. Gray and R. G. Meyer, *Analysis and Design @ Analog integrated circuit* , New York: Wiley, 1993.
- [10] S. F. Pereira, M. Xiao, H. J. Kimble, and J. L. Hall, *Phys. Rev. A*. **38**, 4931 (1988).
- [11] H. Vahlbruch, S. Chelkowski, K. Danzmann, and R. Schnabel, *New J. Phys.* **9**, 371 (2007).