Audio amplifier

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1. Introduction

This laboratory exercise allows you to explore the basic characteristics of the power amplifier integrated circuit. As an example, an integrated amplifier UL1481, used to supply power to the speaker in the popular audio-video equipment. In this exercise you will measure: the output power, the efficiency, the amplitude frequency response and the nonlinear distortions of the amplifier. **Prior to the laboratory exercise, you need to have some theoretical background (basic information has been presented in the text below). Teacher is obliged to check your preparation for this exercise.**

2. Measurements

2.1 Measuring the output power and the efficiency of the amplifier at different loads R_0 and input voltages

For each load value: R_0=4Ω, 6Ω and 10Ω, perform the following measurements:
- Current consumption of the power amplifier as a function of input voltage $I_{zas}(V_{we})$.
- Power on the load as a function of the input voltage $P_{wy}(V_{we})$.

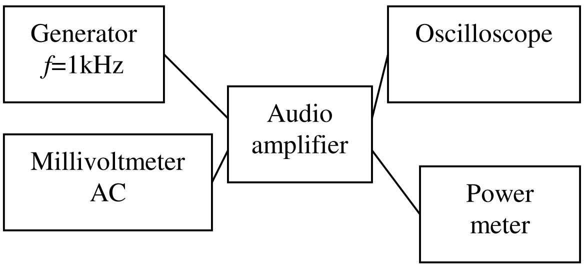


Fig.1 Measurements of the output power

The input voltage V_{we} should be varied from minimum to maximum value $V_{we\,max}$. The value $V_{we\,max}$ should be evaluated from the observation on an oscilloscope as the voltage value above which there are strong distortions of the output signal (cuts of the sine wave). **In any case, the voltage V_{we} must not exceed 40mV$_{RMS}$, because of the possibility of damage to the power amplifier!**

R_o=**4**Ω, f=1kHz

V_{we}	[V]RMS		...		$V_{we\,max}$
I_{zas}	[mA]		...		
P_{wy}	[W]		...		

R_o=**6**Ω, f=1kHz

V_{we}	[V]RMS		...		$V_{we\,max}$
I_{zas}	[mA]		...		
P_{wy}	[W]		...		

R_o=**10**Ω, f=1kHz

V_{we}	[V]RMS		...		$V_{we\,max}$
I_{zas}	[mA]		...		
P_{wy}	[W]		...		

2.2 Measurements of the frequency response of the amplifier

For each load value: R_0=4Ω, 6Ω and 10Ω, perform the measurements of output power versus frequency $P_{wy}(f)$ at the voltage V_{we}=10mV$_{RMS}$.

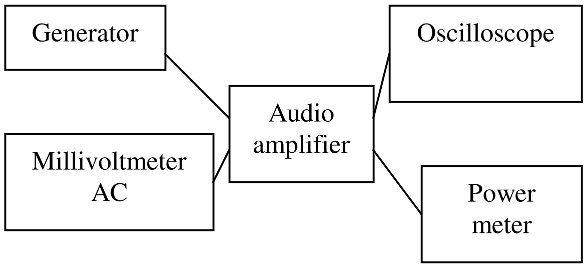


Fig.2 Measurements of the frequency response

R_o=**4**Ω, V_{we}=≤40mV$_{RMS}$

f	[kHz]	0.05	0.1	...	30
P_{wy}	[W]			...	

R_o=**6**Ω, V_{we}≤40mV$_{RMS}$

f	[kHz]	0.05	0.1	...	30
P_{wy}	[W]			...	

R_o=**10**Ω, V_{we}≤40mV$_{RMS}$

f	[kHz]	0.05	0.1	...	30
P_{wy}	[W]			...	

2.3 Measurements of the nonlinear distortions

For each load value: R_0=4Ω, 6Ω and 10Ω, perform the measurements of the coefficient of harmonic content as a function of the output power $h(P_{wy})$ for frequency f=1kHz.

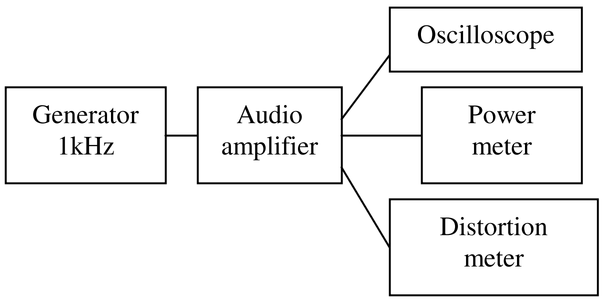


Fig.3 Measurements of the nonlinear distortions

R_o=**4**Ω, f=1kHz, V_{we}<40mV$_{RMS}$

P_{wy}	[W]		...		
h	[%]		...		

R_o=**6**Ω, f=1kHz, V_{we}<40mV$_{RMS}$

P_{wy}	[W]		...		
h	[%]		...		

R_o=**10**Ω, f=1kHz, V_{we}<40mV$_{RMS}$

P_{wy}	[W]		...		
h	[%]		...		

2.4 The measurement of the nonlinear distortion of the signal source

In order to estimate the distortions already supplied to the amplifier by the signal source, measure the distortions of the signal generator for f=1kHz and the voltage about 500mV$_{RMS}$.

3. Elaboration of the results

3.1 Based on the results from the measurements from point 2.1, plot $P_{za}(V_{we})$, $P_{wy}(V_{we})$ and $P_{str}(V_{we})$ on a single graph (coordinates of X and Y axes: linear).
(P_{str} = power loss, which is calculated as: $P_{str}=P_{zas}-P_{wy}$)
Determine the value of V_{we}, at which there is a maximum power loss.

3.2 Using the results from the point 2.2, plot the frequency responses of the amplifier for each R_o together on a single chart. Use the following settings for the axes: *X* = logarithmic, *Y* = linear.

3.3 Plot the measurement results from point 2.3 on one chart. Use linear *X* and *Y* axes.

3.4 On the basis of the performed measurements, determine and justify the optimum load resistance R_o:
a) due to the output power and the efficiency;
b) due to the distortion.

3.5 Compare the results of the measurements of the power amplifier with catalog data and draw conclusions.

4. Theory

4.1 Introduction

Power amplifiers are used to supply power to the load. Power amplifiers are distinguished depending on the frequency range of operation as low- and high-frequency power amplifiers. The most common amplifiers are for the band 15Hz-20kHz (acoustic power amplifiers), hence their use as output amplifiers to control the loudspeakers in the audio paths of radio, television, sound systems, etc.
There are also other uses of power amplifiers, for example: control actuators or output stages of RF (radio frequency) transmitters. The output stage of most operational amplifiers is also a power amplifier with low power output.
The power amplifiers usually work with:
- large output signals;
- heavy loads (i.e. small load resistances).

4.2 Nonlinear distortions in power amplifiers

Nonlinear distortion rate is particularly important parameter in power amplifiers. Transistors operate with strong signals, which lead to the operation in non-linear regions of transistors' characteristics. Providing pure sinusoidal signal at the input of the amplifier, its harmonics are observed the output, in addition to the useful signal. This is the result of amplifier's distortions. Amplitude ratio of *k*-th harmonic to the first harmonic:

$$h_k = \frac{I_k}{I_1}$$

is called a content of the *k*-th harmonic. Total harmonic distortion *h* is defined as follows:

$$h = \sqrt{h_2^2 + h_3^2 + h_4^2 + ...}$$

For the popular audio amplifiers, the acceptable value of *h* is about 10%, while less than 1% is usually required for high fidelity devices.

4.3 Classification and energetic parameters of power amplifiers

Power amplifiers, depending on the nature of their operation, are divided into classes: **A**, **AB**, **B** and **C**. The class membership is determined by the angle of the current flowing through the output transistor. The examples of collector's current flows i_C, belonging to the classes mentioned above, are presented in Fig. 4. If the current i_C flows through the entire period of the input signal (Fig. 4a), the amplifier works in the class A - then the operating point of the transistor is located in the middle of the operating characteristics (Fig. 4b). Class B occurs, when the current i_C flows through the half of the period (Fig. 4c), and the operating point of the transistor is at the beginning of its characteristics near the border of a current cut-off (Fig. 4d). The class C is when the current is less than half the period of the input signal (Fig. 4e) and the operating point is within the cut-off (Fig. 4f).
If current flows through more than half of the period, and less than the entire period, then the amplifier works in a class AB, which is the intermediate stage between classes A and B.

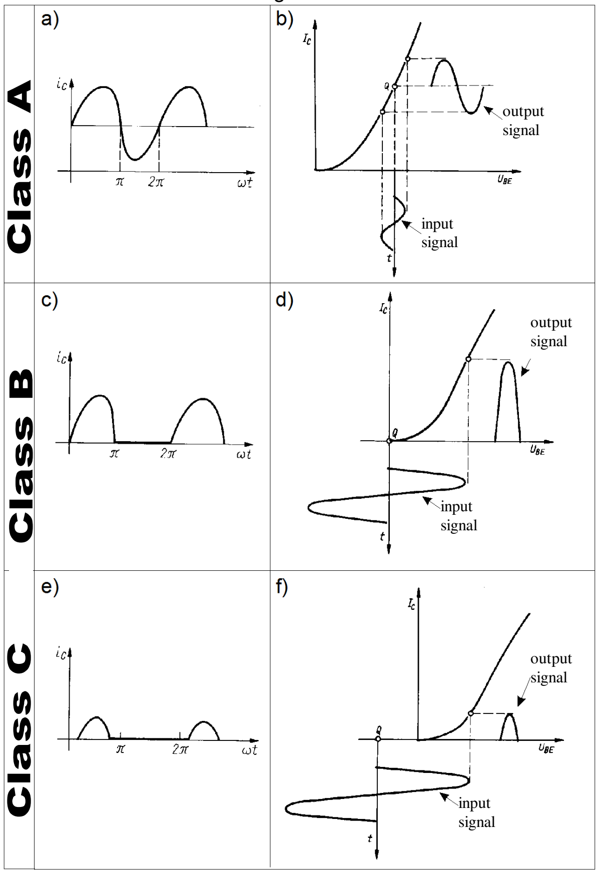


Fig.4 Classification of power amplifiers

Low frequency (LF) power amplifiers without signal processing are usually constructed in classes A, AB and B; mainly in class B and AB, close to class B. Class C is used in RF amplifiers with the load in the form of a parallel resonant circuit.
Basic parameters characterizing power amplifiers are:
- output power of the amplifier P_{wy}, i.e. the power of the signal supplied to the load;
- power supply P_{zas} – this is the power supplied to the amplifier from the power source;
- energy efficiency, defined as follows:

$$\eta = \frac{P_{wy}}{P_{zas}}$$

- nonlinear distortions, determined by the harmonic content in the output signal;
- frequency characteristics, determined by the lower and upper frequency limit.

With the transition from class A, AB, B to C the energy efficiency increases and (unfortunately!) the harmonic distortion increases. In the ideal case, the efficiency of class A amplifier is 50%, class B is 78.5%. Unfortunately, a large efficiency of class B is accompanied by large distortion. Class AB amplifier is a compromise between high efficiency and low distortion.
For audio amplifiers, the following parameters are also important:
- Rated output power, defined as the power which may be released to the rated load impedance at a given frequency or in a given frequency band without exceeding a specified ratio distortion within 10 minutes.
- Linear distortion, which can be divided into frequency distortion and phase distortion. Frequency distortion, also called attenuation distortion, is manifested as uneven voltage gain versus frequency; phase distortions are due to the different shifts of the phase angle between the input and output voltages as a function of frequency.

4.4 Push-pull power amplifiers

Class B amplifiers achieve high efficiency. However, only one half of the input signal is amplified, as it is apparent from the position of the operating point of an active element (i.e. transistor). It is therefore needed to use the push-pull circuit – i.e. to add the second transistor to amplify the second half-wave of the signal. In case of a pair of transistors of the same type, it is necessary to feed them with signals shifted in phase by 180°.
However, when both the transistors operate in class B, so called cross-distortions are generated, which are the result of strong non-linearity in characteristics of the transistors in the vicinity of the origin (Fig. 5).

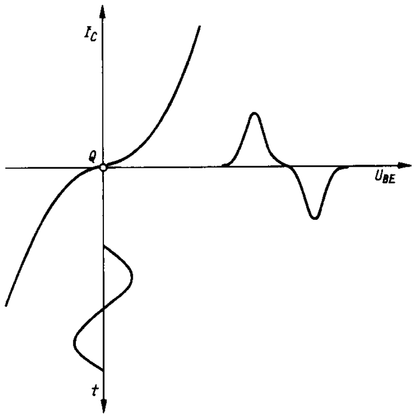


Fig.5 Cross-distortions in push-pull class B amplifier

The solution to this problem is a slight shift of the operating point of each of the transistors towards class A, which means the flow of small, fixed quiescent current, At the expense of small power losses resulting from the flow of quiescent current, a significant improvement in linearity characteristics is achieved, thus reducing distortion (Fig. 6).

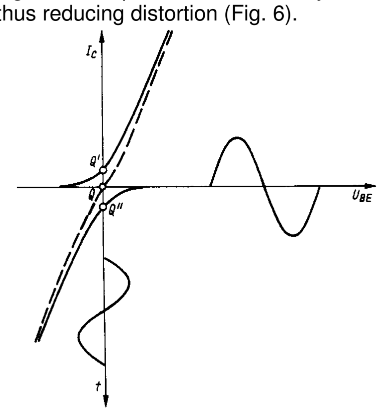


Fig.6 Cross-distortions in push-pull class AB amplifier

As mentioned above, the use of the same transistors in the output stage makes it necessary to separate the control signals shifted in phase. Fig. 7 shows the amplifier, where the transistor T1 controls the power transistors T2 and T3 with the signals shifted relative to each other in phase by 180°.

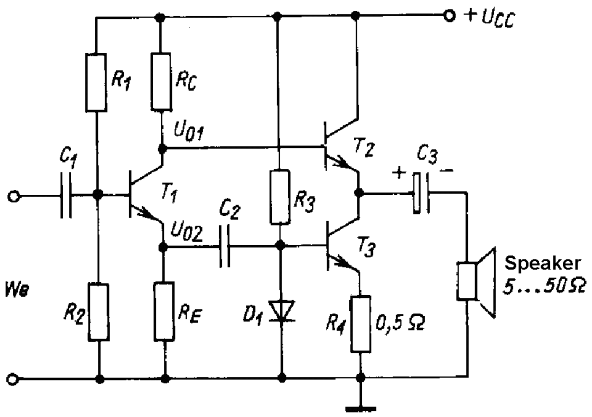


Fig.7 Power amplifier with a pair of identical transistors – class AB

The use of complementary transistors NPN and PNP in the power stage eliminates the need to control the output transistors with two waveforms (Fig. 8). Diodes D1 and D2 and resistors R1 and R2 provide the proper polarity of the power transistors. If the diodes are thermally coupled to the transistors T2 and T3 (e.g. mounted on a common heat sink or on the same silicon chip die) then the further reduction of the temperature drift of the amplifier is achieved. It is necessary, however, to select the transistors T2 and T3 with similar characteristics (often avoided by replacing the transistor T3 with the coupled pair of transistors NPN and PNP - such a couple is identical to a single PNP transistor with the same parameters as in the NPN transistor).

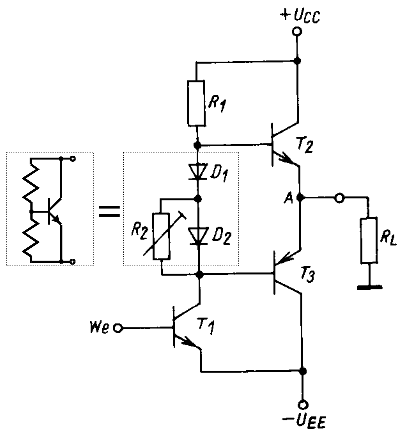


Fig.8 Power amplifier with a pair of complementary transistors – class AB

5. Specifications

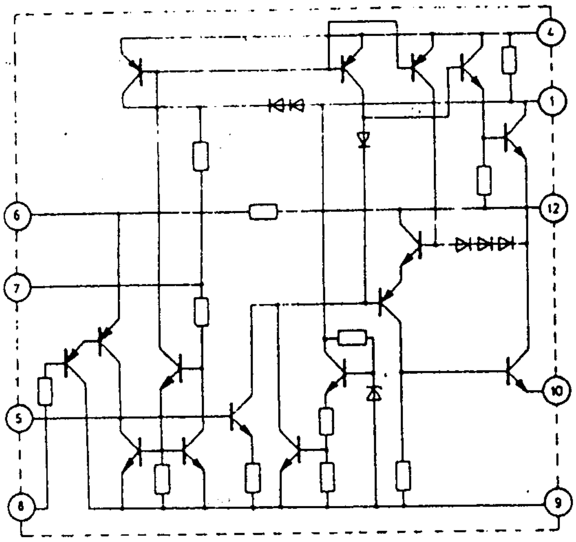
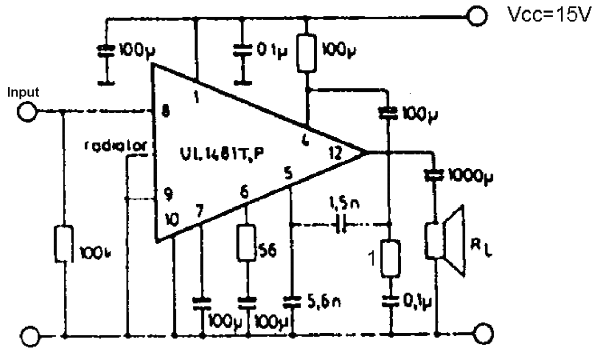


Fig.9 Internal schematic diagram of integrated circuit UL1481



Rys.10 Application of integrated circuit UL1481

References

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Specifications of UL1481

t_{amb} = +25°C

Symbol	Name	Unit	Value			Conditions Remarks	
			min	typ	max		
I_{CCQ}	Quiescent power supply current	mA		12	20	U_{CC}=14.4V	
P_O	Output power	W		6		h=10%	U_{CC}=14.4V R_L=4Ω f_p=1kHz
			3.5	4.6		h=2.5%	
				2.5		h=10%	U_{CC}=9V R_L=4Ω f_p=1kHz
				2.0		h=2.5%	
h	Total harmonic distortions	%		0.3	1.5	U_{CC}=14.4V; R_L=4Ω P_O=50mW...3W; R_f=56 Ω f_p=1kHz	
A_U	Voltage gain	dB	34	37	40	U_{CC}=14.4V; R_L=4Ω R_f=56 Ω; f_p=1kHz	
BW	Bandwidth (3dB)	Hz		40...20000		C=820pF	U_{CC}=14.4V R_L=4Ω R_f=56 Ω
				40...20000		C=1500pF	
U_I	Input voltage	mW		80	220	U_{CC}=14.4V; R_L=4Ω P_O=6W; R_f=56 Ω f_p=1kHz	
I_{IB}	Input bias current	μA		0.4	4	U_{CC}=14.4V	
I_{IN}	Input current noise	nA		0.1		U_{CC}=14.4V; BW=20Hz ... 20kHz	
U_{IN}	Input voltage noise	μV		2		U_{CC}=14.4V; R_g=0Ω BW=20Hz ... 20kHz	
SVR	Supply voltage rejection ratio	dB		48		U_{CC}=14.4V; R_L=4Ω R_f=56 Ω; f_p=100Hz	
R_I	Input resistance	MΩ		5			