FAST HIGH VOLTAGE TRANSISTOR SWITCHES

Model Series HTS

1. General

HTS transistor switches are made up of a large number of MOSFETs, lying parallel and in series, which are combined in a compact, low-inductance bank. Unlike the so-called avalanche transistor switches the MOSFETs of the HTS switches are not operated in breakdown but instead are controlled via their gates, giving rise to a high degree of reliability and a switching performance which is excellent. By means of a special driving circuit the individual MOSFETs are controlled absolutely synchronously and with a low impedance. In conjunction with a connection technique particularly low in inductance it is possible in this way to obtain nanosecond transition times. Galvanic isolation between the control circuit and the load circuit allows the devices to be used as high-side switches. A TTL-compatible control signal and a 5-volt auxiliary voltage are all that are required on the input side. The internal driving circuit takes care of signal conditioning, auxiliary voltage monitoring, frequency limitation and temperature protection[1]. HTS switches are available either with fixed or variable turn-on durations. Numerous models cover a wide range of voltages and currents.

2. Connection

2.1 Control Circuit

The principal connection is shown in Figs. 1 and 2. On the control side a well-stabilized power supply of 5.0 volts (±5%) is necessary which ought to be buffered directly at the switch with approximately 10 μF. An integrated suppressor diode gives protection from overvoltage and wrong polarities, provided the current of the 5-VDC supply is limited to approximately 1 ampere. Voltages below 4.7 volts will always lead to the high-voltage switch switching off whereas voltages above 5.3 volts activate the suppressor diode. The lowest turn-on jitter is obtained at a voltage of between 4.9 and 5.1 volts.

The control input with Schmitt trigger characteristic has a switching threshold of approximately 2 volts and is protected up to 20 volts. For a good signal-to-noise ratio a signal amplitude of 3-10 volts is recommended. If a long signal line is used, a terminating resistor corresponding to the line impedance (e.g. 50 ohms) should be provided in order to avoid reflections.

Due to unavoidable coupling capacitances between the high voltage part and the control part, short positive and negative spikes on the control signal may occur in fast circuits especially when the impedance of the generator is relatively high. However, HTS transistor switches are designed in such a way that temporary disturbances caused by fast high-voltage edges are ignored by the control electronics.

2.2 High-Voltage Circuit

The galvanic isolation allows circuits as high-side switch, low-side switch or push-pull switch for both positive and negative voltages. These basic circuits are represented in

Fig. 1 - Low-Side Switch

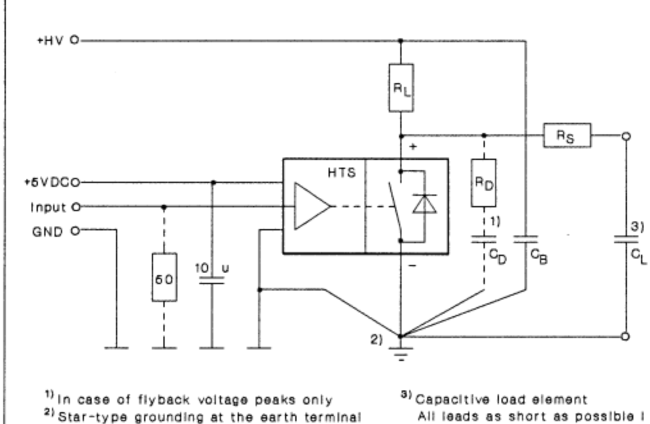


Fig. 2 - High-Side Switch

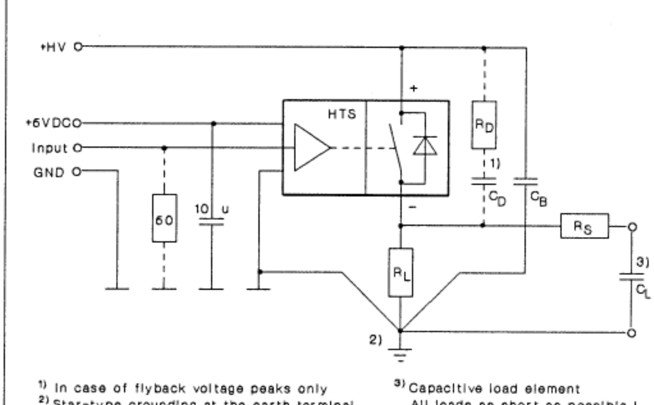
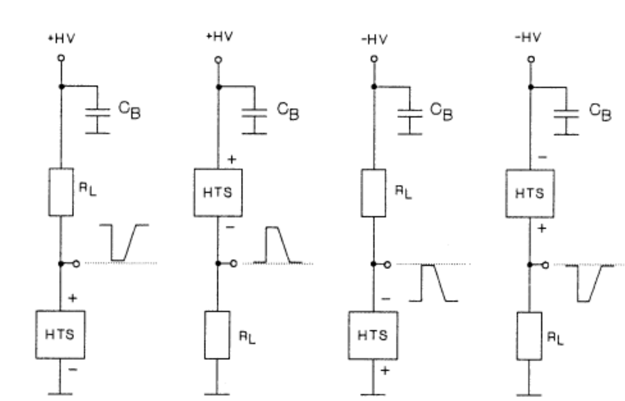
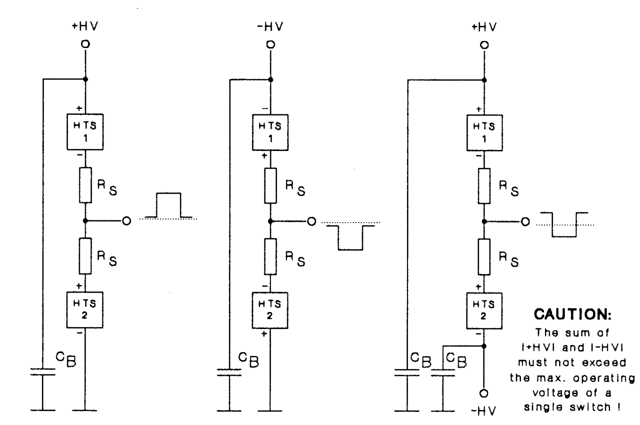


Fig. 3 - Basic Circuit Configurations



Figs. 1 to 4. The line paths should always be kept as short as possible and the high-voltage supply should be buffered as near to the switch as possible by means of a sufficiently large capacitor C_B. Otherwise dangerous flyback voltages might be induced on unbuffered lines (cf. 7.3) or load capacitances might not be charged or discharged fast enough. In the case of push-pull circuits it is vital that series-protection resistors are used, which limit the load current to less than 20% of the maximum peak current $I_{P(max)}$. Since this increases the rise time considerably, it is advisable to use the switches of the GHTS series if the shortest possible transition times are required. For those push-pull circuits which are not earthed on one side and which should be supplied bipolarly instead, the amount of negative and positive voltage must not exceed the voltage proofness of the individual HTS switch.

Fig. 4 - Push-Pull Circuit Configurations



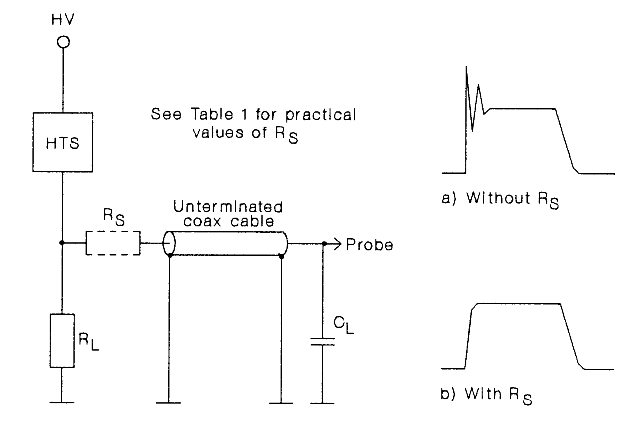
Since HTS transistor switches are fitted with protection circuits which work independently, parallel or series operation should be done only in exceptional cases and then only with the greatest care.

In parallel circuits the partial current of a individual switch must be limited to its maximum permitted peak current $I_{P(max)}$ by means of a series resistor. This is particularly true when using switches with a turn-on duration of more than 150 ns.

In series circuits the load current should be limited to less than 20% of the maximum peak current $I_{P(max)}$. Possible production-related tolerances of the turn-on delay of approximately 10% should be compensated by means of adjustable RC elements at the control input at an initially low HV. Only when the switching edges are steep and straight are the individual switches sufficiently synchronized. The sum of the switch voltages should on no account exceed the specified isolation voltage of the individual switch. The same applies to floating switches in that the sum of the floating voltage and switching voltage should not exceed the isolation voltage of the switch.

When high-voltage pulses are being transmitted, it is advisable to match the impedance between switch, line and load. This is done by means of a low-inductance series resistor R_S, the value of which can best be determined empirically at lower operating voltages. Practical values vary between 10 and 200 ohms according to the set-up, switch and line type. An optimum match is achieved when the over-shooting is not more than 5 to 10% of the wanted signal. If, for loading reasons, a suitable termination of the line is not possible, a coaxial cable as short and as low-capacitance as possible (e.g. the cable RG 59/BU with 75-ohm impedance and a capacitance of 68 pF/m) should be used in the interest of shortest rise times. The voltage

Fig. 5 - Impedance Matching



strength of standard coaxial cable is usually specified for high frequency. Here the DC-voltage strength which is of more interest lies generally about Factor 4-8 higher. If there is any doubt, the cable should be tested for its voltage before being used or else the cable manufacturer should be consulted.

Insofar as HTS switches are to be used for charging or discharging capacitors with more than 1 nF capacitance, the current should be limited to the maximum peak current $I_{P(max)}$ by means of a low-inductance series resistor R_S. Sometimes even fairly small load capacitances require a series resistor R_S in order to damp oscillations caused by parasitic inductance.

3. Noise Immunity

Since HTS switches require only a very low control power, resulting in great changes in current and voltage within a few nanoseconds, the greatest care should be taken with regard to the noise immunity of the circuitry. It is recommended that the general RF-circuit design rules be applied:

- Use low-inductance components such as ceramic capacitors, extended foil capacitors and mass resistors. Never use wire-wound resistors.
- Make line connections short and low in inductance. In printed circuits use stripline technique if possible.
- Keep induction loop areas of dynamically current-carrying lines as small as possible. Use shielded lines.
- Avoid ground loops; create good ground conditions using star-type grounding.
- Damp unavoidable parasitic resonant circuits by means of series resistors.
- Buffer power supplies by suitable capacitors.

In the interest of good noise immunity the ground of the control side should be connected with the ground of the high-voltage side. This should be done with a very short wire. For this reason HTS switches (except for the PCB mounting types) have on the high-voltage side an earth connection which lies internally at the control side's ground. It is advisable to use this pin as a star-type earth point for all high voltage connections. In the case of a difference of potential between the ground points of the control and high-voltage sides the linkage can be effected via a ceramic capacitor of approximately 10 nF. Lines on the control side should be kept away from high-voltage lines and components. Improperly laid or unshielded control lines can lead to the device turning off prematurely. This applies particularly to those HTS switches with a variable turn-on duration.

4. Switching Performance

4.1 Turn-On Rise Time

According to type, HTS switches have turn-on rise times in the region of between 1 and 20 nanoseconds. For these rise times to be used in practice, a circuit design is necessary which is very low both in capacitance and in inductance. If possible, the switches should be placed up next to the load in order to avoid the parasitic inductance and capacitance of a long line, especially in case of mismatched impedances.

4.2 Turn-Off Rise Time

The turn-off rise time depends on the type of switch. With those switches which have a turn-on duration of up to 200 ns and those with variable turn-on duration the intrinsic turn-off rise time is between approximately 5 and 20 ns. On the other hand, switches with an on-time extension option (only for models HTS 20 to 150) have a turn-off rise time of roughly the same duration as their turn-on duration.

In the process of turning off, all circuit capacitances including the switch's own capacitance (30-300 pF depending on type and voltage) must be charged via the working resistor R_L. Therefore the time for the trailing edge is usually considerably longer than for the leading edge. By reducing the time constant working resistance R_L x load capacitance C_L the turn-off edge can be shortened.

However, insofar as truly symmetrical square-wave pulses are to be generated and/or the working resistor R_L cannot be further decreased because of power limits, a push-pull circuit (preferably of the fast GHTS series) should be used.

5. Power Dissipation

On account of the HTS switches' fast rise times, dynamic switching losses can be neglected in most cases. Those types with the on-time extension option are the exception (c.f. 4.2). With these types the turn-off losses have to be considered, particularly in the case of higher load currents and higher switching frequencies. The main losses occur as a result of the internal resistance R_{stat} and the load current flowing trough the switch - this applies equally to all the switch models. These losses must be kept below the maximum power dissipation $P_{d(max)}$.

In the case of resistive loading and low switching frequencies up to approximately 100 Hz the dissipation can be calculated as

$$P_d = \frac{R_{stat} \cdot I_L^2 \cdot t}{T} \qquad (1)$$

with R_{stat} being the static turn-on resistance, I_L being the load current, t being the pulse duration and T being the pulse spacing. Since the static on-resistance varies according to the load current, the value corresponding to the respective current is to be used in accordance with the data sheet.

In the case of capacitive loading and higher switching frequencies the dissipation of a switch with a configuration as in Figs. 1 and 2 can be determined as

$$P_d = \frac{V^2 \cdot f \cdot C_L}{2} \qquad (2)$$

whereby V is the switching voltage, f the switching frequency and C_L the load capacitance. The parasitic capacitance of the circuit layout and the switch's natural capacitance belong to the load capacitance also.

The dissipation determined in this way also occurs in the same extent at the charging and discharging resistor (working resistor R_L). Should the transition times be of only secondary interest, the capacitive losses can be transferred to an additional series resistor, in which case the losses are then divided up in the ratio of switch internal resistance to series resistance. If considerable losses occur as in (1) and (2), they can be added together to an approximate total dissipation. In push-pull circuits with HTS standard switches the dissipation occurs primarily at the series resistors which are necessarily high.

6. Operation

Untested circuit set-ups should first of all be tested for their voltage strength (see 7.2). After the HTS switch has been installed, the operating voltage is to be increased only slowly until it reaches its rated value so that the switching performance and the temperature may be verified. Both the leading and the trailing edge of the high-voltage pulse should be tested by means of an oscilloscope with a band width of at least 100 MHz. If powerful oscillations (ringing) occur in the load circuit or if the pulse shape is different from what might be expected, it is vital that the load circuitry is tested again according to 2.2, 3. and 7.3 before the full voltage is applied. Only when flyback voltages and oscillations have been reduced to an extent which can not harm the switches, may the full voltage be applied.

7. Risks of Overloading

7.1 Thermal Overload

Switching frequency, pulse cycle, load capacitance and working resistance are to be chosen in such a way that thermal overload is avoided. HTS switches are fitted with a sensor[1)] to protect them from too high temperatures, which comes into operation at 70°C. Since the temperature sensor is relatively sluggish on account of the isolation, a fast uncontrolled increase in temperature can cause damage. Especially in the case of laboratory set-ups there is the danger that too high frequencies are set accidentally at the signal generator or too high voltages at the laboratory HV supply. For this reason it is vital that the current at the HV supply is limited.

7.2 Sparkovers and Short Circuits

An effective active protection from high-voltage sparkovers is unfortunately not possible in the current state of technology. For this reason it is vital to avoid sparkovers and unlimitedly high short-circuit currents. Sparkovers are particularly dangerous when larger buffer capacitors with unlimited current are discharged via switched-through HTS switches, e.g. as the result of the breakdown of non-voltage-proof or thermally overloaded load resistors.

Improperly connected high-voltage plugs can also cause short circuits. Sparkovers can occur in load elements installed in vacuum chambers when the vacuum collapses. Badly isolated lines, humidity and unclean isolator surfaces represent other dangers. Untested circuit set-ups should be tested for their voltage strength initially on their own without the switch. The test voltage applied should be at least 1.5 times the value of the rated voltage.

The risk of non-repetitive sparkovers can be reduced to a minimum by means of a current-limiting and overload proof series resistor. The series resistor is to be placed physically as close as possible to the switch terminal. Its value should be chosen such that the short circuit current is limited to the maximum peak current $I_{P(max)}$.

7.3 Flyback Voltages

In conjunction with a primarily inductive load circuit dangerous flyback voltages may occur when high currents are being turned off fast (see Fig. 6). Because HTS transistor switches - particularly those with a short turn-off rise time - can switch off high currents within a few nanoseconds, the parasitic line inductances must already be viewed as a source of danger. The height of the flyback voltage induced at the moment of turn-off is calculated as

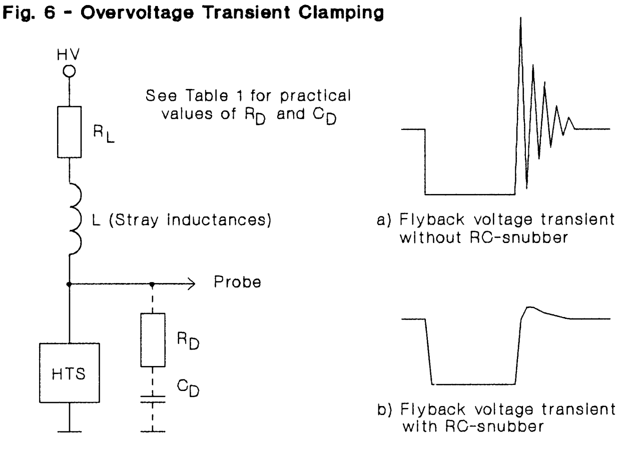
$$V_i = L \cdot di/dt \quad (3)$$

with L being the inductance and di/dt being the rate of change in the load current. Depending on the cross-section area, the inductance of a simple wire with 0.5 - 1 mm^2 amounts to approximately 8 - 10 nH/cm.

For instance, given a 10-cm-long line with an inductance of 100 nH at a 100 A turn-off current and a turn-off time of 10 ns, the flyback voltage will be as much as 1000 volts, which would have to be added to the operating voltage.

If the practical possibilities of a low-inductance circuit design have already been used to the full (stripline technique or thick wires), the voltage spikes must be reduced by means of the well-known classic clamping circuits. In high-voltage circuits passive RC elements are particularly suited. It is advisable to place a series connection consisting of a resistor R_D and and a capacitor C_D directly over the switch terminals, whereby the optimum RC values should be determined empirically using initially low voltages. Depending on the load and type of switch, practical values are 5-50 ohms for the resistor and 10-5000 pF for the capacitor, which should preferably be a ceramic type with sufficient voltage strength. Because RC-snubbers reduce the switching speed and increase the capacitive losses, the stray inductance should be minimized before RC-snubbers

Fig. 6 - Overvoltage Transient Clamping



are used. In particularly difficult cases the load current is to be reduced or switch models with higher voltage strength must be used.

7.4 Current Reversal

A reversal of the direction of the current at the switch poles, caused by powerful oscillations in the load circuit, can result in the parasitic diodes, lying parallel to the individual MOSFETs, being turned on. Since the reverse recovery time of these diodes amounts to between approximately 0.5 and 1 µs, the switches remain turned on for this time if a current reversal has preceded it. In the case of a correspondingly low load impedance and high repetition rate, the switch may become over-loaded.

8. Burst Option

In applications with high-frequency bursts it is necessary to buffer two internally generated auxiliary voltages (15-22 VDC and 24-400 VDC) with additional capacitors insofar as more than 10 pulses per pulse train are generated in less than 20 µs. The connections necessary for this are available as options (standard for PBC mounting types).

The capacitance of the external capacitors is determined by the number of pulses per burst. Generally speaking the rule of thumb C_{ext} = n x 0.1 µF applies. In the burst mode the duty cycle should be chosen such that the maximum switching frequency and the admissible operating temperature too are not exceeded. As soon as the internally generated auxiliary voltages sink in the burst operation to an unacceptable level, the switch is turned-off for several milliseconds. Suitable capacitors would be aluminium electrolyte capacitors of sufficient voltage strength.

Caution: The switch may be damaged by a short circuit of the capacitor connections or by a connection between capacitor terminals and other input terminals.

9. Assembly

For safety reasons the switch should be secured by means of the plastic screws which are delivered with it. If power dissipation is considerable, it is necessary to ensure adequate removal of heat. If need be, forced convection should be provided by a fan. In view of possible radio interferences HTS modules and their load circuits should be built into a hermetically sealed metal casing only.

10. Service

For reasons of isolation the HTS switches are completely moulded. Nevertheless, certain repairs are possible, particularly when it is a matter of damage to the control electronics. If this is the case (e.g. too high an auxiliary voltage having been applied by mistake at the 5-volt input), we ask you to return the module to have it tested free of charge to determine whether it can be repaired or not.

11. Guarantee

We guarantee impeccable quality of our devices in line with the current state of technology. The guarantee lasts for 12 months beginning with the date of delivery. Guarantee claims must be lodged within the above time span either with us or with an authorized representative office and be accompanied by the invoice or delivery note. Within the guarantee period we undertake to rectify free of charge any defects which can be proved to result from material or construction faults. Damage resulting from improper use is not covered by the guarantee. In particular we accept no responsibility for devices damaged by overvoltage, thermal overload or short circuits. The guarantee period is neither extended nor renewed as a result of repairs carried out during this time. A claim for transformation or decrement is not included unless we are unable to rectify the fault. Wider claims for damage are not created by virtue of these conditions of guarantee.

- Do not exceed the maximum operating voltage and the maximum peak current
- Stay within the thermal limits of switch
- Avoid short circuits and sparkovers
- Use high-voltage proof components only
- Avoid self-induced overvoltage spikes
- Do not connect unclamped inductive loads

DANGER - HIGH VOLTAGE

Do not touch the switch under operation !

Table 1 - Practical Components Values

HTS Model	$R_{L(min)}$ 2)	$R_{L(max)}$ 3)	R_S 4)	R_D 5)	C_D 5)
HTS 20-08	25 Ω	20 - 200 MΩ	1 - 25 Ω	5 - 50 Ω	30 -1500 pF
HTS 30	100 Ω	30 - 300 MΩ	8 - 100 Ω	10 - 50 Ω	10 - 500 pF
HTS 30-06	50 Ω	30 - 300 MΩ	3 - 50 Ω	5 - 50 Ω	20 -1000 pF
HTS 50	166 Ω	50 - 500 MΩ	12 - 166 Ω	10 - 50 Ω	10 - 500 pF
HTS 50-06	83 Ω	50 - 500 MΩ	5 - 83 Ω	5 - 50 Ω	20 -1000 pF
HTS 80	266 Ω	80 - 800 MΩ	20 - 266 Ω	10 - 50 Ω	10 - 500 pF
HTS 150	500 Ω	150 -1500 MΩ	35 - 500 Ω	10 - 50 Ω	10 - 500 pF
HTS 50-12	42 Ω	20 - 200 MΩ	2 - 42 Ω	5 - 50 Ω	30 -1500 pF
HTS 80-07	114 Ω	30 - 300 MΩ	8 - 114 Ω	5 - 50 Ω	30 -1500 pF
HTS 50-08-UF	63 Ω	1 MΩ	4 - 63 Ω	5 - 50 Ω	30 -1500 pF
HTS 50-12-UF	42 Ω	1 MΩ	3 - 42 Ω	5 - 50 Ω	30 -1500 pF
HTS 80-12-UF	66 Ω	2 MΩ	6 - 66 Ω	5 - 50 Ω	30 -1500 pF
HTS 21-14	14 Ω	20 - 200 MΩ	1 - 14 Ω	5 - 50 Ω	30 -1500 pF
HTS 21-50	4 Ω	6 - 60 MΩ	0.3 - 4 Ω	5 - 50 Ω	100 -5000 pF
HTS 31	100 Ω	30 - 300 MΩ	8 - 100 Ω	10 - 50 Ω	10 - 500 pF
HTS 31-06	50 Ω	30 - 300 MΩ	3 - 50 Ω	5 - 50 Ω	20 -1000 pF
HTS 51	166 Ω	50 - 500 MΩ	12 - 166 Ω	10 - 50 Ω	10 - 500 pF
HTS 51-06	83 Ω	50 - 500 MΩ	5 - 83 Ω	5 - 50 Ω	20 -1000 pF
HTS 51-20	25 Ω	15 - 150 MΩ	1 - 25 Ω	5 - 50 Ω	50 -2500 pF
HTS 81	266 Ω	80 - 800 MΩ	20 - 266 Ω	10 - 50 Ω	10 - 500 pF
HTS 81-09	89 Ω	25 - 250 MΩ	5 - 89 Ω	5 - 50 Ω	30 -1500 pF
HTS 151	500 Ω	150 -1500 MΩ	35 - 500 Ω	10 - 50 Ω	10 - 500 pF
HTS 301	1000 Ω	300 -3000 MΩ	70 -1000 Ω	10 - 50 Ω	10 - 500 pF

Notes:

2) Lowest permissible value at the maximum operating voltage. Pulse operation only (cf.section 5).
Caution: In case of very low working resistances and high currents dangerous flyback voltages may occur!
3) Depending on operating voltage, temperature and justifiable voltage drop at R_L.
4) Depending on operating voltage. These values are valid for protection purposes and oscillation damping only.
5) In case of flyback overvoltage peaks (cf. section 7.3)