The selective measurement amplifier

Principles

Figure 3.1 shows the dynamic characteristic $U_D(t)$ of the output signal of the E-field probe. It results from the superposition of the square-wave shaped “wanted signal” of the frequency f_r (here $f_r = 976$ Hz) with the noise signal $U_n(t)$. If the rms value

$$u_{n,rms} = \sqrt{\overline{U_n^2(t)}} \qquad (3.1)$$

of the noise signal is larger than the amplitude of the voltage step $\Delta U = U_{max} - U_{min}$ to be determined, than this determination is made considerably more complicated, if not impossible should no additional measures be taken on the signal processing side. These considerations lead to the sensitivity limits of the measurement method.

In order to recognize which measures lead to an increase of the sensitivity (lowering of the sensitivity limits), it is advantageous to consider the frequency spectrum of the signal $U_D(t)$. Figure 3.2 (above) depicts this frequency spectrum, which consists of spectral lines at the frequencies f_r, $3\,f_r$, $5\,f_r$ etc. belonging to the wanted periodic signal and a continuous noise spectrum. The first spectral line at f_r belongs to the fundamental frequency component.

$$U_D(t) = \hat{u} \cdot \cos(2\pi\, f_r\, t) \qquad (3.2)$$

whereby $\hat{u}$ is definitely related to ΔU via $\boldsymbol{\hat{u} = 2 \cdot \Delta U/\pi}$ (Fourier analysis).

If the received signal $U_D(t)$ is sent through a narrow bandpass filter (see Fig. 3.2, middle) with the center frequency of $f_0 \approx f_r$, then the first spectral line and thus the fundamental frequency component $U_D(t)$ is almost completely retained. However, only a “small” part of the noise spectrum remains which is determined by the effective bandwidth of the filter. The signal-to-noise-ratio is considerably increased by means of this form of selective frequency filtering. And this increase is even greater the narrower the bandwidth of the filter. In the corresponding dynamic signal characteristic obtained downstream from the bandpass filter, the fundamental frequency component remains nearly the same in comparison to the input signal, but the rms value of the noise signal has been reduced in proportion to the bandwidth of the filter. Based on the principle expounded upon until now you could replace the bandpass filter with a narrow-band low-niose amplifier and supply its output signal to an AC voltmeter. Thus, a **frequency selective measurement amplifier** is obtained; a principle often applied in the measurement of small signals.

However, if a still greater increase in the sensitivity is desired, then we must also make it clear that there is a limit to the reduction of the filter’s

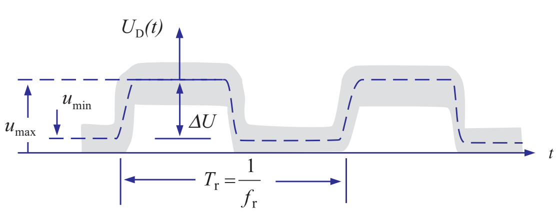

Fig. 3.1: Dynamic characteristic of the output signal of the E-field probe with superpositioned noise voltage ($f_r = 976$ Hz)

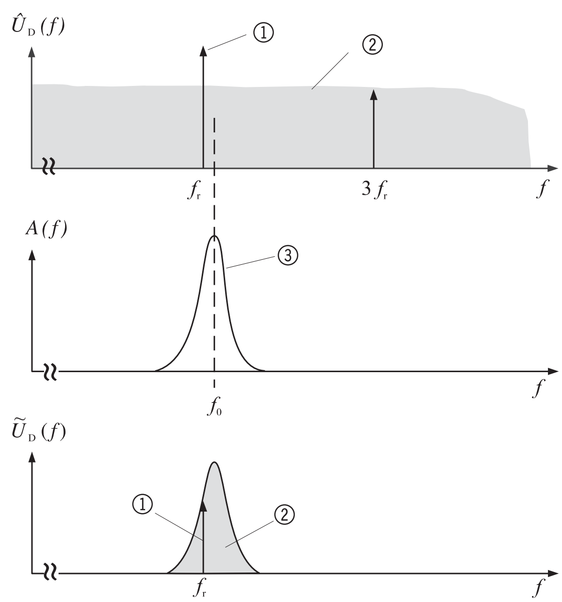

Fig. 3.2: Frequency spectrum of the signals according to Fig. 3.1 upstream (above) and downstream (below) from a narrow-band bandpass filter.
① Wanted signal
② Noise
③ Frequency response of the filter

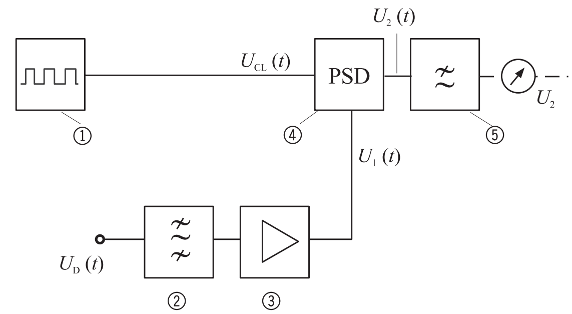

Fig. 3.3 Design of the lock-in amplifier
① Clock generator
② Bandpass filter for suppesing the harmonics
③ Amplifier
④ Phase-sensitive rectifier (Synchronuos rectifier)
⑤ Low-pass filter

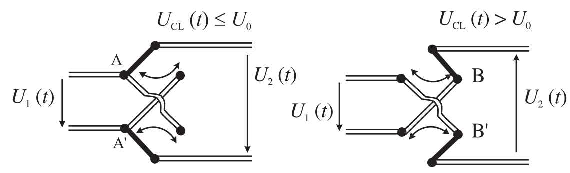

Fig. 3.4: Voltage controlled switch as phase-sensitive rectifier (PSD). Switch set to position A, if voltage $U_{Cl}(t)$ of clock generator is smaller than threshold value U_0. Otherwise in setting B.

bandwidth using the principle dealt with up to now. The narrower the bandwidth of the filter is, the better its center frequency f_0 must coincide with the clock frequency f_r, so that the wanted signal is not significantly attenuated by the filter. Due to drift phenomena in the filter, e.g. of a thermal nature or due to fluctuations in the clock frequency, deviations between f_0 and f_r must be tolerated to a certain extent. Therefore, the bandwidth of the filter cannot be reduced to arbitrarily low values.

A solution to this problem can be found when the clock signal, on which the voltage $U_D(t)$ to be measured is based, is available and can thus be used for the "synchronization" (f_0 joined with f_r) of the bandpass filter.

This basic idea is utilized in the so-called **"lock-in" amplifiers**, the fundamental principle of which is explained in the following paragraphs. First a simple bandpass filter (with no extreme demands on the bandwidth) eliminates the received signal $U_D(t)$ from harmonics of a higher mode and spectral noise components and then the filtered signal can be amplified in a low-noise, narrow-bandwidth amplifier. The resulting signal $U_1(t)$ (downstream from the amplifier (3), see Fig. 3.3) is supplied together with the signal $U_{CL}(t)$ of the clock generator to a phase sensitive detector (PSD), sometimes called a synchronous detector. Figure 3.4 shows a simple design for a PSD. Here the signal of the clock generator controls a switch so that the output signal is alternatively identical to the input signal $U_1(t)$ or the negative input signal $-U_1(t)$. The resulting output voltage $U_2(t)$ for the case that $U_1(t)$ is in phase with the clock signal $U_{CL}(t)$, is shown in Fig. 3.5 (right). If a very narrow-band low-pass filter (e.g. bandwidth 2 Hz) is arranged behind the PSD, this filter supplies the mean value u_2 [DC voltage component, see Fig. 3.5 (right)] to its output, which is clearly in conjunction with $\hat{u}_1$. In order to conduct a more exact analysis of the lock-in amplifier features, you can observe its "response" to an input signal of any given frequency f and phase φ in accordance with the equation

$$U_D(t) = \hat{u}(f) \cdot \cos(2\pi f t + \varphi) \tag{3.3}$$

Only if f equals f_r or a multiple of f_r in whole numbers, is there a DC voltage value u_2 other than zero at the output. A very high frequency

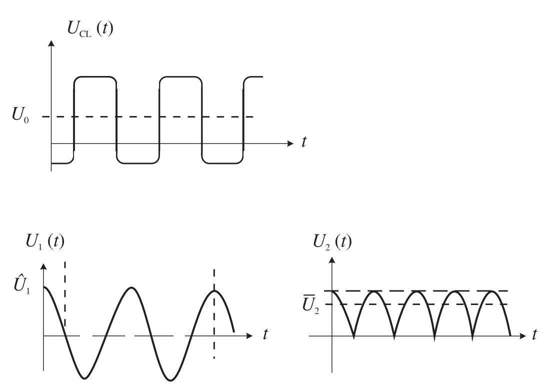

Fig. 3.5: Voltage characteristics of the single phase-sensitive rectifier
Clock generator voltage $U_{Cl}(t)$ (above),
Input voltage $U_1(t)$ (bottom left),
Output voltage $U_2(t)$ (bottom right)

selectivity is achieved by selecting a very narrow bandwidth for the low-pass filter (= prolonged duration of the integration time). This yields a considerable improvement in the signal-to-noise ratio (see above). Thus, extremely weak signals can be detected in measurement systems which are based on the lock-in amplifier principle.
If it is true that $f = f_r$, but $\varphi \neq 0$ (phase-shift between the clock and receiving signal), then

$$\bar{u}_2 = \frac{2\hat{u}_1}{\pi} \cdot \cos\varphi \qquad (3.4)$$

Thus, we obtain not only frequency- but also phase-selectivity.
In the lock-in amplifier version considered up until now the receiving signal $U_D(t)$ appears in its baseband. Such systems are referred to as **homodyne** and is the type of system integrated into the basic unit of the existing training system. It is designated here (equipment designation) as “SWR Meter”. The designation SWR meter (“standing wave ratio”) comes from its frequent use in determining the standing wave ratio on transmission lines.
In improved systems of greater complexity the received signal is first converted into a (fixed) intermediate frequency (IF) and supplied to the PSD (**Heterodyne** System).

Required equipment

1 Basic unit	737 021
1 Gunn oscillator	737 01
1 Waveguide 200 mm	737 12
1 Transition waveguide/coax	737 035
1 Coax detector	737 03
1 Set of thumb screws (2 each)	737 399

Additionally required equipment

1 Oscilloscope	575 29
4 Stand bases	301 21
3 Supports for waveguide components	737 15
2 Stand rods 0.25 m	301 26
2 Coax cables with BNC/BNC plugs, 2 m	501 022

Experiment procedure

1. *Operation of the selective measurement amplifier*

1.1 Set up the experiment as specified in Fig. 3.6. Position the two waveguide ends opposite each other at a distance of approx. 4 cm (The waveguide axes are in perfect alignment without transverse shift).

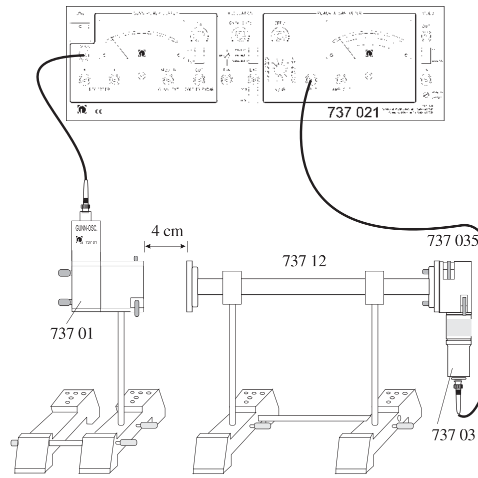

Fig. 3.6: Experiment setup

1.2 Connect the coax-detector to the input of the SWR meter. Set the toggle switch for modulation to “**GUN-INT**”. Connect the Gunn oscillator to the GUNN socket of the basic unit.

1.3 Presetting of the selective measurement amplifier:
Set the gain selection switch of the selective measurement amplifier (SWR meter) to “0 dB”.
Turn the GAIN ZERO to far left stop.

1.4 Set U_G for maximum pointer deflection on the SWR meter (see Experiment 2).
(Note: in this experiment the spectral mode distribution is not decisive, in this context see also “Design of the Microwave Source” in the preface). In the process vary the gain using the selection switch until the display is in the range from 0 to 5 dB. Afterwards set the SWR meter to maximum pointer deflection by setting the ZERO control knob to “0 dB”.

2. *Transverse shift of the waveguide end in 0.5 cm steps.*

2.1 As shown in Fig. 3.7 shift the end of the waveguide in a transverse manner in accordance with the values given in Table 3.1 and read off the respective values (in dB) displayed on the selective measurement amplifier and enter these measured values into column 2 of the table. During this measurement select an appropiate setting for the gain factor of the selective measurement amplifier and take this into account in the result.

2.2 Now connect the detector to the oscilloscope (AC setting) and repeat experiment point 2.1. This time determine the voltage range $\Delta U(x_0) = U_{max}(x_0) - U_{min}(x_0)$ of the receiving signal and enter it into column 3 of the Table.
Note: If you have a BNC-T adapter (cat. no. 501 091) and an additional RF cable (cat. no. 501 022) at your disposal, you can do experiment points 2.1 and 2.2 in parallel.

3. *Demonstrating the sensitivity gain when using the selective measurement amplifier*

3.1 Move one of the waveguides until noise makes it impossible to recognize the square-wave signal on the oscilloscope. Covering one waveguide aperture with your hand should now have no effect on the signal.

3.2 While maintaining the transverse shift as it is, now connect the detector to the measurement amplifier (INPUT socket) and set the display of the SWR meter to a value between –5dB und 0 dB by selecting a suitable gain factor. Now cover one waveguide aperture with your hand and observe the display.

Questions

1. Based on column 3 of the table (ΔU) determine the respective values

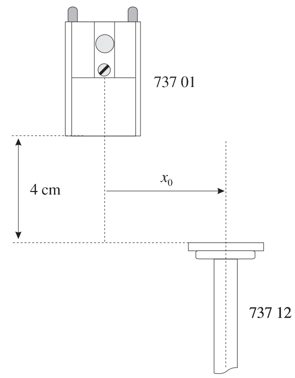

Fig. 3.7: Transverse shift of the waveguide axes (view from above)

$$10 \cdot \log \frac{\Delta U(x_0)}{\Delta U(0)} = 10 \cdot \log \left[\frac{U_{max}(x_0) - U_{min}(x_0)}{U_{max}(0) - U_{min}(0)} \right] \quad (3.1)$$

for the given transverse distances x_0 and enter these into column 4.

2. Compare the findings in columns 2 and 3 of the table.

Comments:

- If under point 2.2 you are already unable to determine $\Delta U(x_0)$ in the range around x_0= 0 up to 2 cm (due to too much noise), reduce the longitudinal distance from 4 cm to a smaller value, and repeat the entire experiment.
- However, if you have too high a signal level you can also increase the longitudinal distance and repeat the entire experiment.

Table 3.1

$\frac{x_0}{\text{cm}}$	$\frac{a}{\text{dB}}$	$\frac{\Delta U(x_0)}{\text{mV}}$	$10 \cdot \log \left[\frac{\Delta U(x_0)}{\Delta U(0)} \right]$
0	0.0		0.0
0.5			
1			
1.5			
2			
2.5			
3			