DESIGN CREDIT (2023 SUMMER TERM)
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Implementation of balanced homodyne circuit on breadboard

● Explanation of the problem statement-

Balanced homodyne detection is a technique used in optical and radio frequency systems to measure the amplitude and phase of a modulated signal. It is commonly used in quantum optics and other applications where precise measurements of the properties of electromagnetic signals are necessary.Balanced homodyne detection is used for precise measurement of signal properties, especially in quantum optics experiments.

● What does "DETECTION" here mean?

In the context of "balanced homodyne detection," the term "detection" refers to the process of measuring or determining the properties of an input signal, such as its amplitude and phase. Balanced homodyne detection is a specific method for detecting or measuring these properties of a signal, especially in the field of optics and quantum optics.

Homodyne and heterodyne detection are two different methods for extracting information from a modulated signal, and they are often used in the context of RF (radio frequency) or optical signal processing.

What is “HOMODYNE”?

The term homodyne means that the frequency of the local oscillator and unknown signal is the same (in contrast to different frequencies in heterodyne detection). Also, the local oscillator and unknown signal must be coherent, they are typically derived from the same light source. The unknown signal and the local oscillator interfere in an interferometer and the output signals are detected.

What is homodyne vs heterodyne Detection ?

Homodyne Detection:

- The homodyne detection is a widely used technique for finding the information encoded in the amplitude and the phase of unknown signal. The unknown signal is compared to the signal with a defined phase/frequency/amplitude known as the local oscillator.The goal is to extract information about the amplitude and phase of the signal.
- It is used for coherent signal processing and is commonly used in optical and quantum optics experiments, as well as in some radio frequency applications.It can be used with any EM signal.. We will use it for optical signals.
- Balanced homodyne detection was firstly applied in the frequency domain. In our case, the homodyne detector is designed for measurements in the time domain.

Heterodyne Detection:

- In heterodyne detection, the incoming signal is mixed with a local oscillator signal at a different frequency (often called the intermediate frequency or IF).

- The result of this mixing is a new signal at the IF, which is easier to process and analyze.

- Heterodyne detection is typically used to convert high-frequency signals to lower-frequency ones for easier processing and filtering.

- It is commonly used in radio communication, radar, and many electronic applications.

In summary, homodyne detection directly measures the properties of a signal at its original frequency, while heterodyne detection shifts the signal to a different frequency for easier processing. The choice between homodyne and heterodyne detection depends on the specific requirements and characteristics of the signal and the intended application.

- ## Fundamentals of homodyne detection

In balanced homodyne detection, an unknown signal is mixed with the known signal of the local oscillator. An unknown signal and the signal of the local oscillator needs to be coherent. The signals interfere and are divided on the 50 % beam splitter into two output signals. These signals have the same intensity. We want them to be as similar as possible. Then these two signals are brought on the photodiodes, where the optical signal is converted into an electric photocurrent. The photocurrents from both photodiodes are subtracted. The differential photocurrent is $I = (N\alpha - NLO)\cdot(T - R) + 4p\ R \cdot T \cdot NLO\ Q(\varphi) + o(NLO, Ubias, Unoise, \ldots)$, (2.6) where $N\alpha$ is the mean photon number of the measured signal, NLO is the mean photon number of the local oscillator, R, T are coefficients of reflection and transmission of the beam splitter and $o(\ldots)$ contains the parasitic elements such as electric noise and others. We want this error element to be as small as possible. $Q(\varphi)$ quadrature is defined as $Q(\varphi) = q \cos \varphi + p \sin \varphi$. The values of this function depend on the angle φ, which describes the angle of the measured state in the phase diagram with respect to the local oscillator. When we scan values of the quadratures for $\varphi = h0, 2\pi i$ we can reconstruct the full information about the measured quantum optical state. We can measure Wigner's function in this state. If the splitting ratio is R = T = 1/2 and we assume that the detection is perfect, the Eq. 2.6 will transform to $I \sim p\ NLO \cdot Q(\varphi)$. (2.7) Final differential photocurrent after subtraction is amplified and shaped, as shown in Fig. 2.2 by a simplified schematic of the charge-sensitive amplifier. We can detect the output signal in the time domain with the oscilloscope or in the frequency domain with the spectrum analyzer. In our detector, the R/T ratio can be almost perfect but an error element will always be there. There are many problems, such as the differences between the two photodiodes and the noise generated by the amplifier. Well designed and precisely adjusted charge sensitive amplifiers are important for a good balancing in homodyne detection.

- ## General homodyne circuit

A homodyne circuit is a type of electronic circuit used in communication systems, particularly in the field of radio frequency (RF) and microwave engineering. The term "homodyne" is derived from the Greek words "homo" (same) and "dyne" (power), indicating that the circuit processes signals at the same frequency.

In a homodyne circuit, the goal is to mix or multiply the incoming signal with a local oscillator (LO) signal that has the same frequency as the carrier signal. This process is known as heterodyning, and it results in a difference frequency signal known as the intermediate frequency (IF). The IF signal is then easier to process and demodulate compared to the original high-frequency signal.

A general homodyne circuit consists of the following key components:

1. Antenna/Input: This is where the incoming RF signal is received by the circuit.

2. Local Oscillator (LO): The local oscillator generates a signal with the same frequency as the carrier signal. The LO signal is mixed with the incoming signal to produce the IF signal.

3. Mixer: The mixer is responsible for combining the incoming signal with the local oscillator signal. This multiplication process creates sum and difference frequencies. In the case of homodyning, the difference frequency (IF) is the desired output.

4. Filter: A bandpass or low-pass filter is often used to isolate the desired IF signal and filter out unwanted frequencies.

5. Amplifier: An amplifier may be used to boost the strength of the IF signal for further processing.

6. Demodulator: In communication systems, the demodulator extracts the original information signal from the IF signal. The type of demodulator used depends on the modulation scheme of the original signal.

Homodyne circuits are used in applications such as radio receivers and software-defined radios (SDRs). They offer advantages like simplicity and efficiency but may face challenges such as image frequency interference, which can be mitigated through appropriate filtering.

- ## **Self-Subtraction**

"Self-subtraction" in the context of homodyne circuits typically refers to a technique used to eliminate or suppress undesired components in the output signal. The idea is to subtract a portion of the signal or a related signal to enhance the quality or purity of the desired information. This technique is often employed to improve the signal-to-noise ratio or to cancel out unwanted interference.

• Variable Gain

Variable gain in a homodyne circuit refers to the ability to adjust the amplification level of the signal at different stages of the circuit. Variable gain is often desirable in communication systems for several reasons, including adapting to changing signal conditions, optimizing the signal-to-noise ratio, and accommodating variations in the received signal strength.

In a homodyne circuit, where the goal is to mix an incoming signal with a local oscillator signal to produce an intermediate frequency (IF) signal, variable gain can be implemented in different ways:

1. Variable Gain Amplifiers (VGAs):

- VGAs are amplifiers whose gain can be adjusted dynamically. These components can be incorporated at various stages of the homodyne circuit, such as after the mixer or before the demodulator.

- By adjusting the gain of the amplifier, the overall sensitivity of the receiver can be controlled. This is particularly useful in situations where the received signal strength varies, such as in mobile communication devices that may experience signal fading.

2. Automatic Gain Control (AGC):

- AGC is a feedback control system that adjusts the gain of an amplifier based on the strength of the received signal. It helps maintain a relatively constant output signal level despite variations in the input signal strength.

- In a homodyne circuit, AGC can be applied to the amplifiers following the mixer or in the intermediate frequency (IF) stage. The AGC system continuously monitors the output signal strength and adjusts the gain accordingly.

3. Variable Local Oscillator Power:

- The strength of the local oscillator (LO) signal used in the mixing process can impact the performance of the homodyne circuit. By adjusting the power of the LO signal, the overall gain of the circuit can be effectively controlled.

- This approach may involve using a variable attenuator or a variable power source for the LO signal.

4. Digital Gain Control in Software-Defined Radios (SDRs):

- In software-defined radios, where much of the signal processing is done digitally, gain control can be implemented in the digital domain.

- Digital gain control allows for fine-grained adjustments and can be adapted to different communication standards or changing signal conditions.

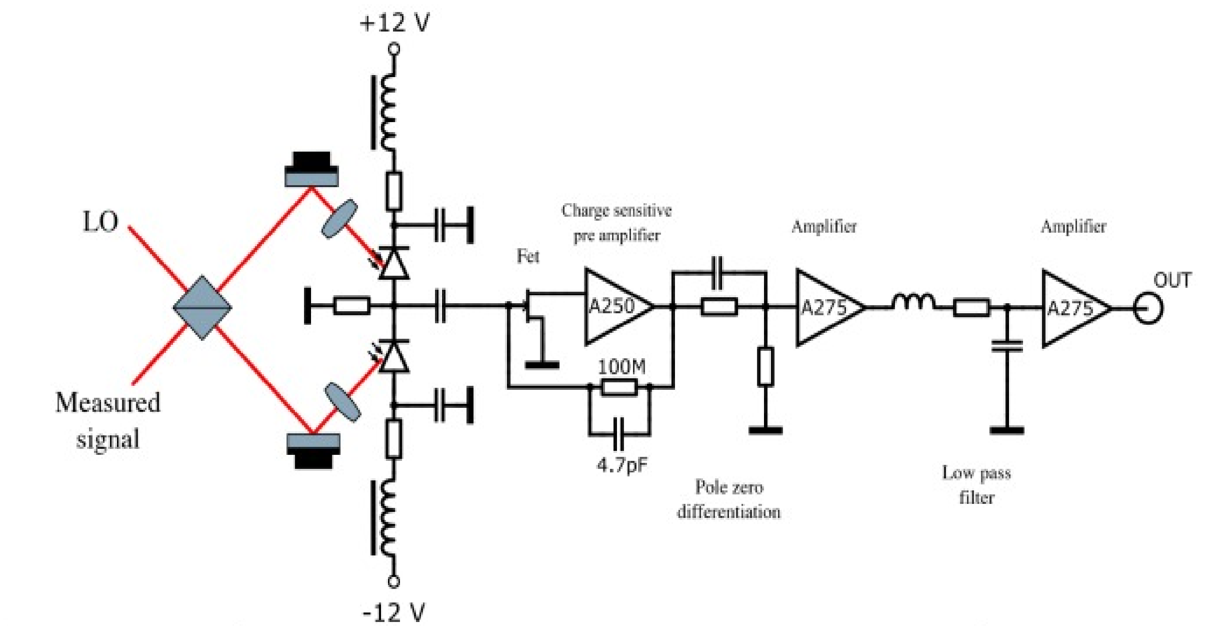
Variable gain in a homodyne circuit is crucial for maintaining optimal performance across a range of operating conditions. It enables the system to adapt to varying signal strengths, interference levels, and other factors that can affect the quality of the received signal.

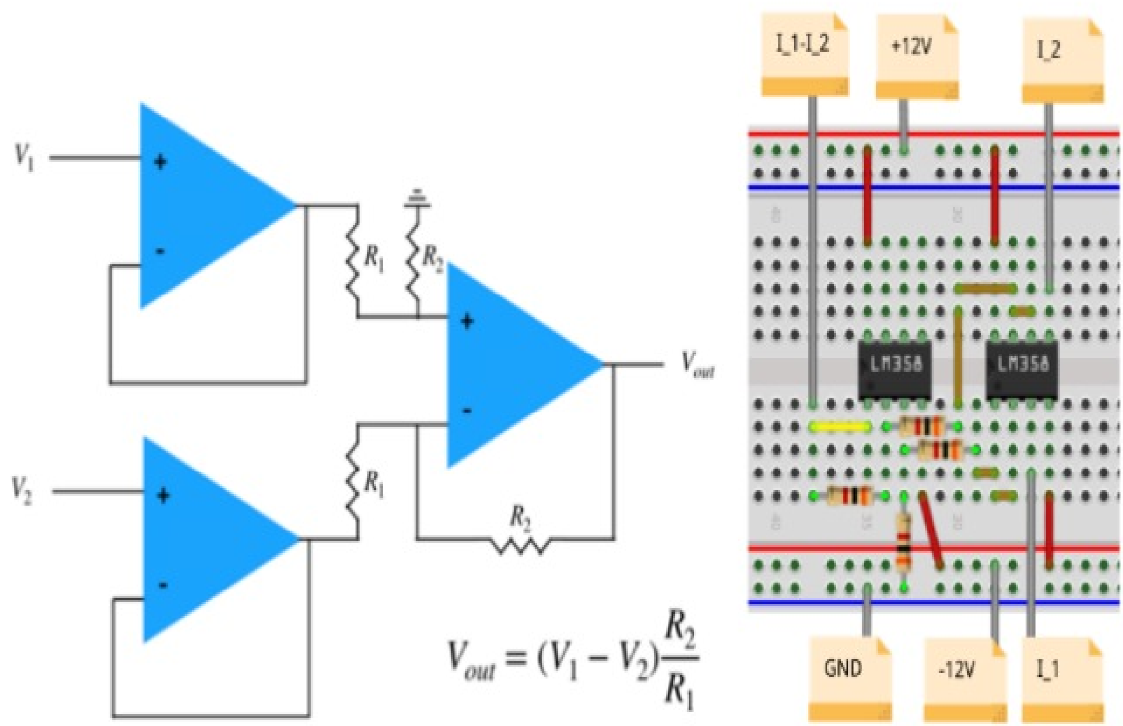
- **Balanced Homodyne Circuit On a Breadboard**

Balanced homodyne circuit on a breadboard:

- [ ] Laser Source: Provides a coherent light signal.
- [ ] Beam Splitter: Splits the laser beam into a signal and reference beam.
- [ ] Photodetectors: Convert optical signals into electrical signals.
- [ ] Mixer/Differential Amplifier: Combines the signal and reference beams for measurement.
- [ ] Local Oscillator: Generates a reference signal for phase-sensitive detection.
- [ ] Phase Shifter (optional): Adjusts the relative phase between beams.
- [ ] Data Acquisition & Processing: Analyze the electrical signal for amplitude and phase information.

- **SCHEMATIC OF OUR CIRCUIT:**





(a) Schematic (b) Implementation