Amplification and its measurement

Contents

1. Voltage amplification

1.1 Basic definitions

The voltage amplification factor (or voltage transfer factor) is an important parameter of analog signal transfer devices. The voltage amplification factor is simply called voltage amplification, or even more simply, amplification. If the amplification is less than 1, then instead of amplification we talk about attenuation. An analog signal transfer device is considered here in a general sense: it can be a telecommunication channel, a measurement amplifier or a signal conditioner module connected to a sensor, assuming that the input and output signals are both analog.

The amplification generally depends on the frequency of the signal. The range where the amplification can be considered practically constant (and for which the amplification factor decreases significantly outside this range) is called the passband. A special case of the passband is when it contains the 0 frequency. In this case, we talk about a direct current voltage amplifier, or DC-amplifier. DC-amplifiers are mostly used in measurement and control applications.

By definition, the amplification factor is the ratio of the voltages of the output and the input signal. In general, this is a complex function. When measuring voltage amplification (A_u), usually only the absolute value of the amplification function is considered, which is the ratio of the amplitudes of the output and input sine waves of a given frequency:

$$|A_u| = U_{aout} / U_{ain} ,$$

where U_{aout} and U_{ain} denote amplitude of the output and the input signals, respectively.

The phase angle of the amplification factor is simply called **phase shift**.

The amplifications is frequency dependent. The description and representation of the frequency dependency is called **frequency response**. If we want to differentiate between the frequency dependence of the magnitude and the phase shift, then we talk about **magnitude response** (or **gain**) and **phase response** (see also the **Bode-diagrams**).

In transmission technology, the **group delay** function is considered, because the frequency dependence of this quantity describes the conditions of a distortion free transmission in a more expressive way.

1.2 The deciBel scale

In measurement theory, the amplification is described by its numerical value, but in communication technology usually a logarithmic scale, the deciBel scale (dB) is used. In case of voltage amplification:

$$A_u\,[\mathrm{dB}] = 20 \log (U_{aout} / U_{ain})$$

In case of power amplification:

$$A_p\,[\mathrm{dB}] = 10 \log (P_{out} / P_{in}) .$$

In communication technology, the dB scale is also used in so-called level measurements, where the signal value is compared to some fixed reference value commonly settled. In case of a **dBm** value, the reference value is the voltage value that indicates 1mW performance. The power also depends on the resistance of the device on which the voltage drops the given value, thus the value of the resistance also has to be commonly settled. The usual value is 600 Ohm, and this is also the default setting of the Agilent 34401 multimeter used in the measurement laboratory, when selecting dBm indication. If the resistance is 600 Ohm then 0,775 Veff (V_{RMS}) corresponds to 1 mW power. In telecommunication, other standard in- and output resistance and impedance values are used, if the dBm value corresponds to such a reference then this has to be indicated. In the engineering practice the notation **dBμ** is also used, which is the voltage value ratio corresponding to the 1 μV reference value.

2. Measuring the voltage amplification

The measurement can be performed by a manual method or by means of an automatic measuring instrument. Automatic measuring instruments usually also determine the frequency response, so these devices will be detailed later.

The methods for measuring the absolute value of the voltage amplification can be classified into the following two groups, according to the classical taxonomy:

- Methods with two voltmeters
- Measurement by comparison with a calibrated attenuator

The measurement methods for phase shift will be detailed later on, in Section 3.

2.1 Methods with two voltmeters

In the classical setting of the so-called **two voltmeter method,** one voltmeter is used measure the input voltage of the examined device (U_{in}), and the other measures the output voltage (U_{out}), and the amplification is the ratio of the two measured values, by definition:

$$A_u = U_{out}/U_{in} .$$

The value of the amplification depends more or less on the load of the output, the voltage source, the temperature, the frequency, etc., so the measurements should be carried out in environments similar to the operating conditions.

The sketch of the measurement layout can be seen on *Figure 1*. The magnitude of the signal used for the measurement has to be chosen such that the amplitude of the output signal is not too small, otherwise the inner and outer noises and distortions cannot be neglected. On the other hand, the amplitude has to fall below the upper limit of the measurement range in order to avoid distortions of the signal form that would change the measurement results.

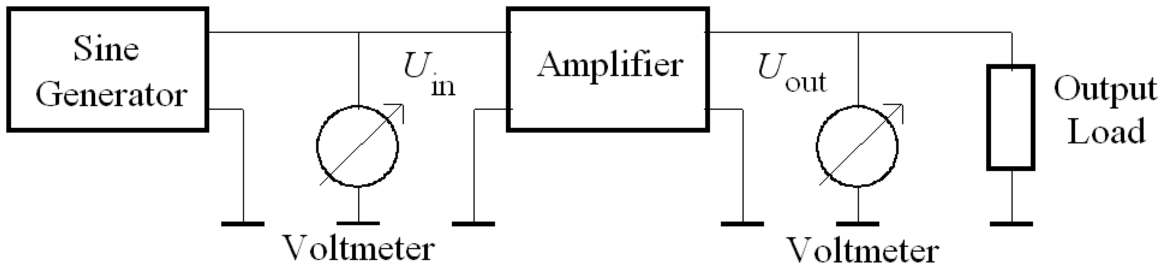

Figure 1. Amplification measurement with two voltmeters

We can check whether the signal is noise free and undistorted by connecting an oscilloscope to the output.

Naturally, the measurement can also be implemented by only **one voltmeter** switching the voltmeter from the input to the output (see *Figure 2*). The advantage of this method is that the calibrating error and the frequency dependence error mainly disappear. In this measurement setting, the load effect of the voltmeter can cause errors, since it may effect either the input or the output. The load effect of the modern electronic voltmeters can be usually neglected.

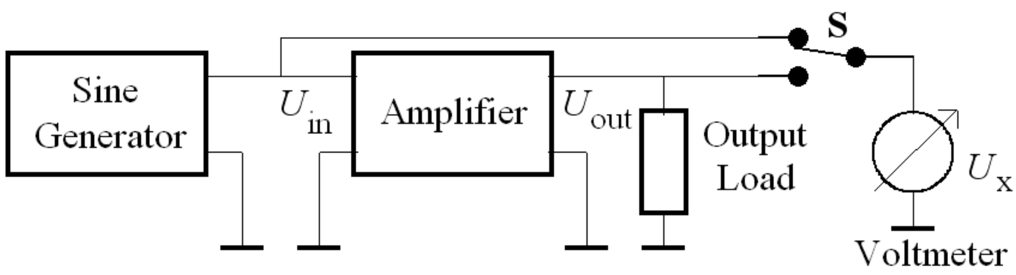

Figure 2. Amplification measurement with switched voltmeter

2.2 Measurement with calibrated divisor

Comparison with a **calibrated divisor** had been widely used for a long a time, since it was easier and cheaper to construct attenuators of great accuracy than constructing accurate voltmeters. Because of the development of the electronic voltmeters, this method nowadays is only used in the microwave range.

3. Measuring the phase shift

If we want to measure the phase shift, then we have to compare the phases of the input and output sine wave. In manual methods, this can be performed by applying a so-called vector voltmeter that is able to measure the phase of the output, but the most simple way of the measurement is to use an oscilloscope.

In the measurement with oscilloscope, the phase shift can be simply determined from the time delay between the input and the output signal. In case of a two channel oscilloscope, this time delay can be determined by the simultaneous plotting of the input and output signals. It is useful to determine the relative value of the time delay according to the period time, instead of determining its exact value (see *Figure 3*). In this case, the error of the time scale factor of the oscilloscope disappears.

To decrease the reading errors, it is worth setting the amplification ratio of the channels and the horizontal time delay such that the figure of one period becomes large enough on the screen. In addition, the point (the voltage level) of the sine wave that is chosen for measuring the time delay should be located on that part of the signal which has greater slope, in order to decrease the horizontal reading error. An advantageous choice is the point where the zero line is crossed.

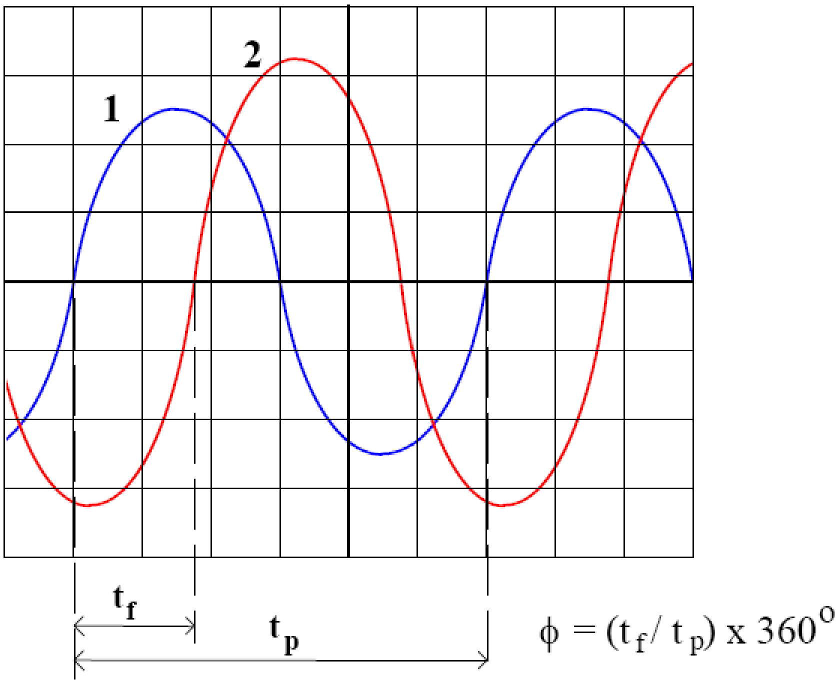

Figure 3. Measuring the phase shift with an oscilloscope.

A digital oscilloscope that contains an embedded processor can usually perform the above measurement automatically.

In textbooks, when describing the phase shift measurement with oscilloscope, it is common to mention the Lissajoux figure method. The Lissajoux figures are generated by switching the oscilloscope in x-y mode, and controlling the bias in one direction through the input signal, and the other direction by the output signal. As the frequencies of the two signals are the same, the obtained curve will be an ellipse. The ratio of the horizontal and vertical intersections of the ellipse determines the absolute value of the phase angle, but in order to determine the sign of the phase shift other examinations have to be applied. The Lissajoux figure method is usually inaccurate.

4. Determining the frequency response

It is a frequent task to determine the frequency response of an amplifier, in other words how does the amplification depend on the frequency. This means the determination of two curves, the magnitude response and the phase response. The magnitude response is the absolute value of the amplification (the ratio of the amplitude of the output signal and the amplitude of the input signal) plotted against frequency. The phase response means the phase shift between the output signal and the input signal plotted against frequency.

There are two methods of determining the frequency response:

- the "manual" method or
- by using an automatic instrument.

4.1 Measurement of the frequency response by the "manual" method

The frequency response measurement can be carried out by one of the previously presented amplification measurement methods, by measuring the amplification and the phase shift at different frequencies.

During the evaluation of the measurement, the **relative amplification response** is commonly calculated. The relative amplification response is the product of the constant amplification at the center frequency (A_{uo}) and a frequency dependent relative amplification ($a_u(j\omega)$):

$$A_u(j\omega) = A_{uo}\, a_u(j\omega)$$

We have to make sure, that the voltmeter used for the measurement has a wider frequency range than the bandwidth of the amplifier under test. The measurement procedure is simpler if the amplitude of the input sine wave is constant during the measurement, as in this case it is not necessary to measure the amplitude voltage of the input signal separately for all the frequencies.

If the specifications of the amplifier are given in dB, then it is useful to use voltmeters with a dB scale. The measurement is simpler if it is possible to set such an input voltage that the voltmeter at the output displays exactly 0 dB at the beginning of the measurement. Afterwards, at different frequencies the dB value shown at the display of the voltmeter is equal to the $|a_u|$ value in dB. More sophisticated voltmeters (such as the Agilent 34401A used at the laboratory) can be configured to have a user defined voltage level as the denominator of the dB scale. In this case, the measurement is also very simple.

So far, only the determination of the magnitude response was shown, in order to have the frequency response, we also have to measure the phase response. This can be done by the method explained earlier in Section 3.

4.2 Measurement of the frequency response by an automatic instrument

The first automatic instruments to measure the frequency response were the **wobbler-generators**. A wobbler-generator outputs a sine wave with constant amplitude and varying frequency. The frequency sweep is repeated with a certain period. Besides this varying frequency sine wave, the generator also outputs a control signal. The amplitude of this control signal is proportional to the actual frequency of the sine wave. The measurement setup with a wobbler-generator is shown in Figure 4.

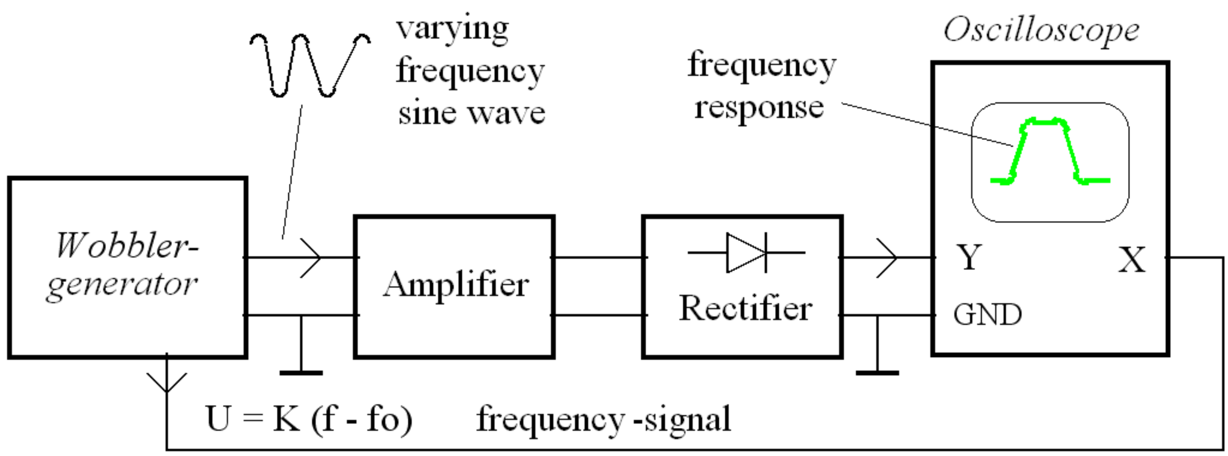

Figure 4. Frequency response measurement with a wobbler-generator

Programmable instruments can also be used to measure the frequency response similarly to the two voltmeter method. The generator can be a programmable function generator, the voltmeter can be replaced by a high resolution A/D converter. By the digital processing of the output of the A/D the frequency response can be easily determined in software. The processing computer can also provide other parameters, such as harmonic distortion.

For fast measurements, nowadays **multisine input signal**s are used. A multisine signal is the sum of multiple sine waves with different frequencies. For example, the MMTS (Multi Tone Test Signal) is a multisine test signal used in telecommunications. The amplification at different frequencies can be determined by Fourier analysis of the output signal. The advantage of this method is that the whole measurement can be performed in one step.