White Paper No. 1

HUBERT 4-quadrant amplifier

Introduction

In industrial measuring technology, LF high-performance amplifiers are used for various applications. Generation of magnetic fields or special test signals for material test stands and for EMC measuring technology are typical tasks. The amplifier must be suitable for a wide range of signal shapes and loads and provide reliable and durable operation. Special conditions for the power amplifier result from operation at reactive loads, e.g. inductivities and electric motors, which are capable of returning energy to the amplifier. The amplifier must be capable of emitting and taking in current.

The principles by which HUBERT amplifiers comply with these requirements are discussed in the sections below.

Basics

In analog power amplifiers bipolar power transistors are typically used in push-pull operation. The demand for high output performance is fulfilled through a corresponding number of emitter followers connected in parallel.

The maximum achievable output power depends on a number of limit values of the power transistor, which are quickly reached particularly with a high proportion of reactive power.

The most important limit values are maximum permissible current I_{ce} flowing through the transistor and the maximum permissible voltage drop V_{ce} occurring at the transistor. The product of these two variables is the incurring transistor dissipation power P_v.

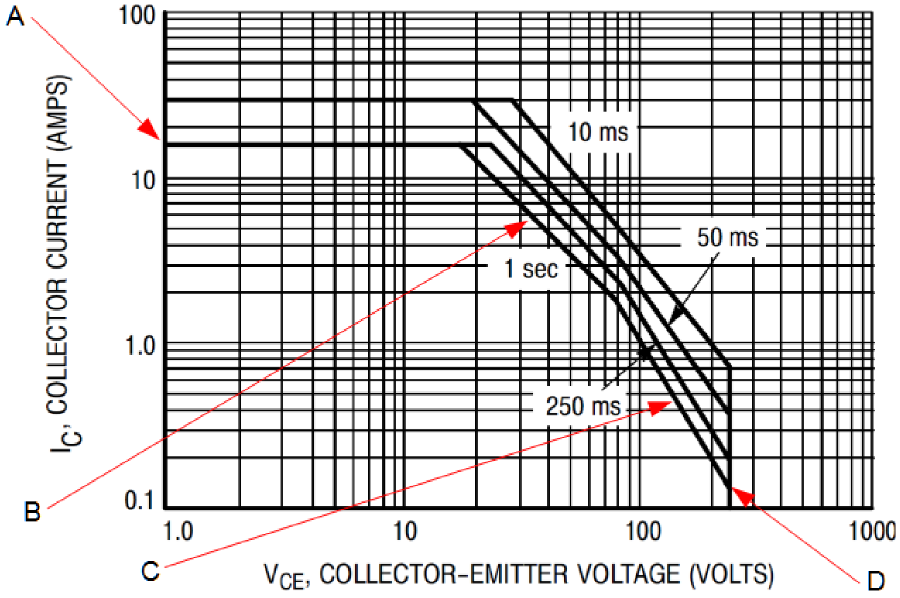

Figure 1: Safe operating area

The Vce / Ice diagram in Figure 1 illustrates the safe operating area (SOA) of a bipolar power transistor based on the load duration with a temperature at the transistor housing of 25° C. The area is limited by four straight lines:

- A: max. collector current I_{ce} = 15 A @ t = 1 sec
- B: max. dissipation power P_v = 200 Watt @ t = 1 sec
- C: second breakdown; here, the dissipation power is no longer consistent!
- D: max. collector-emitter voltage V_{ce} = 260 V @ t = 1 sec

Depending on the value of the voltage applied to the transistor, the maximum current can be read. The higher the voltage values, the more significantly the permissible current is decreased. The maximum current value I_{ce} is a function of V_{ce}.

Examples:

- With a voltage of V_{ce} = 10 V, I_{ce} = 15 A if the signal is applied at the transistor for 1 sec.
- With a voltage of V_{ce} = 100 V, I_{ce} ~ 1 A if the signal is applied at the transistor for 1 sec.

Please also note the reduction of the permissible current of the SOA in section B by approx. 10% per 10°C above a housing temperature of 30°C.

However the maximum output current of the amplifier can be increased by an appropriate number of power transistors connected in parallel.

What is a 4-quadrant amplifier?

Based on the SOA characteristic of the power transistor used, the safe operating area of the entire power amplifier can be illustrated in a U_{out} / I_{out} diagram. Where U_{out} is the output voltage and I_{out} is the output current of the amplifier.

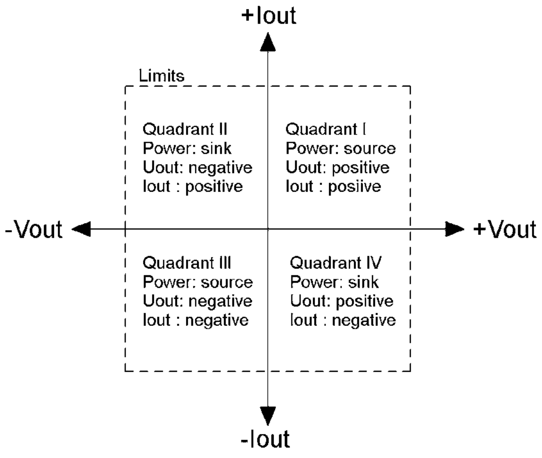

Figure 2: 4-quadrant definition

The possible maximum operating conditions can be read from Figure 2. Maximum positive or negative output voltage at positive or negative output current:

The U_{out} / I_{out} diagram is divided in 4 quadrants.

A power amplifier that can be operated in all 4 quadrants is referred to as 4-quadrant amplifier. In quadrant 1 and 3 it emits energy to the connected load (source operation), in quadrant 2 and 4 it takes in energy from a connected load (sink operation).

In general, this is a property found in all power amplifiers. But particularly in audio amplifiers, where the connected passive speaker functions as a reactive load and thus feeds back energy into the power amplifier.

Some important aspects for assessment of the performance and capacity of a 4-quadrant amplifier are:

- Is the power of the amplifier equal in all four quadrants?
- What are the differences between source and sink power, if any?
- What is the performance range?
- For which period is the specified power provided?

Operation in quadrant II and IV is particularly demanding for power amplifiers. Since there is a phase shift between the output voltage and the output current by 180°, the V_{ce} value may become very high at the current-carrying transistor.

The example below using a low-ohm coil as a load clarifies this situation:

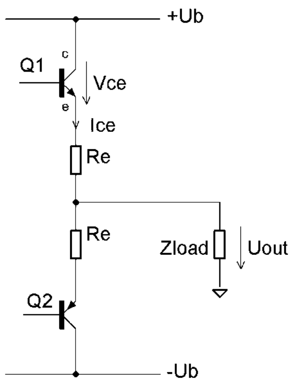

Figure 3: Output stage

Figure 3 illustrates the typical output stage of a power amplifier in a simplified manner.

The shown transistors Q1 and Q2 represent the sum of all power transistors connected in parallel. The voltage drop at Re and the transistor saturation voltage is neglected for the considerations below: The output current I_{out} corresponds to the sum of all collector currents I_{ce}.

The voltage at the transistor is: $V_{ce} = U_b - U_{out}$

The amplifier is assumed to have a capacity of 1000 W at 3 Ohm and thus an operating voltage of U_b = 90 Volt. The data of the power transistors used (8 units per polarity) correspond to that of the SOA characteristic above.

The intended application requires an output voltage of

$\hat{U}_{out}$ = 50 V / 4 kHz sine at the load Zload = 0.04 Ohm + 86 uH.

With Zload = Rload + jXload, it follows that:

| Z | = 2.16 Ohm, phase = 89° at 4 kHz

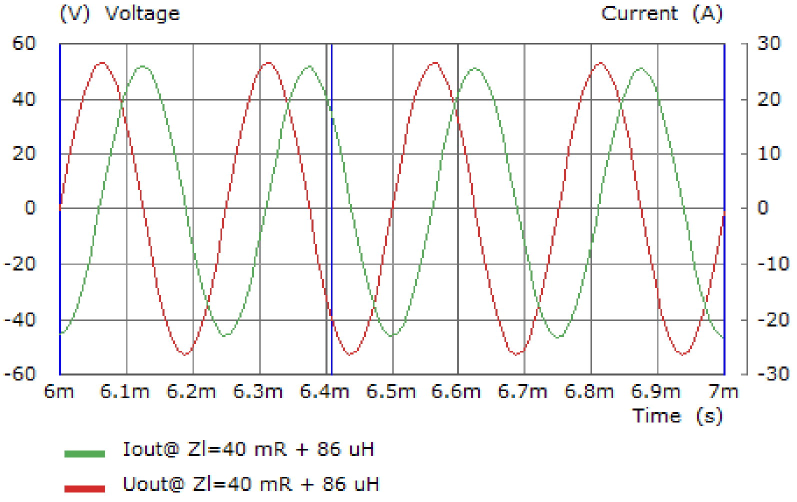

Figure 4: Output Voltage / Current @ 4 kHz

Figure 4 shows the output variables $\hat{U}_{out}$ = - 40 V and $\hat{I}_{out}$ = +16 A for the time t1 (position of the blue marker).

The current I_{ce} is positive at this time and the voltage at the current-carrying transistor Q1 is higher than its operating voltage at V_{ce} = 90 V - (-40 V) = 130 V_p. Taking a look at the SOA characteristic one realizes that the power transistors operate in the critical range C:

Characteristic for 10ms → max 2 A * 8 transistors → max 16 A at transistor housing temperature of 25° C.

This operating condition is certainly not possible for a longer period at rising temperatures.

With a resistive load, i.e. a phase angle between the output variables voltage and current is 0 degrees, a significantly less demanding operation is achieve for the power transistors:

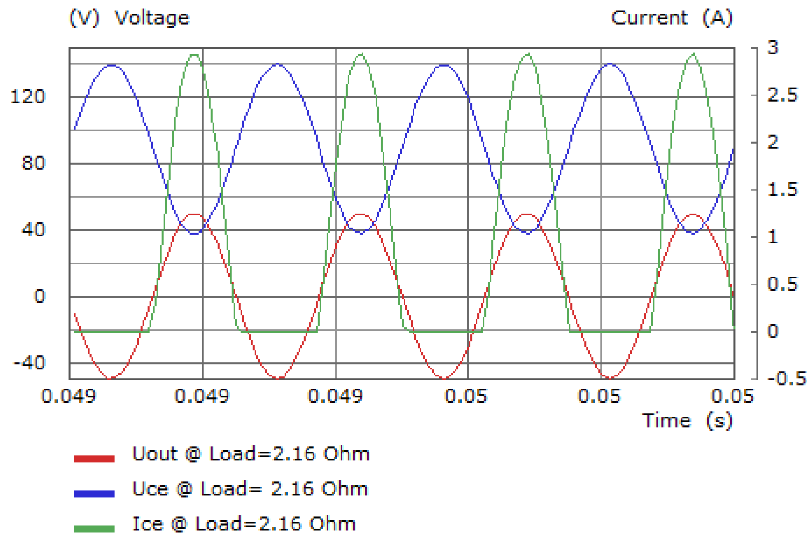

Figure 5: U_{out}, V_{ce} and I_{ce} (1 Transistor) @ R_{load} = 2.16 Ohm

Figure 5 illustrates the time-based characteristics of output voltage U_{out}, of voltage at the transistor V_{ce} and of output current I_{ce}. The load is Z_{load} = 2.16 Ohm.

At the point of maximum V_{ce} I_{ce} = 0 A or I_{ce} is at its maximum with V_{ce} = 40 V_p!
With $\hat{U}_{out}$ = 50 V / 4 kHz, dissipation power of “only”:

$P_t = (((\hat{U}_{out} * U_b)/\pi) - \hat{U}_{out}^2 / 4) / R_l$ = 373.8 W is obtained.

From the examples follows that:

The dissipation power of the amplifier is increased with an increasing phase angle of the load.

With the large varieties of power amplifiers offered on the market, this factor separates the wheat from the chaff. The mentioned audio amplifiers are not intended for such heavy-duty permanent operation with reactive loads. Their protective circuit will cause interruptions of operation and (hopefully) prevent potential damage. There are great differences between source and sink output.

The next chapter provides answers for the question about performance and capacity of the HUBERT amplifier range and the associated concepts.

Supply

The considerations above convey that an important objective for conception of a 4-quadrant amplifier must be to keep the voltage at the power transistor as low as possible of all load cases in order to optimize operational safety and efficiency Thus, the occurring dissipation power is also minimized; the efficiency of the amplifier is improved.

With the HUBERT amplifier range this load reduction at the power amplifier is ensured by a variable supply voltage. There are 3 symmetrical operating voltages available for optional selection.

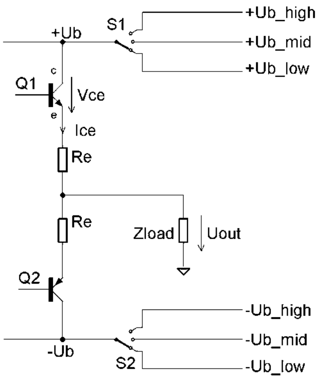

Figure 6: HUBERT output stage

Figure 6 illustrates the typical output stage of a HUBERT power amplifier with three available operating voltages in a simplified manner.

$\pm U_{b\_low} = 30V$; $\pm U_{b\_lmid} = 60$ V and $\pm U_{b\_lhigh} = 90$ V

The operating voltage is adjusted for the power transistors $+U_b$ or $-U_b$ of the required output voltage and thus the voltage V_{ce} is kept at a low level.

This concept ensures a safe operating condition for the “reactive” example stated above.

With $\pm U_{b\_lmid} = 60$ V the require output voltage $\hat{U}_{out} = 50$ V can be realized.

At the time t1 $V_{ce} = 60$ V - (-40 V) = 100 V_p ant thus the transistors are out of the “hazard zone“:

SOA characteristic for 10ms → max 3.5 A * 8 transistors → max 28 A at transistor housing temperature of 25° C.

In amplifiers from the A1110-X-E range by HUBERT, the required supply voltages $+U_b$ and $-U_b$ are synchronously adjusted manually (switch S1=S2) via an operating field on the front panel of the amplifier. The associated application software allows for remote control of this function and saving of the required start-up configuration. For integration of the A1110 product range into automated test systems, a number of command sets are available.

The amplifiers from the A1110-X-QE product range are equipped with “auto-commutating” voltage supply. This means that the required supply voltages are automatically and asynchronously (S1≠S2) switched depending on the output voltage.

The available operating voltages are:

$\pm U_{b\_low} = 10V$; $\pm U_{b\_lmid} = 45$ V and $\pm U_{b\_lhigh} = 90$ V

The functioning principle is explained below using the example for reactive loads.

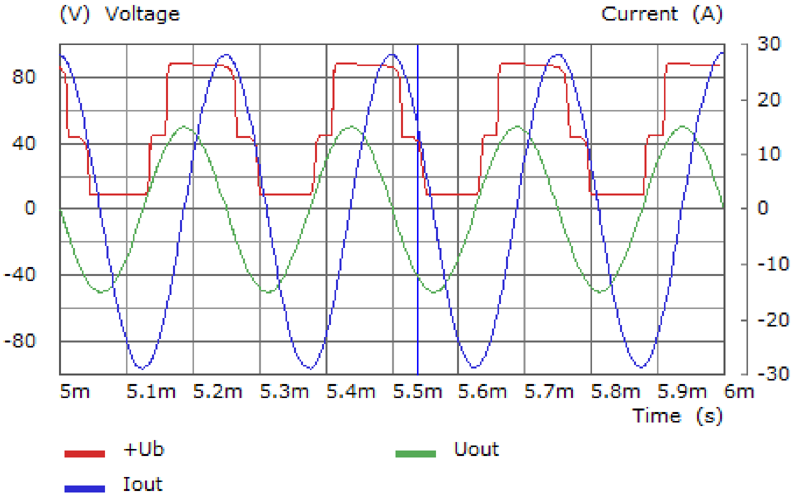

Figure 7: Supply Voltage; Output Voltage and Current @ 4 kHz

Figure 7 illustrates the time-based characteristics Operating voltage $+U_b$ (for clearer illustration only the positive operating voltage is shown), output voltage U_{out} and output current I_{out}.

The operating voltage is switched to the respectively required potential in accordance with the output voltage. For example, at the time t1 = 5.54 ms (blue marker) the current $I_{out} = 16\ A_p$ is positive and the output voltage $U_{out} = -40$ V is negative. However, since the operating voltage was switched to $U_b = 45$ V, the voltage at the transistor is only $U_{ce} = 85$ V and not 130 V as in the example above!

This results in significant relief of the power transistors and thus in safe permanent operation without any activity of the protective circuits.

Since asymmetrical switching of the supply voltages is possible, the devices from the A1110-X-QE amplifier range can also be operated as active loads.

The most important performance data of the HUBERT 4-quadrant amplifiers are listed in the corresponding data sheets. The limit values for operation in the individual quadrants are provided in the appertaining U_{out} / I_{out} diagrams.

Conclusion

In particular with reactive loads, power amplifiers are under “performance stress” and the permissible operation is “burdened” in all 4 quadrants.

The presented concept of the HUBERT 4-quadrant amplifiers ensures considerable “relief” of the output stage. Depending on the signal wave form, the dissipation power of the transistors may be kept at an uncritical level in all operating modes.