FAST HIGH VOLTAGE TRANSISTOR SWITCHES

DESCRIPTION

The high-voltage switches described here have a variable on-time and are comparable with classical solid-state relays; they are turned on as long as a control signal is applied to the control input. BEHLKE HTS switches are actively controlled devices (no avalanche technique) and show highly reliable and reproducible switching behaviour regardless of temperature, voltage or load condition. Compared to conventional high voltage switching elements, such as gas discharge tubes and spark gaps, BEHLKE solid-state switches do not show aging effects and achieve life times by several orders of magnitude higher than any other classical high voltage switch.

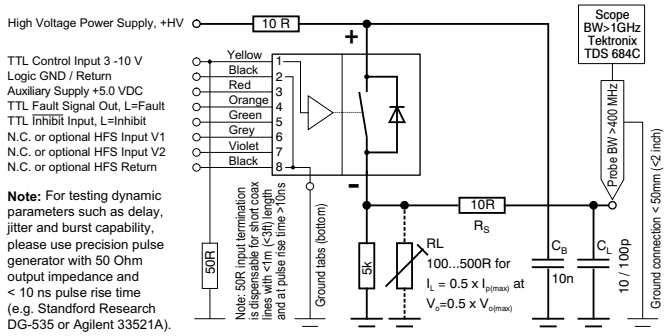
The switches are very easy to handle and only require a simple +5 VDC auxiliary supply (4.5 to 5.5 VDC) and a TTL-compatible control signal. The control signal can be any positive going pulse of at least 25 ns duration and 2 to 10 volts amplitude. Due to the Schmitt-Trigger input characteristics and the very high signal amplification neither the switching behavior nor the turn-on rise time will be influenced by the waveshape of the control pulse. The recovery time after a switching cycle is less than 150 ns, making burst frequencies of up to 6 MHz possible. Burst frequencies of even up to 10 MHz can be achieved by means of the option **HFB**. The maximum continuous switching frequency is primarily limited by the power capability of the internal driver and by the power dissipation of the high-voltage switch. Standard switches without optional cooling and without optional **HFS** supply can reach several 10 kHz, depending on operating voltage and load capacitance. Higher frequencies require an additional auxiliary supply for the internal driver, which is connected by means of the option **HFS**. The switch must also be sufficiently cooled if the frequency depending power dissipation exceeds the specified $P_{d(max)}$ value. For the individual cooling requirements are various cooling features available, such as option **CCS** (ceramic cooling surface), **CF** (copper cooling fins), **CF-CER** (ceramic cooling fins), **CF-GRA** (graphite cooling fins), **GCF** (grounded cooling flange), **ILC** (indirect liquid cooling) or **DLC** (direct liquid cooling). In connection with option **DLC** the continuous switching frequency can be increased up to 3 MHz.

The switches are equipped with the new "intelligent" driving and control circuit VC4, which provides active input filtering, signal conditioning, auxiliary voltage monitoring, frequency limitation and temperature protection. The input filter allows an un-shielded input wiring of at least 25 cm (10") length. Undefined control signals, noise and transients are uncritical to the switch. The high-voltage MOSFET stack is always safely controlled regardless to the pulse width or waveshape of the control signal. The control circuit has 3 integrated temperature triggers. One thermotrigger with a response time of <60 seconds protects the high-voltage switch, two further sensors with <10 seconds response time are placed in the critical areas of the driver circuit. An inhibit input (pin 5, L=Inhibit) allows the connection of external thermotriggers, over current detectors and / or coolant flow detectors from liquid cooling systems. The operating conditions are indicated by three built-in LEDs. In case of a fault (auxiliary voltage < 4.5 VDC, frequency > f(max), case temperature > 75°C and / or Inhibit = Low), the red LED will indicate an error and the switch is inhibited for at least 2 seconds respectively for the duration of the fault condition. At the same time a TTL compatible fault signal occurs at pin 4 (Low = Fault). In case of over temperature the switch can be locked for several minutes, depending on the individual cooling conditions. A green LED indicates "Ready for Operation" and a yellow LED indicates the on-state of the switch as well as short control pulses with a pulse duration down to 30 ns. The design concept of these switching modules offers a large selection of cooling and housing options as well as a very high flexibility regarding the adaption to individual OEM requirements. Please refer to the separate options page for some examples of individual switch solutions. In case the built volume is the main design concern, then the HTS compact series (HTS xx-xx-C) is recommended, which has widely the same electrical data except for Max. Power Dissipation and Max. Continuous Frequency.

CIRCUIT DESIGN RECOMMENDATIONS

In order to achieve the minimum turn-on rise time and the best HV pulse shape, all leads and circuit paths should be of lowest possible inductance. This can be achieved by means of very wide and short circuit tracks on the printed circuit board, if necessary in several layers (multi layer PCB). Part components such as R_S, C_{BP} and C_B must be "inductance-free" and should only be connected with shortest possible wires / circuit tracks. Ground conducting tracks including the logic ground must be connected to a common ground point (star-type ground). Induction loop areas of dynamically current-carrying circuit paths should always be as small as possible. HV wiring and control circuitry should always be separated by a proper distance. For further design recommendations please refer to the general instructions.

Test Circuit (High-Side Switch)

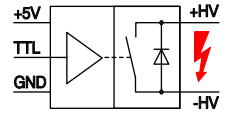


Note: For testing dynamic parameters such as delay, jitter and burst capability, please use precision pulse generator with 50 Ohm output impedance and < 10 ns pulse rise time (e.g. Standford Research DG-535 or Agilent 33521A).

HTS 61- 02	6000 VDC / 25 A (pk)
HTS 61- 05	6000 VDC / 50 A (pk)
HTS 101-01	10000 VDC / 15 A (pk)
HTS 101-03	10000 VDC / 30 A (pk)
HTS 151-01	15000 VDC / 12 A (pk)
HTS 151-02	15000 VDC / 24 A (pk)

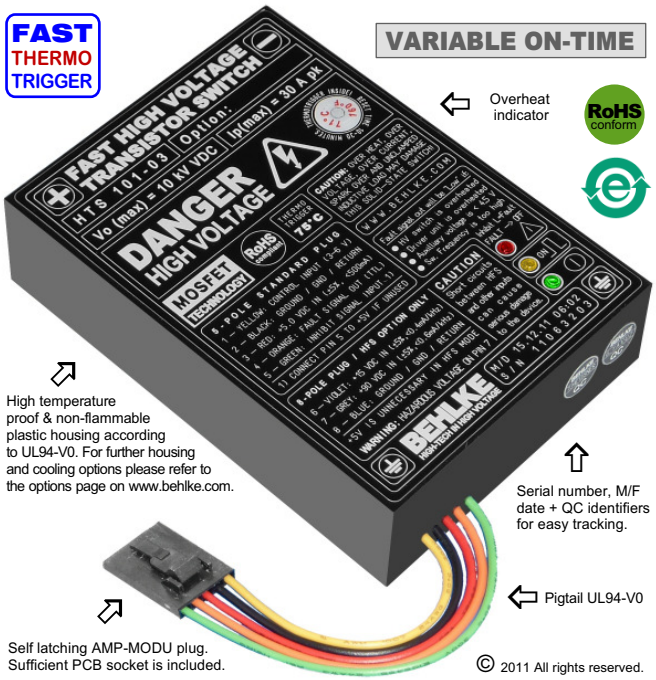
MOSFET TECHNOLOGY

VC4 DRIVER



FAST THERMO TRIGGER

VARIABLE ON-TIME



Overheat indicator

RoHS conform

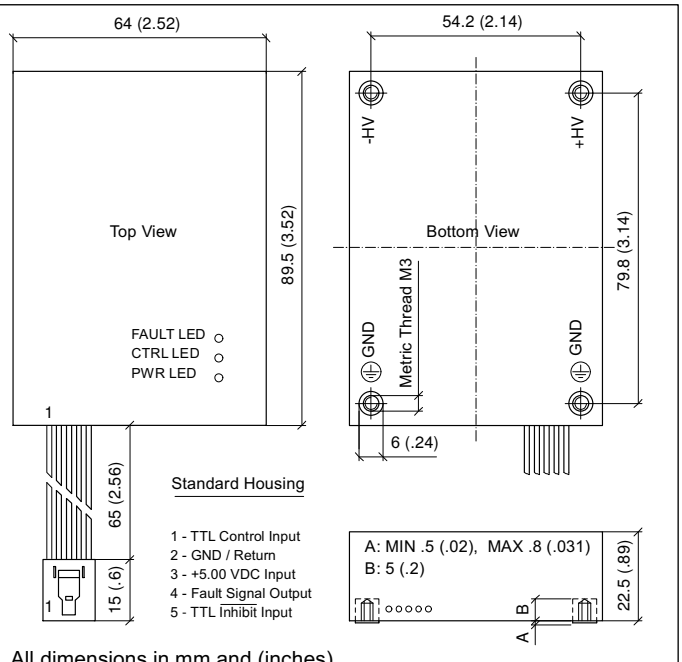
High temperature proof & non-flammable plastic housing according to UL94-V0. For further housing and cooling options please refer to the options page on www.behlke.com.

Serial number, M/F date + QC identifiers for easy tracking.

Pigtail UL94-V0

Self latching AMP-MODU plug. Sufficient PCB socket is included.

5 ns Rise Time • 3 MHz Rep Rate
6 MHz Burst • $t_{(on)}$ = 50 ns ... ∞



All dimensions in mm and (inches).

	Specification	Symbol	Condition / Comment	HTS	61-02	61-05	101-01	101-03	151-01	151-02	Unit
ABSOLUTE MAXIMUM RATINGS	Maximum Operating Voltage	$V_{O(max)}$	I_{off} < 50 µADC, T_{case} = 70°C		± 6.0	± 6.0	± 10.0	± 10.0	± 15.0	± 15.0	kVDC
	Maximum Isolation Voltage	V_I	Between HV switch and control / GND, continuously		± 30						kVDC
	Max. Housing Insulation Voltage	V_{INS}	Between switch and housing surface, 3 minutes		± 40						kVDC
	Maximum Turn-On Peak Current	$I_{P(max)}$	T_{case} = 25°C	t_p< 200 µs, duty cycle <1%	25	50	15	30	12	24	ADC
	Maximum Continuous Load Current	I_L	T_{case} = 25°C T_{fin} = 25°C T_{flange} = 25°C T_{inlet} = 25°C	Standard devices & FC, forced air 4 m/s	0.75	1.04	0.38	0.53	0.36	0.51	
				Devices with option CF, forced air 4 m/s	1.92	2.67	0.97	1.37	0.94	1.32	
				Devices with option GCF, on heat sink.	2.36	3.27	1.19	1.68	1.15	1.62	
				Devices with option ILC, water 0.1 l/min.	2.36	3.27	1.19	1.68	1.15	1.62	
				Devices with option DLC-0.2 (DLC-1.0)	2.7 (6.1)	3.8 (8.5)	1.4 (3.1)	1.9 (4.3)	1.3 (3)	1.9 (4.2)	ADC
	Max. Continuous Power Dissipation	$P_{d(max)}$	T_{case} = 25°C T_{fin} = 25°C T_{flange} = 25°C T_{inlet} = 25°C	Standard devices & FC, forced air 4 m/s	15						
				Devices with option CF, forced air 4 m/s	100						
				Devices with option GCF on heat sink.	150						
				Devices with option ILC, water >0.1l/min	150						
				Devices with option DLC-0.2 (DLC-1.0)	200 (1000)						Watt
	Linear Derating		Above 25°C	Standard devices & FC, forced air 4 m/s	0.33						
				Devices with option CF, forced air 4 m/s	2.22						
				Devices with option GCF, on heat sink.	3.33						
				Devices with option ILC, water 0.1 l/min.	3.33						
				Devices with option DLC-0.2 (DLC-1.0)	5.71 (28.6)						W/K
	Operating Temperature Range	T_O	Standard devices & options CF, GCF, ILC. (Option DLC)		-40...70 (60)						°C
	Storage Temperature Range	T_S	Switches with option ILC may require frost protection!		-50...100						°C
	Max. Permissible Magnetic Field	B	Homogeneous steady-field, surrounding the whole switch		25						mT
ELECTRICAL CHARACTERISTICS	Operating Voltage Range	V_O	Positive or negative voltage (depending on connection)		0 - 6.0		0 - 10.0		0 - 15.0		kVDC
	Typical Breakdown Voltage	V_{br}	**NOTE:** V_{br} is a test parameter for quality control purposes only. Not applicable in normal operation!	I_{off} > 0.5 mA	6.6		11.0		16.5		kVDC
	Typical Off-State Current	I_{off}	25°C, @ 0.8xV_O. Lower leakage current optionally available.		< 10						µADC
	Typical Turn-On Resistance	R_{stat}	T_{case} = 25°C, T_{flange} = 25°C, T_{fin} = 25°C, T_{inlet} = 25°C.	0.1 x $I_{P(max)}$	12	6	40	20	60	30	
				1.0 x $I_{P(max)}$	27	14	106	53	114	57	Ohm
	Typical Propagation Delay Time	$t_{d(on)}$	Resistive load, 0.1 x $I_{P(max)}$, 0.8 x $V_{O(max)}$, 50-50%		100						ns
	Typical Output Pulse Jitter	t_j	Impedance matched input, V_{aux} / V_{ctrl} = 5.00 VDC		< 500						ps
	Typical Turn-On Rise Time	$t_{r(on)}$	10-90%. t_r can be customized in certain limits.	R_L = 5kΩ, 0.2 x $V_{O(max)}$, C_L= 10pF	3.4	3.3	4.9	5	5.8	4.5	
				R_L = 5kΩ, 0.8 x $V_{O(max)}$, C_L= 10pF	6.4	4.9	9.5	8	13	11	
				R_L = 5kΩ, 0.8 x $V_{O(max)}$, C_L=100pF	20	16	36	22	56	33	
				V_O= 0.5 x $V_{O(max)}$, I_L = 0.5 x $I_{p(max)}$	<7	<7	<12	<12	<5	<5	ns
	Typical Turn-Off Rise Time	$t_{r(off)}$	10-90%, resistive load @ 1.0 x $I_{p(max)}$		< 10						ns
	Maximum Turn-On Time	$t_{on(max)}$	No limitation, true on-off switch with relay character		infinite						ns
	Minimum Turn-On Time	$t_{on(min)}$	10-90%, resistive load @ 1.0 x $I_{p(max)}$		50	100	50	100	50	100	ns
	Max. Continuous Switching Frequency	$f_{(max)}$	@ V_{aux}= 5.00 V Sw. shutdown if $f_{(max)}$ is exceeded	Standard devices without HFS option	>22	>40	>22	>40	>20	>38	
				Standard devices with HFS supply	150	100	150	100	150	100	
				Opt. HFS + sufficient cooling option	3000	1500	2000	1000	1500	750	kHz
	Maximum Burst Frequency	$f_{b(max)}$			6	4	5	3	5	3	MHz
	Maximum Number of Pulses / Burst	$N_{(max)}$	f_b=1MHz (1µs spacing). Switch shutdown if $N_{(max)}$ is exceeded.		200 Use burst option HFB for >200 pulses						Pulses
	Coupling Capacitance	C_C	Switch against control side	Standard devices & options CF, DLC	8						
				Devices with options GCF, ILC	30 ... 60						pF
	Natural Capacitance	C_N	Between switch poles, @ 0.5 x $V_{O(max)}$		5	10	4	8	5	10	pF
	Control Voltage Range	V_{ctrl}	The V_{ctrl} has no impact on the output pulse shape.		2 ... 6						VDC
	Auxiliary Supply Voltage Range	V_{aux}	The +5 V supply is not required in the HFS mode.		4.5 ... 5.5						VDC
	Typical Auxiliary Supply Current	I_{aux}	V_{aux} = 5.00 VDC, T_{case} = 25°C.	0.01 x $f_{(max)}$	100						
			Active current limitation above 700 mA.	@ specified $f_{(max)}$	500						mADC
	Opt. HFS, Ext. Supply Voltage V1	$V_{HFS(V1)}$	Stability ±3%, current consumption <0.4 mA/kHz @ 25°C		15						VDC
	Opt. HFS, Ext. Supply Voltage V2	$V_{HFS(V2)}$	Stability ±3%, current consumption <0.5 mA/kHz @ 25°C		85						VDC
	Intrinsic Diode Forward Voltage	V_F	T_{case} = 25°C, I_F = 0.3 x $I_{P(max)}$		9		8.5		9		VDC
	Diode Reverse Recovery Time	t_{rrc}	T_{case} = 25°C, I_F = 0.3 x $I_{P(max)}$, di/dt = 100 A/µs		660		600		520		ns
HOUSING	Dimensions		Standard housing		89 x 64 x 22.5						
			Devices with option FC		89 x 64 x 17						
			Devices with option CF		89 x 64 x 58						
			Devices with option GCF / FH		114 x 66 x 31						
			Devices with option ILC & DLC-0.2 (DLC-1.0 on request)		89 x 64 x 35						mm^3
	Weight		Standard housing		232						
			Devices with option FC		185						
			Devices with option CF		334						
			Devices with option GCF		595						
			Devices with option ILC & DLC-0.2 (DLC-1.0 on request)		400						g

FUNCTIONS	
Control Signal Input	**Pin 1** / Yellow (LS-C: Pin 1). TTL compatible (LS-C: With 100Ω termination). Schmitt-Trigger characteristics. Control voltage 2-10 V (3-5 V for low jitter).
Logic GND / 5V Return	**Pin 2** / Black (LS-C: Shielding). The ground pin is internally connected with the safety earthings terminals (threaded inserts) on bottom side.
5V Auxiliary Supply	**Pin 3** / Red (LS-C: Pin 4). The 5 V input is used for rep rates up to the specified max. frequency $f_{(max)}$. Higher rep rates require option HFS.
Fault Signal Output	**Pin 4** / Orange (LS-C: Pin 3). TTL output, short circuit proof. Indicating switch & driver over-heat, over-frequency, low auxiliary voltage. L = Fault.
Inhibit Signal Input	**Pin 5** / Green (LS-C: Pin 2). TTL compatible, Schmitt-Trigger characteristics for the connection of external safety circuits. L = Switch Inhibited.
LED Indicators	**GREEN**: "Auxiliary power good, switch OFF". **YELLOW**: "Control signal received, switch ON". **RED**: "Fault condition, switch OFF"
Temperature Protection	**A)** Standard switches and switches with opt. FC, CF , GCF: Thermo trigger 75°C, response time < 60 s @ 3xPd(max), ΔT=25K (50 to 75°C). Separate driver protection. **B)** Switches with option DLC: 65°C, response time < 3 s @ 3xPd(max), ΔT=25K (40 to 65°C), coolant flow > 3l / min. Separate driver protection.

ORDERING

HTS 61-02	Fast HV Transistor Switch, 6kV, 25 A	**Option MBC**	Mechanical Backward Compatibility to HTS 81, 51, 31 ff.	**Option CCS**	Ceramic Cooling Surface. $P_{d(max)}$ can be increased by the factor 2 to 3.
HTS 61-05	Fast HV Transistor Switch, 6kV, 50 A	**Option LS-C**	Shielded Control Input (LEMO socket). For EMC critical designs.	**Option CF**	Copper Cooling Fins. $P_{d(max)}$ can be increased by the factor 3 to 10.
HTS 101-01	Fast HV Transistor Switch, 10kV, 15 A	**Option HFS**	High Frequency Switching (two auxiliary supply inputs V1 & V2)	**Option GCF**	Grounded Cooling Flange (copper). $P_{d(max)}$ can be increased by the factor 3 to 15.
HTS 101-03	Fast HV Transistor Switch, 10kV, 30 A	**Option LP**	Low Pass. Input filter for increased noise immunity.	**Option ILC**	Indirect Liquid Cooling (for water). $P_{d(max)}$ can be increased by the factor 3 to 15.
HTS 151-01	Fast HV Transistor Switch, 15kV, 12 A	**Option UFTR**	Ultra Fast Thermotrigger. Response time for shut down < 5s.	**Option DLC**	Direct Liquid Cooling (for FPE/PFC). $P_{d(max)}$ can be increased by the factor 10 to 100.
HTS 151-02	Fast HV Transistor Switch, 15kV, 24 A	**Option UFTS**	Ultra Fast Thermosensor. Response time < 5s. NTC 10k / ± 1%	**FOR FURTHER PRODUCT OPTIONS PLEASE REFER TO THE OPTIONS PAGE.**	

OPTIONS LIST for Behlke HTS switches with variable on-time

MBC	**Mechanical Backward Compatibility** to the previous switch models. All connectors, dimensions and attachment identical with the "historical" switch models such as HTS 81, 51, 31 ff.
HFB	**High Frequency Burst:** Improved burst capability of driver. Improved recovery time for shorter pulse spacing and connectors for external driver buffer capacitors, so far required.
HFS	**High Frequency Switching**: External supply of auxiliary driver voltage (50-350 VDC according to type). Necessary if the specified Max. Operating Frequency shall be exceeded. (2)
LP	**Low Pass**: Low pass filter at the control input. Propagation delay time will be increased by ~50 ns. Jitter + 500 ps. Improved EMC, better noise immunity and less critical wiring. (3)
UFTR	**Ultra Fast Thermotrigger**: Advanced temperature protection for the high-voltage switch. Switch shut down within 5 seconds if Pd(max) is exceeded by 300% @ ΔT=25K (50 to 75°C)
UFTS	**Ultra Fast Thermosensor**: Temperature measurement directly on the power semiconductors by means of a special sensor with high electrical isolation and low thermal impedance.
TT-C	**Customized Transition Time**: Customized rise & fall times to meet individual design requirements. (2)
MIN-ON	**Minimum On-Time**: Individually increased Minimum On-Time to ensure a minimum on duration indepently of control signal. For safety relevant circuits.
MIN-OFF	**Minimum Off-Time**: Individually increased Minimum Off-Time to ensure a minimum off duration indepently of control signal. For safety relevant circuits.
ST	**Stage Tapping**: Connectors at the individual stages of stack in order to utilize single power semiconductors. To achieve fast rise times also at very low operating voltages (<0.01xVo).
LL	**Low Leakage Current**: Off-state current reduced to less than 10% of the specified value. Not available in connection with cooling fin options.
LN	**Low Noise**: Internal power driver modified for zero noise emission for a specific period of time. Relevant in conjunction with sensitive detector amplifiers (e.g. SEV/MCP) only. (2)
ISO-25	**25 kV Isolation**: Isolation Voltage increased to 25 kVDC. Housing dimensions may change for some models.
ISO-40	**40 kV Isolation**: Isolation Voltage increased to 40 kVDC. Housing dimensions may change for some models. Only in connection with option PT-HV.
ISO-80	**80 kV Isolation**: Isolation Voltage increased to 80 kVDC. Housing dimensions may change for some models. Only in connection with option PT-HV.
ISO-120	**120 kV Isolation**: Isolation Voltage increased to 120 kVDC. Housing dimensions may change for some models. Only in connection with option PT-HV.
I-PC	**Integrated Part Components**: Integration of small part components according to customers specifications (e.g. capacitors, snubbers, damping resistors, diodes, opto couplers). (2)
I-FWD	**Integrated Free-Wheeling Diode**: Built-in parallel diode with short recovery time. In connection with inductive load only.
I-FWDN	**Integrated Free-Wheeling Diode Network**: Built-in parallel diode plus serial blocking diode with short recovery time. In connection with inductive load only.
I-TS	**Integrated Thermo Sensor**: Integrated temperature sensor for external temperature measurements according to customers specifications (NTC, KTY, PT-100 etc).
LS-C	**Shielded Socket for Control Connection**: Shielding for all inputs. Input impedance 100 Ohm. With 1m (3ft) linkage cable and 2nd socket. Improved noise immunity. (3)(4)
PT-C	**Pigtail for Control Connection**: Flexible leads (l=75 mm) with PCB connector (AMP-modu) instead of pins. Recommended for modules with options CF & GCF.
PT-HV	**Pigtails for HV Connection**: Flexible leads with cable lugs. For increased creepage. PT-HV is standard for all types with >25 kV switching voltage. Not for extremely fast circuits.
SEP-C	**Separated Control Unit**. Control unit with LED indicators in a separate housing (dimension 79 x 38 x 17 mm). Linkage cable (<1m) with plug. Control unit with soldering pins or pigtails.
PC	**Pulser Configuration**. Switch combined with custom specific part components. Integrated in a plastic flange housing with HV connectors according to the customers specifications. (2)
UL94	**Flame Retardant Casting Resin**: Casting resin according to UL-94-V0. Minimum order quantity required. (2)
TH	**Tubular Housing**: Tubular instead of rectangular housing. Adaption to specific ambient conditions or in case of difficult assembly situations. (2)
FC	**Flat Case**: Height of standard plastic housings reduced to 19 mm or less. Not in combination with cooling options CF, GCF and DLC.
ITC	**Increased Thermal Conductivity**: Special moulding process to increase the thermal conductivity of the module. Pd(max) will be increased by approx. 20-30%. (2)
CF	**Non-Isolated Cooling Fins**: Standard sizes in categories I to VII according to model. Nickel plated copper 0.5 mm, fin height 35 mm. For air and oil cooling.
CF-1	**Non-Isolated Cooling Fins d=1mm**: Nickel plated copper 1.0 mm instead of 0.5 mm. The Max. Power Dissipation will be increased by ~80 %. For air and oil cooling.
CF-X2	**Non-Isolated Cooling Fins enlarged by x2**: Fin area enlarged by factor 2. Not relevant in connection with liquid cooling.
CF-CS	**Non-Isolated Cooling Fins with customized shape**: Individual shape to meet specific OEM requirements. (2)
CF-LC	**Non-isolated Cooling Fins optimized for liquid cooling**: Double fins, nickel plated copper, 0.5 mm thickness, height 20 mm.
CF-GRA	**Non-isolated Cooling Fins made of graphite**. Very light weight compared to copper at similar heat transfer, but reduced heat capacity. 0.5 or 1 mm thickness, height 35 mm.
CF-CER	**Isolated Cooling Fins made of ceramics**. Heat transfer properties similar to alumina. Forced convection recommended, height 35 mm.
CCS	**Ceramic Cooling Surface**. Top side of switching module made of special ceramics. Heat transfer properties similar to alumina. 10 kVDC isolation. Forced convection recommended.
C-DR	**Cooling for Driver**: Extra cooling for the driver and control electronics. Recommended in combination with option HFS at higher switching frequencies. (2)
GCF	**Grounded Cooling Flange**: Nickel-plated copper flange for High Power applications. Max. isolation voltage 40kV. Increased coupling capacitance CC.
ILC	**Indirect Liquid Cooling**: Liquid cooling for all kind of conductive coolants incl. mains water. Internal heat exchanger made of ceramics. For medium power and medium frequencies.
DLC	**Direct Liquid Cooling**: Internal cooling channels arround the power semiconductors. The most efficient cooling for high frequency applications. For non-conductive coolants only.
HI-REL	**High Reliability** / **MIL Versions**: Available on request. (2)

(1) New option code: Data sheets may differ from this coding system (especially older ones) and do not indicate all possible options as per above table. (2) Please consult factory for detailed information. (3) These options are recommended for industrial applications, difficult noise envinronments, prototype experiments with flying leads and for users without special EMC design experience. (4) This option is not available in connection with Sync. I/O for parallel connection.

Examples of standard options and modifications for switches with variable on-time:

Note: Mechanical drawings for the options below are available on request.

1) HTS 101-03 with shielded control input (LS-C)

2) HTS 101-03 in flat case (FC) with pins (PIN-C)

3) HTS 101-03 with ceramic cooling surface (CCS)

4) HTS 101-03 with nickel plated copper fins (CF)

5) HTS 101-03 with graphite cooling fins (CF-GRA)

6) HTS 101-03 with ceramic cooling fins (CF-CER)

7) HTS 101-03 with potential-free Cu cooling flange (GCF)

8) HTS 101-03 for indirect liquid cooling with water (ILC)

9) HTS 101-03 for direct liquid cooling with Galden(DLC)

10) HTS 101-03 in pulser configuration (PC)

11) HTS 101-03 with separated control unit (SEP-C)

12) The HTS compact series for lower power dissipation