Phase Sensitive Detection(Lock-in-amplifier) Applications

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Phase sensitive detection (Session 2)

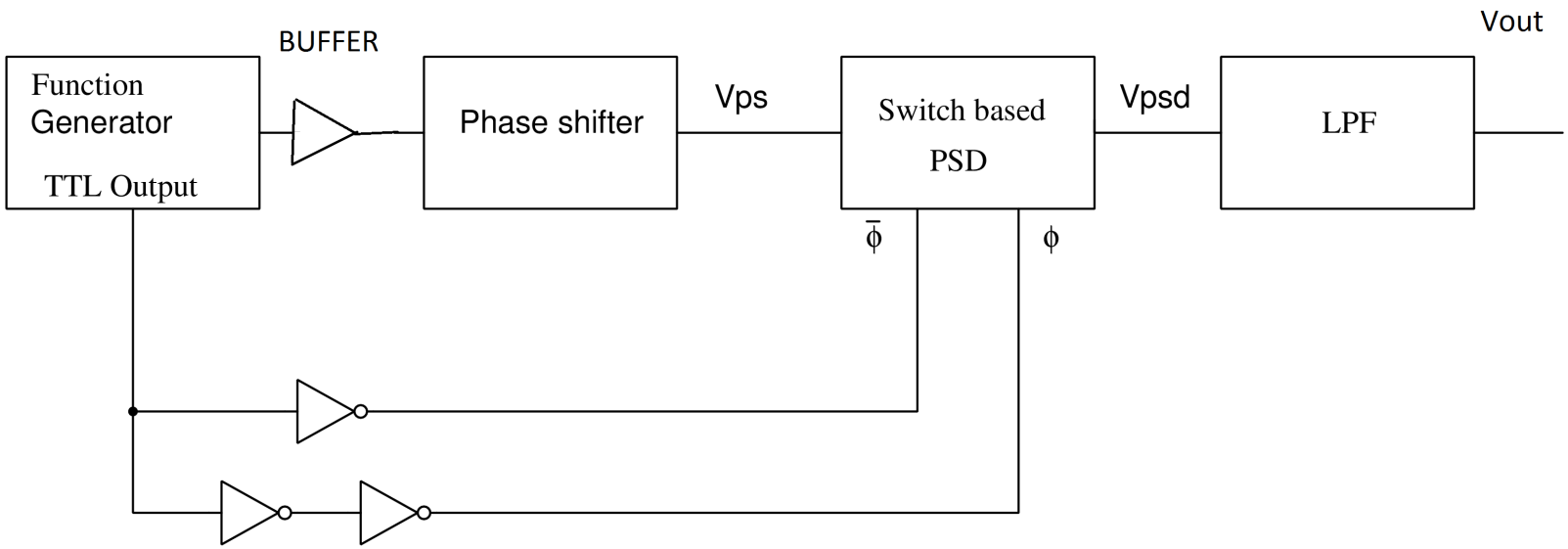
We have studied the principle of phase detection in the last week. In this session, we will study two applications of phase sensitive detection:

- To extract capacitance and resistance using a single PSD system.
- To measure the signal buried in noise.

Phase sensitive detection (Session 2)

You will use the preassembled circuit from the last week with following blocks:

1. Buffer: 741 based voltage follower
2. Phase shifter
3. Switch driving circuit: generating complementary clock signals using 74C04
4. Switch based phase sensitive detector
5. Low pass filter



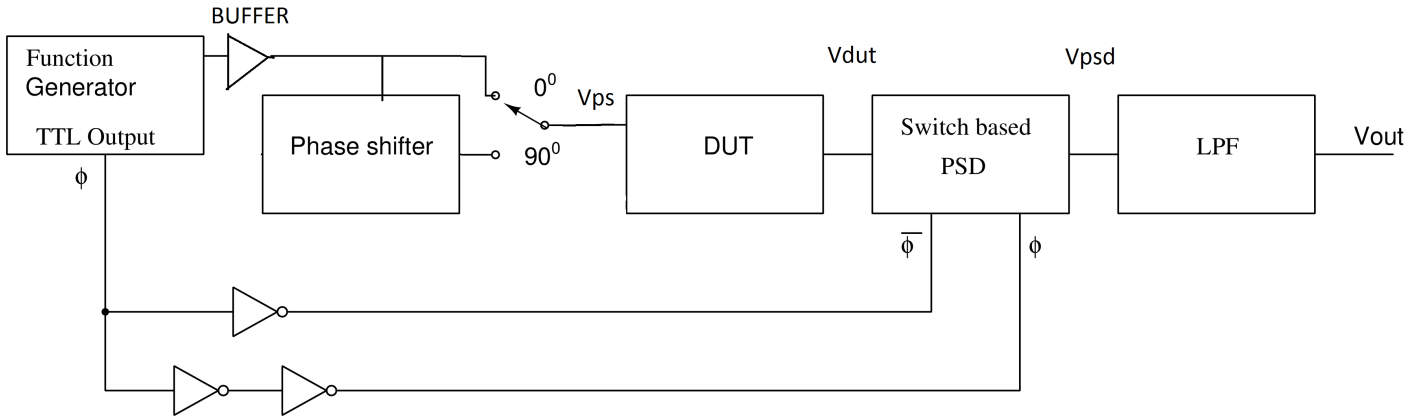
Testing the last week's PSD circuit

Before the actual measurements, we shall quickly test the last week's circuit on your breadboard.

- Apply $1V_{p-p}$, 1kHz sinusoidal signal from CH1 of AFG.
- Connect the TTL output of AFG to TTL input to the switch driving circuit.
- Using oscilloscope, make sure that you get appropriate signals at the output of each block.

Phase sensitive detection: Extracting capacitance and resistance using a single PSD system

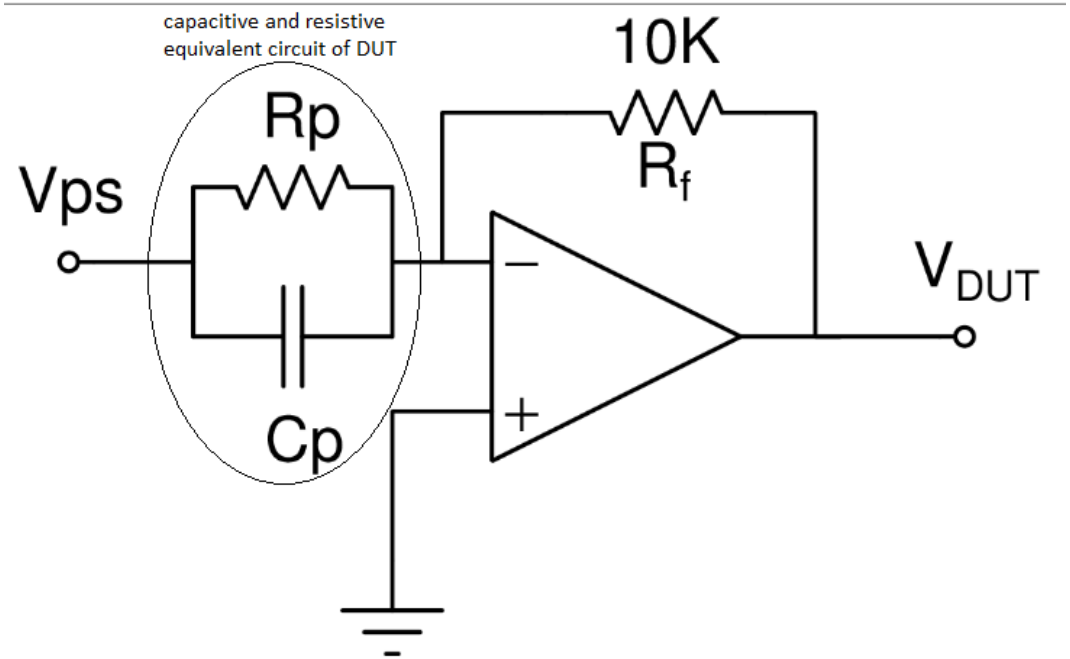
The simplified block diagram for this experiment is shown below.



- The main blocks of the PSD system are the same as we did in the last week.
- For this application, we need either 0^0 shifted signal (the input signal from AFG) or 90^0 phase shifted signal (from the phase shifter) with respect to reference signal. Hence the phase shifter can be adjusted for 90^0 and a wire can be used to switch to between 0^0 or 90^0 phase shift.
- The DUT block consists of the actual "Device Under Test" (the parallel combination of R_p and Cp) with an inverting opamp.

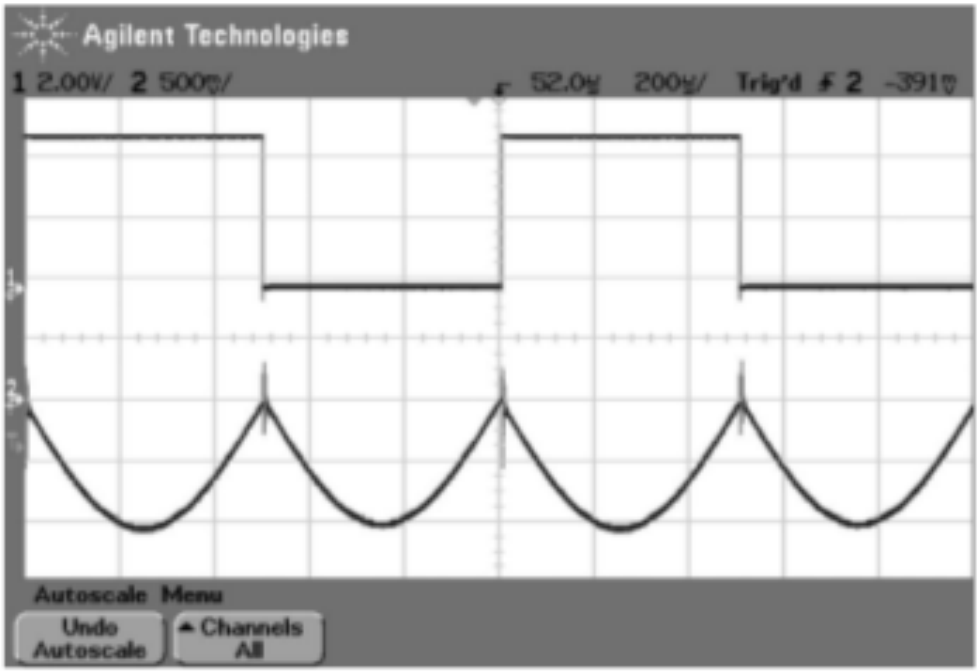
Testing DUT block

- Connect the DUT circuit is as shown below. Use $R_p = 10\text{K}$ and $C_p = 10$ nF. We shall test this block for 0^0 phase shift for the sake of simplicity.
- Derive the expression for V_{DUT} in terms of R_p, C_p, R_f, and V_{ps}.
  - Connect only R_p first by leaving the terminals for capacitor open and observe V_{DUT}. The circuit acts as an inverting amplifier with gain -1.
  - Now connect only the capacitor. What do you expect at the output? Observe V_{DUT} with respect to V_{ps}.
  - Now connect both R_p and C_p and observe V_{DUT} with respect to V_{ps}. What should you get at the output of DUT block? Verify with your estimated values(amplitude and phase).



Testing the Switch Based PSD

- Connect only R_p (10K) in the DUT circuit.
- Connect the output of DUT to the input of PSD.
- Check the two reference signals ϕ and $\overline{\phi}$.
- Observe V_{psd} with respect to ϕ.
- You should get negative rectified waveform as shown below (this is due to an addtional inverting amplifier with gain -1 in DUT block).



Testing the Low pass filter

- Connect the output of the phase sensitive detector as input to LPF.
- Measure the output of LPF (V_{out}). What is the expected output? Its value should be around $\frac{2V_m}{\pi}$, where V_m is the amplitude of the input signal. This is the maximum output voltage of the lock-in-amplifier for the current values of R_p and C_p. Observe the waveform V_{psd} on DSO with maximum sensitivity.
- If you get any abrupt transition in the V_{psd} waveform, it is because of some inherent phase difference between CH1 and TTL output of the AFG. In such a case, adjust the phase of the CH1 output (CH1 menu) such that you get the complete full wave rectified output.
- Now put the switch in 90^0 position and observe the output of PSD on DSO and that of LPF on DMM. You should measure the output voltage closed to zero. (Why?) If it is not so, fine tune the potentiometer of the phase shifter to read minimum voltage at the output of LPF.
- Show the readings and waveforms for both the phase angles to your TA.

This completes the testing of the PSD CIRCUIT!

Extracting the values of R_p and C_p

- We shall now evaluate the performance of our lock-in-amplifier by extracting capacitance C_p and loss-conductance (in terms of R_p) of a medium or a sensor. We shall use a parallel combination of known R_p and C_p for measurement and will verify the measurement.
- Put the switch in 0° position to measure resistance and in 90° position to measure capacitance. (Why?)
- Connect R_p (10K) only. Measure the output of LPF on DMM. Use this value of V_{out} as V_{in} for the calculations as dc equivalent of the input signal.

Extracting the values of R_p and C_p continued..

- Now connect C_p (10nF) also and observe V_{psd} with respect to ϕ and measure the output voltage of LPF using DMM.
- Repeat the measurements for all combinations of R_p and C_p of values 4.7K,10K, 10nF, and 22nF.
- Tabulate the observations and calculate the values of R_p and C_p in each case and complete the table. Compare the calculated values with actual values of R_p and C_p measured using DMM/ LCR meter.

$$R_p = R_f \frac{V_{in}}{V_{out}}$$

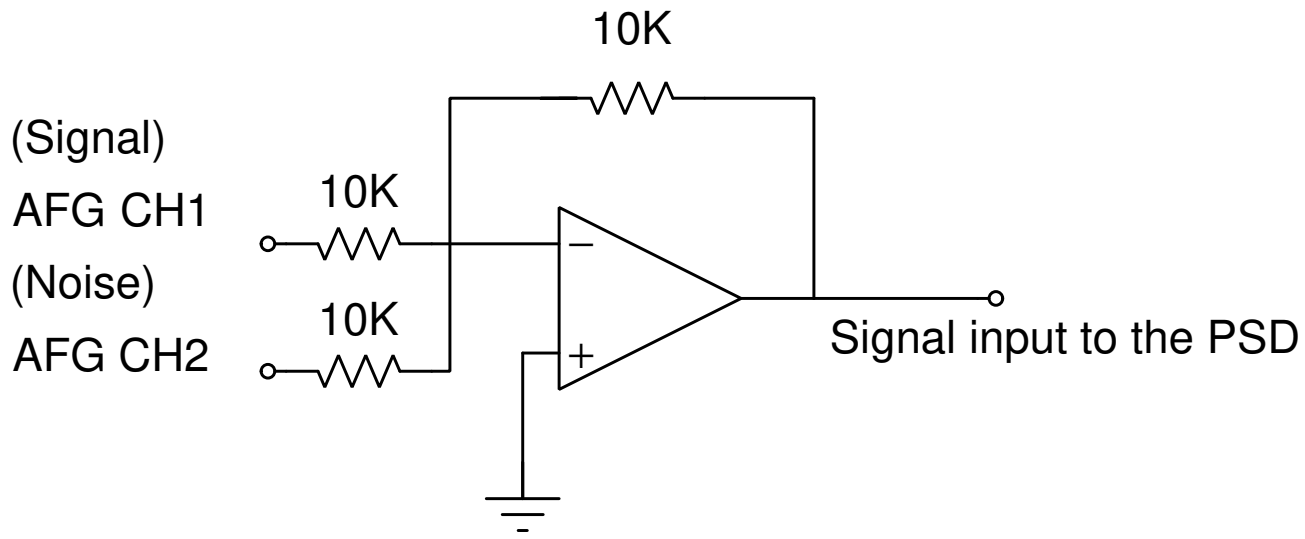
where, V_{out} is measured at 0^0 phase shift

$$C_p = \frac{V_{out}}{\omega R_f V_{in}}$$

where, V_{out} is measured at 90^0 phase shift

Measurement of signal buried in noise

- In this part of the experiment, we shall see how the output of lock-in-amplifier is insensitive to noise signal.
- Connect a simple opamp adder (that adds signal and noise) on your breadboard.
- Apply $1V_{p-p}$, 1kHz signal and $1V_{p-p}$, 500 Hz as noise input.
- Observe the output waveform of this adder circuit on DSO. Can you distinguish between signal and noise?



Measurement of the signal buried in noise continued..

- Now connect the output of this adder circuit as signal input to the buffer.
- Bypass the DUT block and connect V_{ps} directly as input to switch based PSD block.
- Observe the output of PSD on DSO and that of LPF on DMM for all the readings.
- Vary the noise voltage from $1V_{p-p}$ to $4V_{p-p}$ in steps of $1V_{p-p}$ keeping frequency constant at 500Hz. Note the output of the LPF in each case.
- Now keep the noise amplitude constant at $1V_{p-p}$ and vary the frequency of noise signal from 500Hz to 1.5 kHz in the steps of 100 Hz. Note the output of the LPF in each case.
- Tabulate your observations.
- What is the effect of changing the noise frequency and amplitude ? What do you observe at the noise frequencies close to the signal frequency?

What should you report

Part 1:Extracting the values of R_p and C_p

- Take the pictures of the following waveforms and include them in the report:
  - V_{ps} and ϕ at 90^0 phase shift
  - The two reference signals ϕ and $\overline{\phi}$
  - V_{psd} with respect to ϕ with only R_p connected
    - at phase shift 0^0.
    - at phase shift 90^0.
- Your observations for the measurement of R_p and C_p in tabular form.

Part 2: Measurement of signal buried in noise

Your observations in tabular form.

circuit layout on breadboard