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The Olympic Games to be held this summer in Barcelona are a superb example of mankind's competitive spirit. If we're not competing for survival or gain, then it seems we compete for fun. Of course, competition in any form is healthy. Whether between individuals or teams in sport, or between multinational companies like Philips fighting for market share, competition sharpens the faculties and helps cut down on the flab. The Olympics, however, are also something of a paradox. As well as encouraging sporting competition between countries, they're also an excellent medium for encouraging harmony, cooperation and understanding between nations. If we really embrace the spirit of this year's Olympics, perhaps as one team we could move towards solving the real problems confronting our world rather that being continually side-tracked by our individual interests. In the original Olympics of Ancient Greece, which date back to 776 BC, it's said that even wars were halted for the duration of the games. Now wouldn't that really be something!

The KM110BH family of magnetoresistive-sensor modules for rotation and angle measurement

JAN LONT

Universally acknowledged as providing a highly effective means of measuring both linear and angular displacement, the magnetoresistive sensor is now featured in several series of ready-to-use, active sensor modules. These modules satisfy the great demand for magnetic contactless measurement systems, which offer three major advantages over systems using other techniques:

- wear-free operation
- a long operating life
- high reliability.

KM110BH modules also provide an easy and cost-effective way of measuring very accurately, thanks to their laser-trimmed sensors and other advanced hybrid circuitry. Used directly (without any adjustments) or as the basis of customized measurement/control equipment, the applications of these modules are many and varied. However, their ruggedness and ability to operate over a wide temperature range make them especially suitable for automotive and industrial applications.

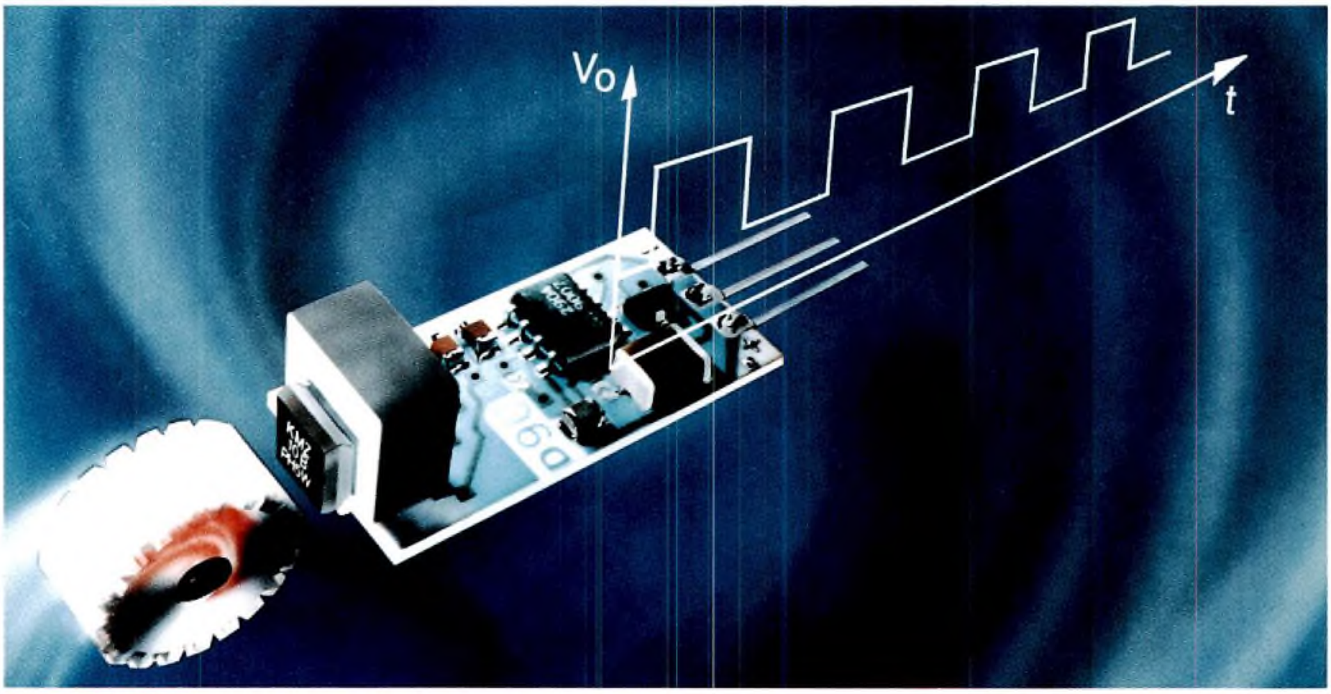


Fig.1 Photograph of a radial KM110BH/1 module for rotation sensing and reference-mark detection

ROTATION MEASUREMENT AND REFERENCE MARK DETECTION

With the proliferation of electronically-controlled mechanical processes, interest in all kinds of sensors is greatly increasing. For the problem of low-cost rotation sensing and reference-mark detection under difficult environmental conditions, magnetic contactless detection, based on the influence of ferrous components on magnetic fields, provides the ideal solution.

In the automotive industry, for example, inductive (variable reluctance) sensors are often used because of their ruggedness and large output-signals. However, they have two disadvantages:

- output signals become very small when detecting slow movements
- high-frequency vibrations can generate large noise signals in their output.

Magnetic field sensors that measure field variations statically overcome these disadvantages. Our KMZ10B magnetoresistive sensor is such a device. Moreover, because it's rugged and highly sensitive, our KM110BH/1 range of modules, for rotation sensing and reference-mark detection, are based on it.

ANGLE MEASUREMENT

Until now, most magnetic-field sensor systems for angle measurement have used a rotating magnet to measure the magnetic *field strength* as a function of angle. Simple systems generate an output signal that is usually a sinusoidal function of the angle between the rotating magnet and a predefined zero point. Although such systems can measure angles up to 180°, the tolerance and temperature drift of the magnet, and the mechanical arrangement, influence the measured field strength and therefore the output signal. This has the major disadvantage that trimming is necessary *after* assembly of the sensor system.

Our KMZ10B magnetoresistive sensor can measure angles by measuring the angle-dependent field strength. However, it can also measure angles without the above disadvantage by measuring *field direction* as a function of angle, provided a magnet with sufficient field strength is used. The sensor then operates in 'saturation mode' (with internal magnetization parallel to the external field) and the field strength becomes irrelevant to the measurement. Moreover, the distance between sensor and magnet, and the magnet's temperature dependence are no longer critical. This allows the sensor to be pre-trimmed, as in our KM110BH/21 range of angle-measurement modules.

ROTATIONAL SPEED MEASUREMENT WITH DIRECTION INDICATION

Formerly, two magnetic field sensors were needed to indicate the rotational direction of, for example, a toothed wheel. The technique required placing the sensors a specific distance apart, around the wheel, to ensure that the two sensor output signals were optimally phase-shifted by 90°. The distance, of course, varied with the pitch diameter and the number of teeth of the specific toothed wheel used. However, with filters to suppress offset signals, it was possible to vary the distance between the sensors and thus use different wheels.

Our KM110BH/31 module uses a circuit which enables it to indicate rotational direction, as well as accurately measure rotation speeds, from a single KMZ10B magnetoresistive sensor. The single-sensor technique is based on separate signal-processing for the sensor's two half-bridge signals.

THE KM110BH MODULE FAMILY

All our KM110BH modules are thick-film hybrid circuits with ceramic substrates. They operate from a standard supply of 5 V and include temperature compensation.

The KM110BH/1 range for rotation sensing and reference-mark detection

Four versions are available, with circuitry optimized for specific application areas:

- two quasi-static types for slow movement sensing (i.e. speed measurements down to zero)
- two types module with a high-pass filter for use at larger measuring distances (and speeds above zero).

Within each of these categories, the type difference relates to the sensor position: the module is supplied with the sensor either radially or tangentially arranged. Figure 2 shows both mechanical arrangements set to measure rotation of a toothed wheel.

The modules' output is a noise-free digital signal that can directly control or display rotational/linear motion, or detect the presence of a reference mark. What's more, types can operate:

- quasi-statically (0 Hz frequency)
- at a large distance from the object to be measured
- from −40 to +150 °C
- without external magnets.

Specifications of KM110BH/1 types are given in Table 1.

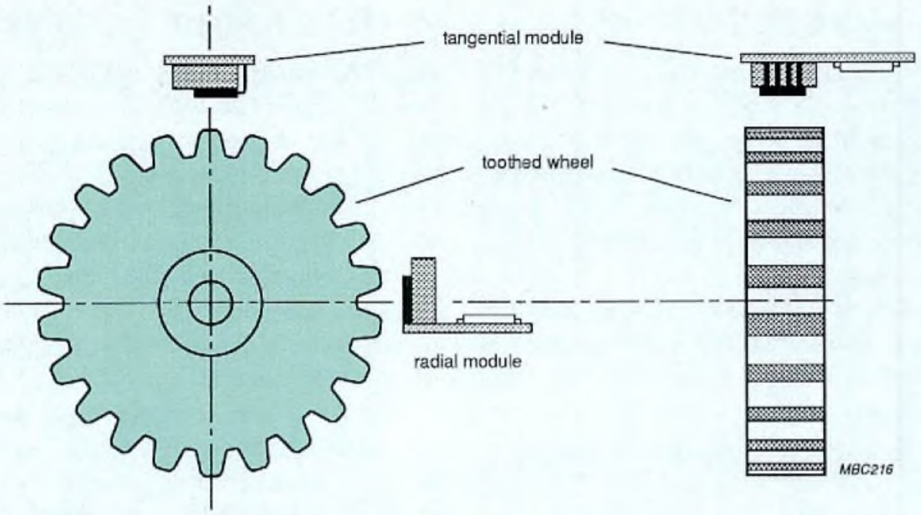
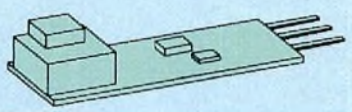
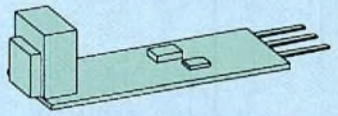


Fig.2 Radial and tangential versions of the KM110BH/1 module arranged for rotation measurement of a toothed wheel

TABLE 1
Specifications for KM110BH/1 magnetoresistive-sensor modules

	tangential module 		**radial module** 	
type number	KM110BH/11 (without filter)	KM110BH/12 (with filter)	KM110BH/13 (without filter)	KM110BH/14* (with filter)
frequency range for toothed wheel	0 to 3000 Hz	1 to 3000 Hz	0 to 3000 Hz	1 to 3000 Hz
measuring distance, d**	2.5 mm	3.5 mm	2.5 mm	3.5 mm
supply voltage, V_S	5 V (4 to 10 V; max. ripple for filter version is 50 mV)			
output signal, V_O	0/5 V, digital; peak is relative to V_S			
operation temperature	−40 to +125 °C (150 °C max.; 500 h)			
min. external load	100 kΩ (lower with external pull-up resistor)			
mounting	the sensor's axis of symmetry corresponds with that of the module's magnet. This axis should also correspond with the equivalent axis of the toothed wheel to operate at the specified measuring distance			

* a new version of this module is now available: the KM110BH/14H has an extended frequency range up to 100 kHz
** measured from a steel toothed-wheel: diameter 48 mm, width 16 mm, 22 teeth

The circuit and sensor-position options enable the module to be used in many applications. For example, customers can now perform incremental measurements easily and at low-cost. Furthermore, a module could be used as the first stage of customized speed-sensing equipment.

Circuit

Using a standard supply of 5 V, the circuit amplifies the sensor signal and then digitizes it using a comparator to provide the digital output signal. For good switching performance (especially at low frequencies) and to suppress small noise signals, the comparator has a built-in switching hysteresis.

The KM110BH/21 range for angle measurement

KM110BH/21 modules (see Fig.3) come ready trimmed (sensitivity, offset, zero point) and contain integrated temperature-compensation, which virtually eliminates the influence of the temperature sensitivity of the external magnet (the only external component required). In the automotive field alone, their potential applications are numerous, for example, electronic control of the accelerator pedal, chassis position, steering angle and throttle position. Like the KM110BH/1 range, the circuit and the magnetic parameters have been chosen so that these modules can be used directly or for the development of custom equipment.

There are two types in the KM110BH/21 range: the /2130 and the /2190, trimmed for a 30° and 90° range respectively (see Fig.4), although the /2190's range can be extended to about 135° by using two magnets. The zero point is defined in the middle of each range. The /2190's output signal is approximately sinusoidal and the /2130's is linear (from −15° to +15°, the non-linearity ≈ 1%). Table 2 gives the /21 range specifications.

Each module's sensor is precisely mounted onto the hybrid substrate so that no further adjustments or trimming are required. The modules operate in temperatures ranging from −40 to +125 °C.

Circuit

Apart from the magnetoresistive sensor, the circuit includes an operational amplifier, and temperature sensor to compensate temperature drift. With a nominal supply of 5 V, the output voltage ranges from 0.2 to 4.8 V. The modules have been trimmed so that the specified angle range corresponds with an output ranging from 0.5 to 4.5 V. For an angle $\alpha = 0$ (see Fig.4), the output voltage is 2.5 V.

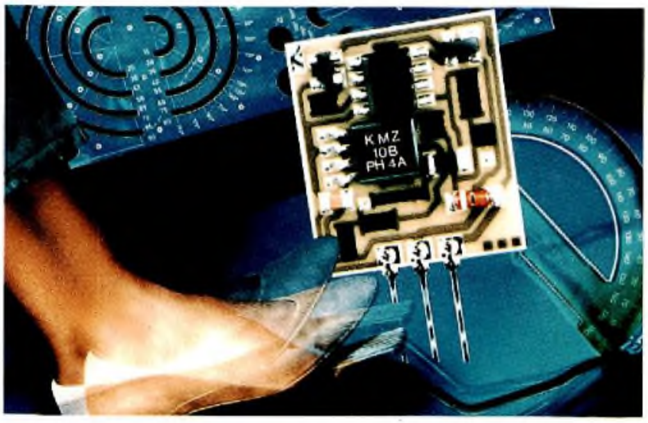


Fig.3 Photograph of a KM110BH/21 module for angle measurement

The magnet

The optimum distance between the sensor and the magnet depends on the strength of the magnet. Using a rare-earth magnet of dimensions 11.2 × 5.5 × 8.0 mm enables an optimum distance (d) of 2.5 mm between the sensor and the magnet. Changes in d influence the measurement range by only 1%/mm. The sample kits (available with either the KM110BH/2130 or the KM110BH/2190) are supplied with this magnet.

TABLE 2
Specifications for KM110BH/21 magnetoresistive-sensor modules

	KM110BH/2130	KM110BH/2190
angle range, $\Delta\alpha$ (H = 100 kA/m)	30° (−15° to +15°, linear)	90° (−45° to +45°, sinusoidal)
max. angular speed	10 °/ms	30 °/ms
supply voltage, V_S	5 ± 0.5 V	
supply current, I_S	9 mA (typ.)	
output signal, V_O	0.5 to 4.5 V	
load resistance, R_L	≥ 10 kΩ	
operation temperature	−40 to +125 °C	
measuring distance, d (H = 100 kA/m)	2.5 mm (typ.)	
zero-point accuracy ($\alpha = 0°$)	0.2° (typ.)	
zero-point thermal drift ($\alpha = 0°$)		
over the range $-40 < T_{amb} < +85$ °C:	0.3° (typ.)	
with $T_{amb} = 125$ °C:	0.5° (typ.)	
thermal drift at $\alpha = 15°$		
over the range $-40 < T_{amb} < +85$ °C:	0.4° (typ.)	
with $T_{amb} = 125$ °C:	0.9° (typ.)	

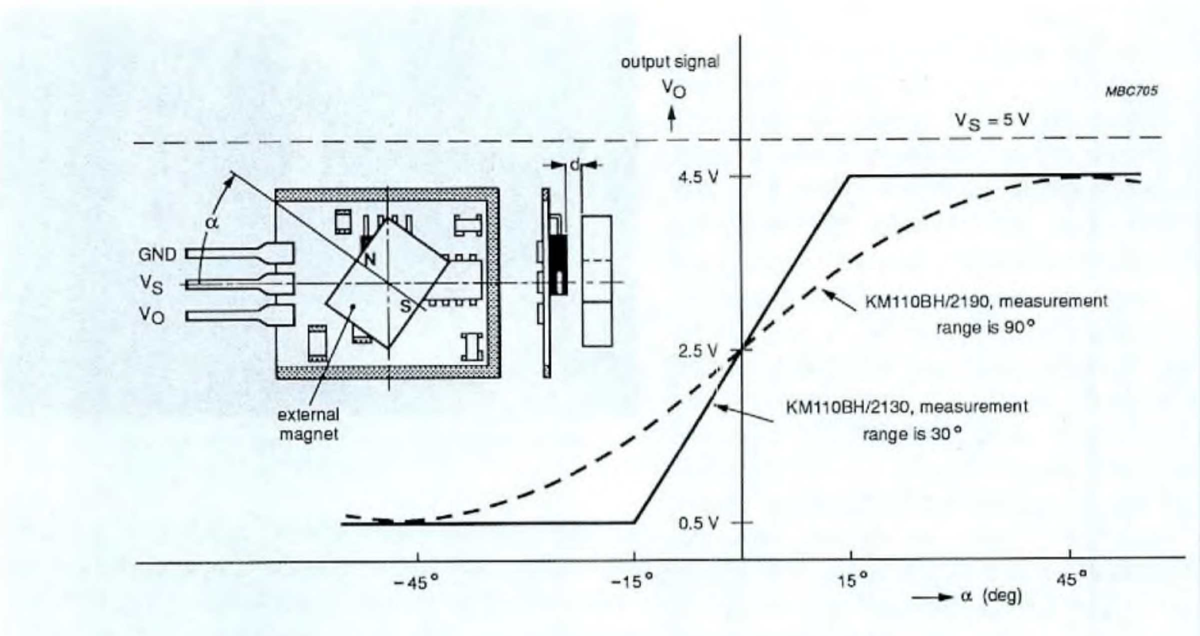


Fig.4 Output characteristics of KM110BH/2130 and /2190 modules

The required field strength can be obtained with very small magnets, but mechanical tolerances are very fine. Bigger magnets considerably simplify the design. Sufficient field strength (about 70 kA/m) can be obtained with a ferrite magnet of 10 × 7 × 8 mm (d = 0.5 mm). A field strength of about 100 kA/m can be obtained with a rare-earth magnet (NdFeB) of 11.2 × 5.5 × 8.0 mm (d = 2.5 mm).

The KM110BH/31 module for rotational speed measurement with direction indication

Similar to the radial types of the KM110BH/1 range, this module differs in that its circuitry provides two digital output signals whose phase difference indicates the rotational direction. Furthermore, the KM110BH/31 operates from 2 Hz to 50 kHz.

Single-sensor direction indication, in the KM110BH/31, is based on separate signal-processing for the sensor's two half-bridge signals. As the bridge geometry is fixed within the sensor chip, the KM110BH/31 has an optimum wheel 'Module'1) (of 0.8 mm; see Fig.9). Nevertheless, it operates successfully using toothed wheels with a wide range of pitches. Although the stability of the two half bridges is reduced with non-optimal pitches, filtering compensates for this and allows the KM110BH/31 to operate at long distances from the wheel. Without filtering, the circuit could indicate zero speed, and be capable of incremental counting, but the operating range would be limited.

Mounting

The sensor operates like a magnetic Wheatstone bridge measuring non-symmetric magnetic conditions such as when teeth or pins move in front of the sensor. The KM110BH/31 can sense this movement in two possible directions (shown in Fig.5), so the mounting position is very important for accurate measurements. Two types of mounting error affect the /31's performance:

- allowing an angle between the sensor's symmetry axis (the centre line in Fig.5) and that of the toothed wheel
- vertically shifting the sensor away from the optimum position shown in Fig.5.

The sensor's symmetry axis corresponds with that of the built-in magnet: the chip is not mounted in the centre of the sensor encapsulation.

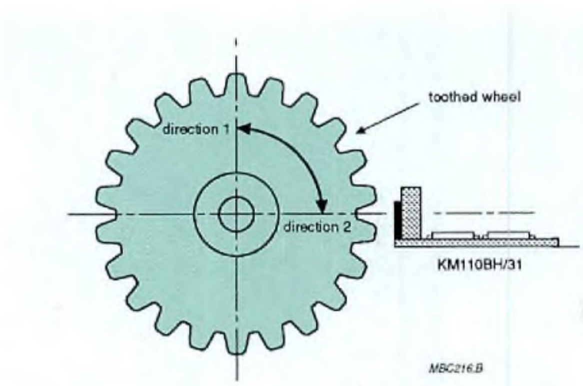


Fig.5 Optimum operating position

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1) The Module of a toothed wheel = pitch diameter (in mm)/the number of teeth. (The distance between teeth = $\pi \times$ Module).

Circuit

The digital output signals for each half of the bridge, V_{O1} and V_{O2}, are connected directly to the output pins. The circuit design enables evaluation of the output signals by a microcomputer. Figs 6 and 7 show how both output signals vary with rotational direction. If desired, the two output signals may be connected to a flip-flop, for a direct indication of rotation direction (Fig.8).

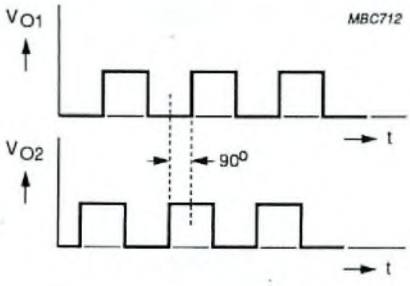


Fig.6 Output signals (direction 1)

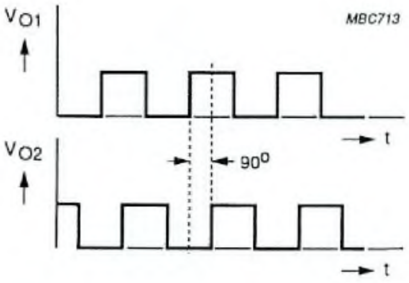


Fig.7 Output signals (direction 2)

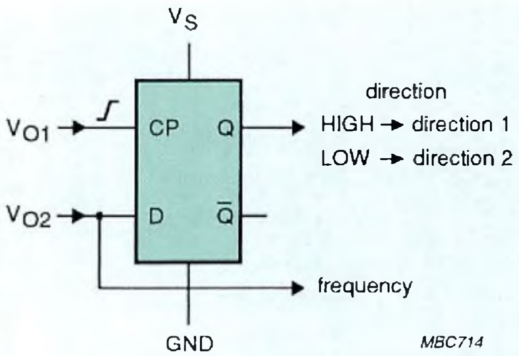


Fig.8 Interface for direction indication (D-type flip-flop, such as HEF4013 or 74LS74)

Performance

The measuring distance range depends on the structure of the toothed wheel and also on the accuracy of mounting. The latter may influence the output signal form and cause an effective phase shift if the measuring distance (d) is very small.

If different wheel Modules are used from the range given in Fig.9, the measuring distance range has to be found by measurement.

Table 3 gives the specifications of the KM110BH/31.

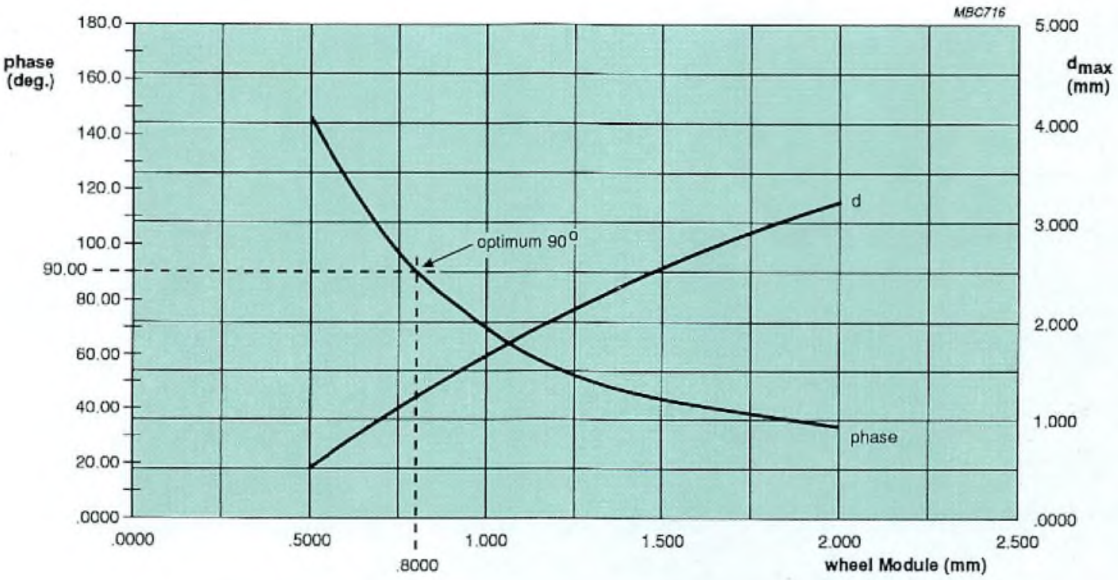


Fig.9 Effect of different toothed wheel structures on the KM110BH/31

TABLE 3
Specifications for the KM110BH/31 magnetoresistive-sensor module

supply voltage, V_S	5 V (4 to 10 V; max. ripple is 40 mV)
output signals, V_{O1} & V_{O2}	0/5 V, digital; peak is relative to V_S
operation temperature	−40 to +125 °C (150 °C max; 500 h)
measuring distance, d	see Fig.9
frequency range	2 Hz to 50 kHz
output resistance	100 Ω (LOW), 10 kΩ (HIGH)
min. external load	100 kΩ (lower with external pull-up resistor)

TOPFET – a new concept in protected MOSFET

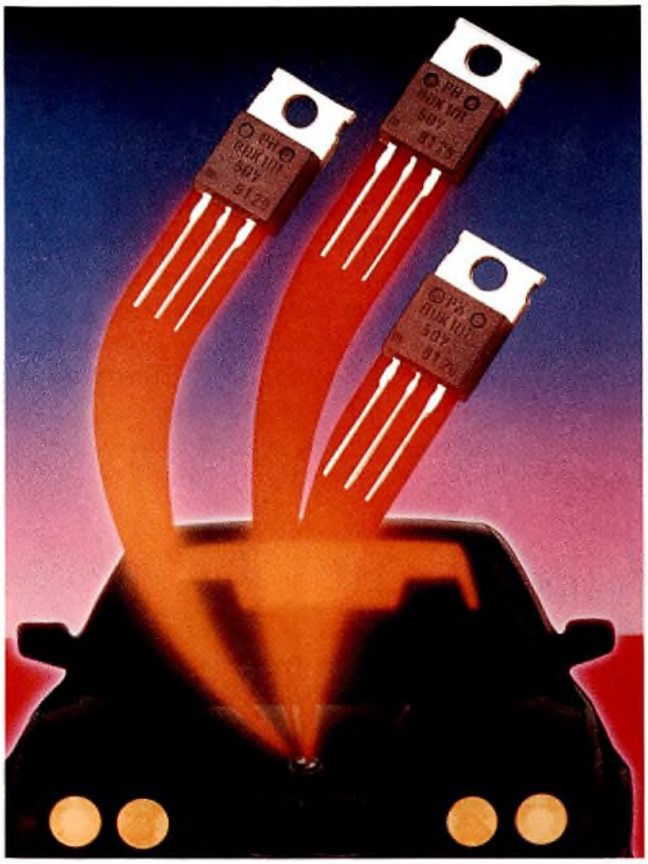
CHRIS HAMMERTON

In response to designers' demands Philips Semiconductors, have developed a diffusion process allowing the production of power MOSFETs with many useful on-chip functions. The first generation of these devices are called TOPFETs (Temperature and Overload Protected Field-Effect Transistors), and include all the necessary protection circuits "on-chip" to ensure they survive even in the most arduous of operating conditions. They are particularly well suited to automotive electronic systems but will also find uses in a wide range of general industrial applications such as the switching of lamps, motors and solenoids. As they can be driven directly from conventional logic-level FET driver circuitry, they can be used as direct replacements for MOSFETs in existing equipment, as well as in new designs. TOPFETs therefore offer designers the chance of enhanced circuit protection with significant savings in circuit board area and component count.

PROTECTING MOSFETs

The commercial necessity of producing reliable systems means that circuits must be designed to survive abnormal operating conditions. It's essential, therefore, that the main power switching device can withstand overtemperature, overvoltage and overload conditions. Selecting devices with large safety margins is one way of achieving this, but such components can be extremely costly.

A better solution is to incorporate protection circuits in the system that can monitor operating conditions and adjust the power switch's operating state accordingly. The advantages of this solution have led to its adoption by many designers. Its disadvantages, however, are an increase in the design time, an increase in component count and a subsequent increase in circuit board area. TOPFETs, with their on-chip protection circuits, overcome all these problems.


TOPFETs are ideal for use in automotive electronics

Overtemperature protection

TOPFETs have an integrated circuit that measures the absolute temperature of the component. Because this sensing circuit is on-chip, the temperature measured is the chip's actual temperature. Other types of sensing methods are more remote and therefore less accurate because of the inevitable temperature gradient between the power chip and the sensor. Making allowance for this error involves setting the trip temperature below the maximum allowed junction temperature. This means that there will be safe operating conditions which the remote sensor can misinterpret as dangerous and cause the switch to be turned off. The proximity of a TOPFET's sensor to the power part of the chip means that the trip point can be safely set at the junction temperature. This allows the designer to fully use all the TOPFET's capabilities, secure in the knowledge that the protection will work when and only when it's needed.

Short-circuit protection

Another example where the monolithic nature of a TOPFET enhances protection is that of a shorted or partially shorted load. When a load becomes short-circuit, a MOSFET power switch can be subjected to a massive overload current which may cause the device to overheat very quickly. It's important, therefore, that a protection circuit must react quickly to prevent damage to the power switch. However, a conventional protection circuit with a quick reaction time has a lower accuracy (i.e. it reacts before protection is actually needed) and so is inefficient and unacceptable.

The overload protection circuit in a TOPFET has sensors so close to the power part of the chip that it senses the effect of the overload dissipation directly. The circuit monitors the situation and reacts by turning off the power device as soon as necessary and not before. This approach means that TOPFET devices cannot be misled by short-duration voltage or current transients. It enables TOPFETs to drive difficult loads, like lamps and motors, whose peak turn-on current can approach that of a true overload current.

Overvoltage protection

The first generation of TOPFET devices are optimized to work in 12 V systems – in particular 12 V automotive electronic systems. In such systems there are many occasions when the voltage, for a short time, can be as high as 50 V or more. Circuit designers tend to use one of four strategies for dealing with this situation.

- use devices with high breakdown voltage
- add suppressors
- use devices with rugged breakdown
- connect MOSFET to operate as dynamic clamp.

The TOPFET is protected against overvoltage by a combination of a rugged avalanche breakdown and an internal circuit making it operate as a dynamic clamp. Modelling has shown that this combination provides good protection against both short- and long-duration overvoltage transients.

Electrostatic discharge protection – ESD

The input pin of a TOPFET is fitted with low-voltage, low-impedance zener clamp diodes. The primary function of these diodes is to protect the control circuits and the MOSFET gate from the potentially harmful effects of ESD.

The use of low-voltage zeners does place a restriction on the allowed input voltage. However, their use has the great advantage that the ESD transient energy is diverted away from the TOPFET and dissipated in the ESD source rather than the TOPFET itself.

TOPFET OPERATION

Figure 1 shows the basic functional blocks within a TOPFET. The majority of a TOPFET's area is occupied by the power MOSFET. This part of the device has the same characteristics as a standard low-voltage MOSFET produced by Philips Semiconductors.

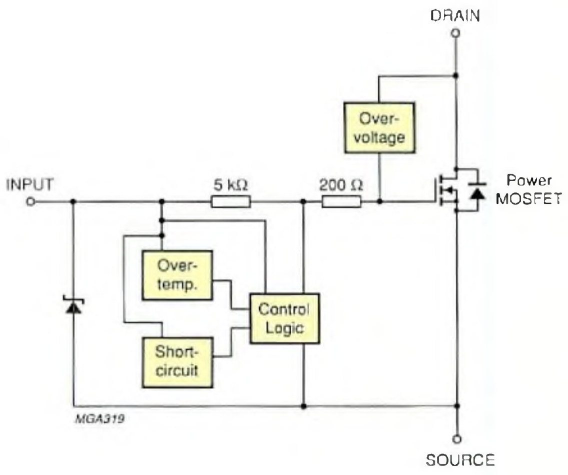


Fig.1 TOPFET block diagram

The initial range of TOPFETs is be as shown in Table 1. The fundamental difference between the three device groups is in the power MOSFET area. The drain and source of the power MOSFET are connected to the package terminals as in a standard MOSFET.

TABLE 1
TOPFET type range

type	$R_{DS(ON)}$ (mΩ)	@ V_{IS} (V)	type	$R_{DS(ON)}$ (mΩ)	@ V_{IS} (V)
BUK100-50GL	125	5	BUK100-50G	100	10
BUK101-50GL	60	5	BUK101-50G	50	10
BUK102-50GL	35	5	BUK102-50G	28	10

The main difference between a TOPFET and a conventional MOSFET is their gate connection. In the first generation of TOPFETs the input is connected to the gate via two resistors with a total resistance of nominally 5.2 kΩ. Adding these resistors means that the power for a TOPFET's protection circuits can be supplied from what would normally be a MOSFET's gate drive. This feature allows TOPFETs to be fitted into many existing designs without the need for modification.

It should be noted that the value of 5.2 kΩ was chosen as a compromise which would be compatible with most standard MOSFET drive circuits. Designers of high-frequency circuits and applications where direct drive from microcontrollers is needed may find this value too high or too low. Variants of the basic device are soon to be produced with input resistances compatible with these, and other application requirements.

The other blocks shown in Fig.1 are the protection circuits and control-logic. The supply for the over-temperature, short-circuit and control blocks is taken directly from the input pin. For these circuits to function properly, the input source voltage must be > V_{ISP} which has a typical value of 3.5 V and a limit of 4 V.

The overtemperature protection circuit uses two sensor units with different temperature coefficients to determine if the chip temperature is too high. The outputs of the sensors are connected to a comparator which changes state when the outputs cross over. The comparator's output is fed to the control unit.

The short-circuit protection circuit has a novel sensor arrangement that measures the temperature in the power MOSFET part of the chip, and so differs from the overtemperature sensor which measures the overall temperature of the chip. After conditioning, a sensor signal is fed to a comparator which changes state if the temperature is too high. The comparator's output is fed to the control logic.

The control circuit contains a latch which is reset when the input V_{IS} is low, and set by a signal from either the overtemperature or short-circuit comparator. The output of this "fault" latch is used to control an NMOS transistor which is connected via a 200 Ω resistor between the power MOSFET's gate and source. If the "fault" latch is set, this transistor is turned on and the gate of the MOSFET is discharged, thus turning it off. The transistor will also try to pull down the input pin, but as this is via a large resistor, and as long the driver is able to supply I_{SPL} at V_{ISP}, the input voltage will still be high enough to supply the protection and control circuits and ensure they continue to give the correct information. If the drive is unable to supply the current, then the protection circuits may be operating incorrectly and the fault latch may reset allowing the MOSFET to turn on again.

The overvoltage protection circuit contains a chain of zeners which start to conduct if the drain-source voltage exceeds 50 V. When they conduct, these zeners turn the main MOSFET partially on, allowing it to act as a dynamic clamp. This prevents the voltage ever reaching the breakdown voltage level of the MOSFET.

The final component shown in the block diagram is the input ESD protection diode. This specially designed "zener" diode can handle ESD pulses, but is not suitable for continuous operation in either its forward-conducting or reverse-breakdown modes. It's important, therefore, that the input to source voltage is kept between the V_{IS} limits of −0.3 V and 11 V.

UNDERSTANDING TOPFET CHARACTERISTICS

This section describes some elementary TOPFET static characteristics and describes the differences between TOPFETs and ordinary power MOSFETs. The information is based on measurements on early development samples of a logic-level type of first generation TOPFET with operation permitted in linear amplifier mode.

Input characteristics

Normal operation

Figure 2 shows the input characteristic during normal operation, which differs from that of an ordinary power MOSFET. The input pin of a TOPFET supplies the current for the control logic and protection circuits, so there is typically 200 µA required at V_{IS} = 5 V. The input also has a "zener" diode for ESD protection which begins to conduct at typically 7 V. The breakdown voltage has a positive temperature coefficient and so the input "zener" should not be subjected to continuous conduction in breakdown mode, as it is only intended for transient protection. This places an upper limit on the value of input voltage for continuous operation. In the data sheet this is given as 6 V maximum to allow for tolerances on the "zener" voltage, but in the laboratory we have done some measurements with V_{IS} = 7 V as part of the output characterization evaluation. Since the supply characteristic is fairly linear from above 1 V, the input current at V_{IS} = 6 V is approximately 25% higher than the value given for V_{IS} = 5 V.

The input characteristic for positive drain-source voltages is essentially the same as that for V_{DS} = 0 V, providing the drain voltage is kept below the maximum continuous limiting value of 50 V.

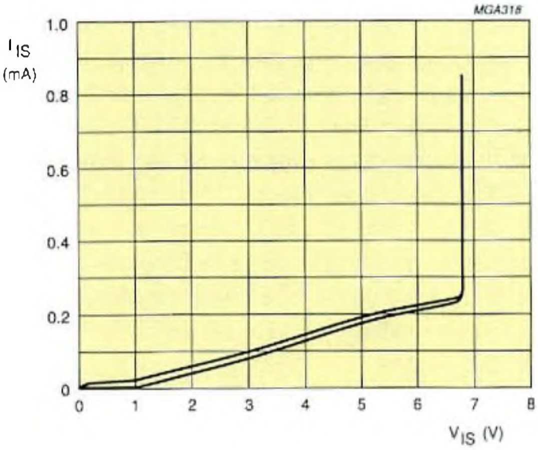


Fig.2 TOPFET typical input characteristic
I_{IS} = f(V_{IS}); V_{DS} = 0 V

Overload operation

The input characteristic following an overload condition is illustrated in Fig.3. After an overload protection function has operated (overtemperature or short-circuit load) the protection circuit latches and keeps the output power MOSFET's gate at a low-voltage and the output switched off. Since there is a fixed internal resistance between the input pin and the power MOSFET's gate, this causes the input current to increase to a typical value of 2.5 mA at V_{IS} = 5 V.

The protection remains latched as long as the input voltage is higher than the latch reset threshold, which has a typical value of 3.5 V to 4.5 V. It's important for the designer to understand that the input drive circuit must be capable of supplying sufficient current to maintain the input voltage above this threshold to guarantee continued latched protection. When the input voltage falls below this threshold, the latch is reset and the device can resume normal operation. If the overload condition still exists, and the input voltage is set high again, the entire process could be repeated. This would continue if the drive circuits were not capable of supplying sufficient current to hold the input high. It's important, therefore, for the designer to make provision for such a holding current from the drive circuit.

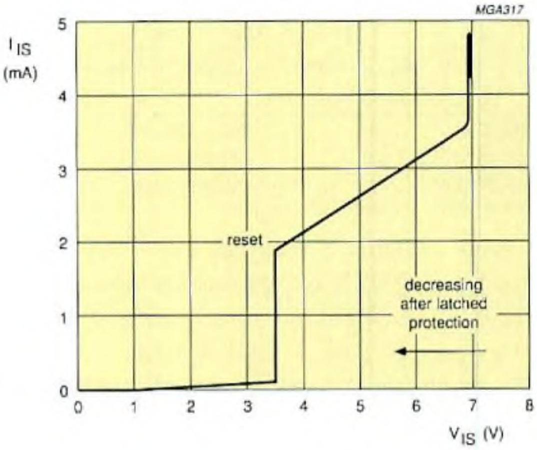


Fig.3 TOPFET typical input characteristics
I_{IS} = f(V_{IS}); protection latched

Negative input voltage

Figure 4 shows the input characteristic for negative input voltage. As the input pin provides the supply to the logic circuits, it should not be reverse biased with respect to the source pin, otherwise all the diode junctions in the logic components become forward biased and conduct. This is not damaging to the device for short duration tests providing the drain voltage is zero, however the input pin must not be allowed to be reverse biased in an application. Similarly, it should be understood that if the intrinsic body-drain diode of the power MOSFET becomes forward biased, then any positive input voltage would collapse to zero during this condition. This is because all the P-wells containing the logic circuits are no longer be in reverse bias with respect to the N-substrate. There is therefore no protection during conduction of the body-drain diode, and so a TOPFET cannot be used as a synchronous rectifier.

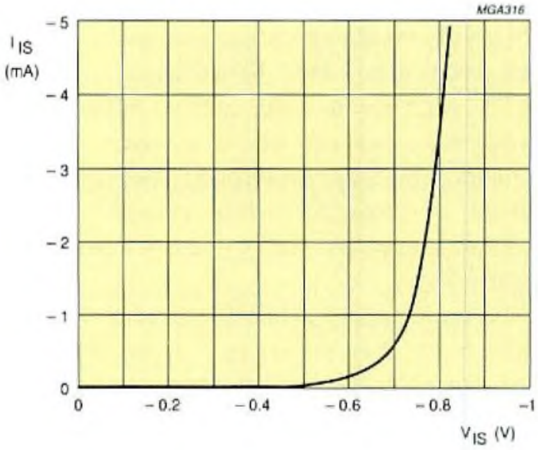


Fig.4 TOPFET typical negative input characteristic
I_{IS} = f(V_{IS}); V_{DS} = 0 V

Output characteristics

Off-state operation

Figure 5 illustrates the output characteristic, which differs from that of an ordinary power MOSFET with zero input voltage. For drain-source voltages below the continuous 50 V rating, there are two main regions to be observed: when V_{DS} is $\leq$ 12 V and when it's > 12 V. When $V_{DS} \leq$ 12 V the drain current I_D is very low, typically in the order of a few nano-amps at ordinary temperatures, perhaps several micro-amps as V_{DS} approaches 12 V. For V_{DS} > 12 V current flows through a high value resistance in the TOPFET's internal hold-off circuit. This resistance has a typical value of 100 kΩ at 25 °C, and doubles by 150 °C. For drain source voltages above the continuous 50 V rating there are two further regions to be observed: $I_D < 5$ mA and $I_D \geq 5$ mA. For $I_D < 5$ mA the TOPFET clamping circuit begins to conduct, and the voltage may rise a further 6 V in this region. When $I_D \geq 5$ mA the TOPFET clamping circuit actively turns on the output power MOSFET and the resulting slope resistance is very low, typically 0.33 Ω for the BUK101. So, even for an instantaneous drain current of 26 A, the TOPFET can still clamp its drain voltage to typically 66 V when turning off an inductive load.

Since the TOPFET output is being actively clamped via the gate of its power MOSFET, rather than being in avalanche breakdown, it has a high energy capability for non-repetitive inductive turn-off and is limited purely by the transient thermal impedance and peak junction temperatures. The TOPFET has a much lower temperature coefficient of clamping voltage when compared with an ordinary power MOSFET in avalanche breakdown, so the clamping action is described as temperature compensated.

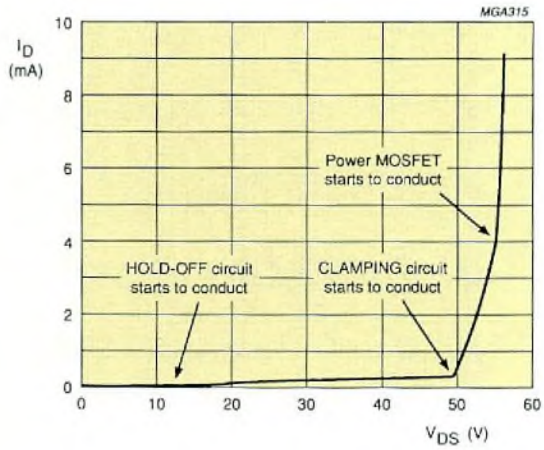


Fig.5 TOPFET typical off-state characteristic
$I_D = f(V_{DS})$; $V_{IS} = 0$ V; $T_j = 25$ °C

On-state operation

Figure 6 shows the output characteristics during the normal operation of a TOPFET. In most respects these are similar to that of an equivalent rated logic-level power MOSFET, except that the continuous input voltage must not exceed 6 V. For low drain voltages, the TOPFET exhibits a resistive on-state characteristic. This example had a drain source on-state resistance $R_{DS(ON)}$ of 25 mΩ for V_{IS} = 5 V. For higher drain voltages, the output current is limited by the saturation velocity of the charge carriers, just as with a similar power MOSFET. For low drain currents the output characteristics are very flat producing a current almost independent of drain voltage. The slightly negative slope for high instantaneous drain currents is due to the transient temperature rise caused by the power pulses. Similar behaviour is observed for an ordinary power MOSFET.

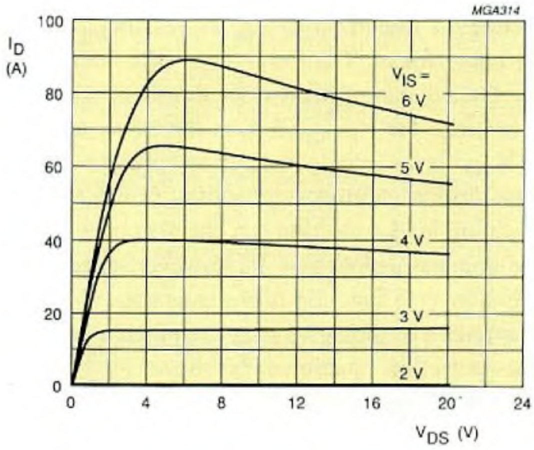


Fig.6 TOPFET typical output characteristics
$I_D = f(V_{DS})$; V_{IS}; $T_j = 25$ °C; $t_p = 250$ µs; $\delta \leq 5\%$

We obtained the on-state characteristic by using a high power digital curve tracer with limited pulse width and duty cycle. Test instruments with a longer pulse duration could cause the short-circuit load protection function to operate for high enough instantaneous powers for input voltages above the minimum limit for valid protection. This is covered in the following section.

Overload operation

The output characteristics, showing an example of overload operation are, illustrated in Fig.7. This shows the drain source supply voltage, with a family of curves for several input voltages V_{IS}, swept down from 31 V in 1 V steps. You can see that the trace for V_{IS} = 6.5 V has caused the short-circuit load protection to operate when V_{DS} > 20 V.

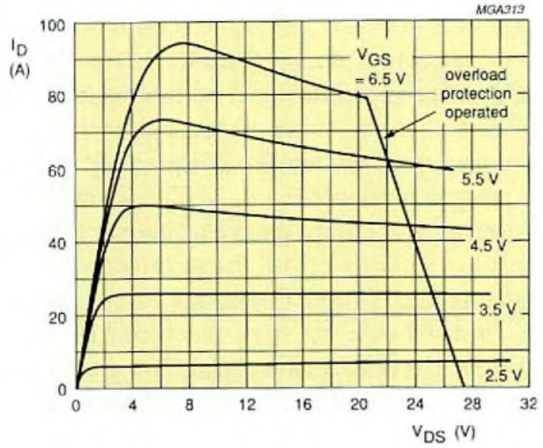


Fig.7 TOPFET typical output characteristics
$I_D = f(V_{DS})$; $t_p = 250$ μs;

The TOPFET turned off to $V_{DS} = 27$ V along the load line of the curve tracer. The lower steps take the input voltage below the protection latch reset threshold with the effect that the trace for $V_{IS} = 6.5$ V is turned on again for $V_{DS} < 20$ V, with the supply voltage swept from maximum.

This critical drain-source voltage is not absolute. The short-circuit load protection can operate correctly for drain-source voltages as low as 4 V. However, since the turn-off time is a inverse function of instantaneous dissipation, the 250 μs pulses of the curve tracer required a higher voltage for the protection function to be shown by this instrument for a TOPFET of this size chip.

Transfer characteristics

Normal operation

Figure 8 shows the transfer characteristic during normal operation. In most respects these are similar to that of an equivalent rated logic-level power MOSFET, except that the continuous input voltage must not exceed 6 V. The drain current begins to increase when the input voltage is higher than the gate-source threshold voltage of the TOPFET's power MOSFET, and increases almost linearly when the input voltage exceeds about 3 V. This example has a forward transconductance g_{fs} with a typical value of approximately 20 S.

Operation of these TOPFET types is permitted in linear amplifier mode with the drain current limited by the gate voltage of the power MOSFET. However it's important to understand that overload protection is only guaranteed for input voltages above the threshold for valid protection. And remember that operation of power MOSFET in linear amplifier mode requires good heat-sinking, and a TOPFET is no exception to this rule.

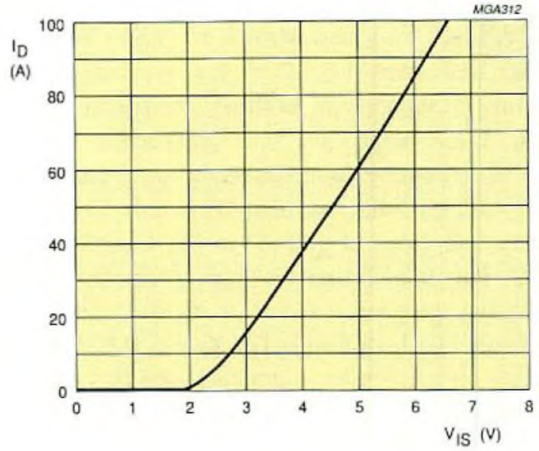


Fig.8 TOPFET typical transfer characteristic
$I_D = f(V_{IS})$ $V_{DS} = 12$ V; $t_p = 250$ μs; $\delta \leq 5\%$

Overload operation

The transfer characteristic following an overload condition is illustrated in Fig.9. This shows the input voltage being swept down from 6.5 V following a brief short-circuit load condition. The TOPFET remains off until the input voltage falls below the latch reset threshold. Below that, the drain current follows the previous transfer characteristic.

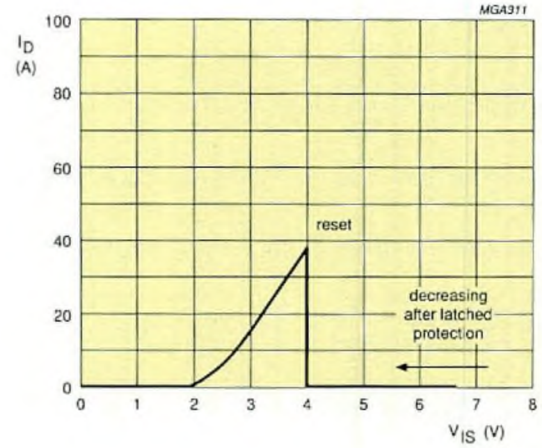


Fig.9 TOPFET transfer characteristic,
V_{IS} sweep from maximum after protection latched

In this example, where the input voltage had to be greater than 4 V for protection to be valid, substantial drain current is still possible at a lower input voltage. This could cause high dissipation against which there would be no protection. This underlines the importance of ensuring that the drive circuit must be capable of providing an input voltage sufficient to ensure valid protection.

SPECIAL CHARACTERISTICS

ESD

The first generation of TOPFET devices have been fitted with low-voltage zener clamps between the input and source. These diodes protect the internal control circuits and the gate of the power MOSFET from the harmful effects of an electrostatic discharge (ESD). The use of low-voltage zeners means that the voltage that reaches these circuits is so low that no damage will be caused. This technique has the great advantage that the ESD pulse energy is diverted away from the TOPFET and is dissipated in the ESD source. The operation of these zeners can be seen in Fig.10. These waveforms show how the open-circuit output of the ESD generator is clamped by the input source zener to a safe level.

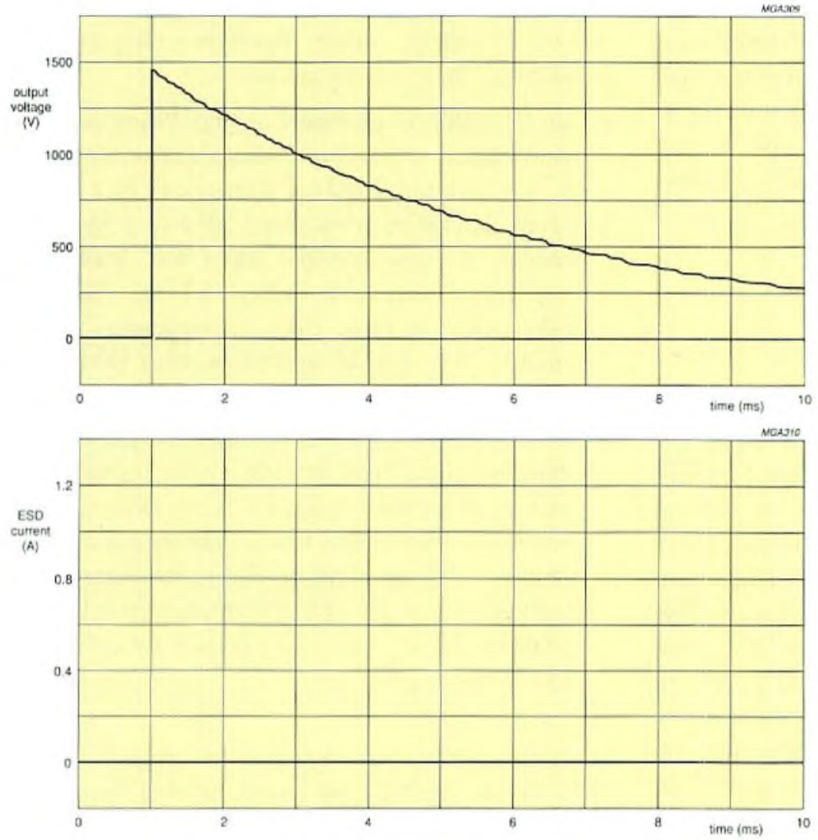
These results are for a positive ESD pulse. Negative ESD pulses are also clamped by the forward biased diode so the clamped voltage will be even lower. A similar clamping technique is used between the other pins, and between combinations of pins, to prevent any positive or negative ESDs from causing damage. Although this clamping technique causes most of the ESD energy to be dissipated in the ESD source, there is some dissipation in the TOPFET. Experiments have shown that TOPFETs can withstand, without damage, ESD pulses of more than 1500 V from a standard "human body model" generator with a capacitance of 250 pF and resistance of 1500 Ω.

Short-circuit protection

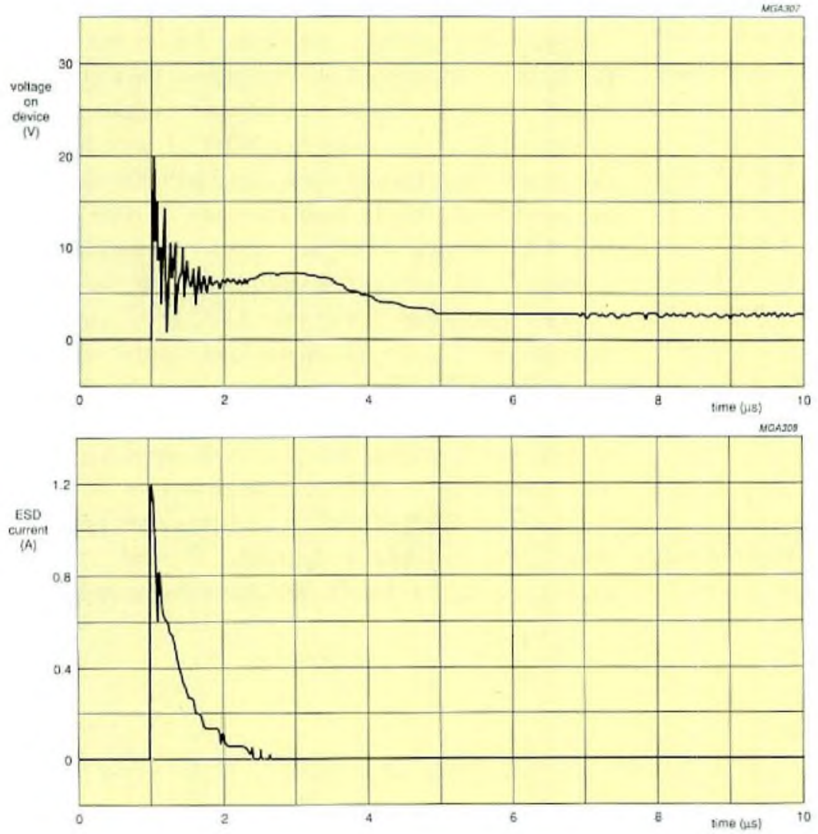
A special temperature sensor on the TOPFET chip detects the instantaneous power dissipation level, typical for a short-circuit load condition, and causes shutdown to protect the device. This method of detecting the disastrous effect of a short-circuit load has many advantages over indirect methods, which are mostly based on voltage or current monitoring. These advantages are:

- the TOPFET is protected against "hard" and "soft" short-circuits. In reality no ideal short-circuit loads (i.e. $R_L = 0\ \Omega$) occur. Practical short-circuit load conditions cover the range from about 10 mΩ ("hard" short-circuits) to some hundred mΩ ("soft" short-circuits) The direct detection method of the TOPFET is independent of these electrical parameters and so it protects the device against a high instantaneous overload produced by any load condition.
- the TOPFET does not erroneously shutdown when it's switched into a load requiring a high inrush current, such as an incandescent lamp. It can safely distinguish between a short-circuit load condition and those kinds of loads. This is achieved due to its direct detection method, without the need for inrush current limiting or disabling the short-circuit protection for a time period after turn-on.

When the short-circuit protection has tripped, the Power MOS in the TOPFET is turned off and the device is "latched". This means the TOPFET will stay off, even when the short-circuit condition has disappeared, until a reset has been applied to the device via the input pin. For this reset, the input must be set to a low- then a high-level. Figure 11 shows the shapes of load current and drain source voltage V_{DS} when the TOPFET switches into a short-circuit load (a) and when a load becomes short-circuit in the on-state (b). In both cases the TOPFET protects itself by shutdown. As already mentioned, the short-circuit protection will not erroneously trip when the TOPFET switches into loads that require high inrush currents. To demonstrate this, Fig.12 shows load current versus time when the TOPFET switches into a cold 60 W car headlamp. The maximum DC power dissipation level allowed for the Power MOS at ideal thermal coupling is not restricted by the short-circuit protection. If, however, shutdown of the TOPFET at or below this power level occurs, the absolute temperature detector must have tripped, e.g. due to insufficient thermal coupling.

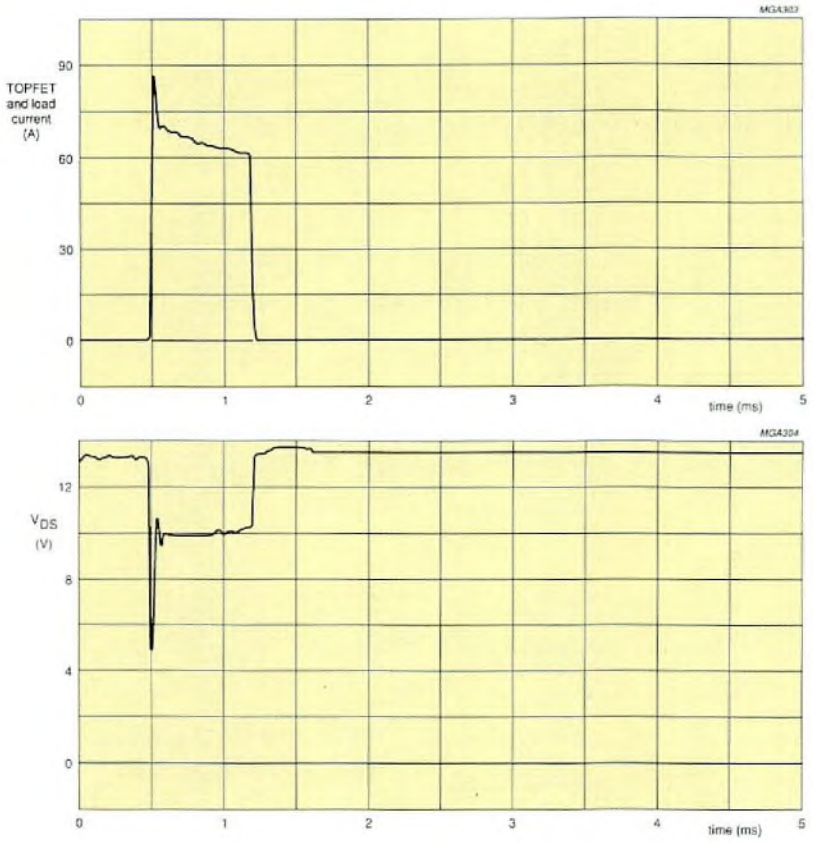


(a) Open-circuit output of ESD generator

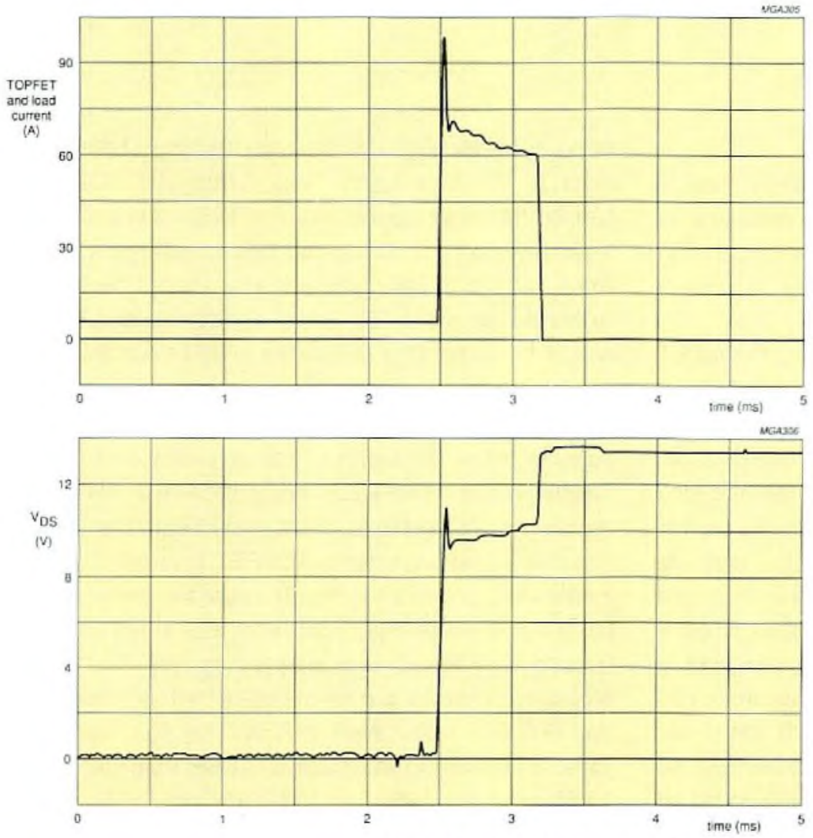


(b) ESD on input of TOPFET

Fig.10 Effect of ESD between input and source



(a) TOPFET turning on into short-circuit load



(b) Load becoming short-circuit when TOPFET is on

Fig.11 Operation of TOPFET short-circuit protection

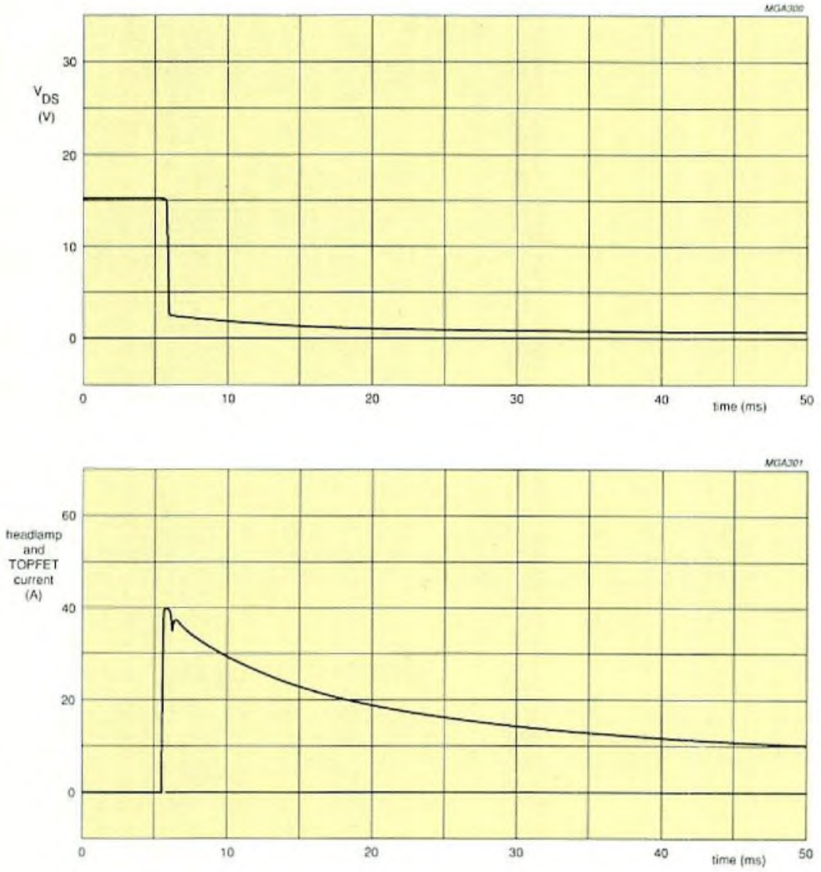


Fig.12 TOPFET current and voltage when turning on headlamp

Overtemperature protection

Unlike the short-circuit protection circuit, which protects the TOPFET from large overloads, the overtemperature circuit responds to subtle faults, like small overloads and gradual changes in temperature. It is set to trip when overall chip temperature is > 150 °C.

When the circuit trips, the gate of the power MOSFET is pulled to the source and the TOPFET stops conducting. When the load is resistive, turning the TOPFET off stops the current and prevent further dissipation. If, however, the load is inductive, turning off the MOSFET will not stop the current. Unless there is an alternative path, the current will continue to flow, forcing the voltage to rise until the overvoltage clamp of the TOPFET is activated. This will result in much higher TOPFET dissipation than when it was ON. Although the dissipation is high, it lasts only a limited time, and so it's possible that the temperature rise it creates will be acceptable providing such faults are infrequent. Calculation of T_j rise is discussed in the Inductive Load Turn Off section. Having succeeded in stopping the current, the TOPFET will now cool but because the fault signal is latched, the TOPFET will not turn on again. The TOPFET will reset if the input voltage is taken below V_{ISR}, the input reset voltage limit, but may reset if V_{IS} falls below V_{ISP}. When the TOPFET has tripped the input current will rise to a value < I_{ISL}. With a high impedance drive circuit, this increase may cause the input voltage to fall. Although this feature could be used to create an automatic reset, a more controlled system would be safer. One possibility would be to have a low-impedance drive, sense the increase in current, and use this signal to trigger a circuit which would, after a suitable delay to allow the fault to clear, interrupt the input signal briefly. If the TOPFET is being used in a PWM system then it will of course be reset every switching cycle. The situation could arise that a TOPFET is required to turn on again while it's still too hot. Because the power MOSFET has a threshold voltage lower than V_{ISP} it will have started to turn on before the temperature can be accurately measured. Therefore, a small current will be flowing when the TOPFET turns itself off, see Fig.13. This will not cause a problem to the TOPFET if the frequency is below 1 kHz and the inductive load turn off losses are being handled properly. It is however a situation which should not be allowed to continue indefinitely and some means of detecting that there is a system fault should be included.

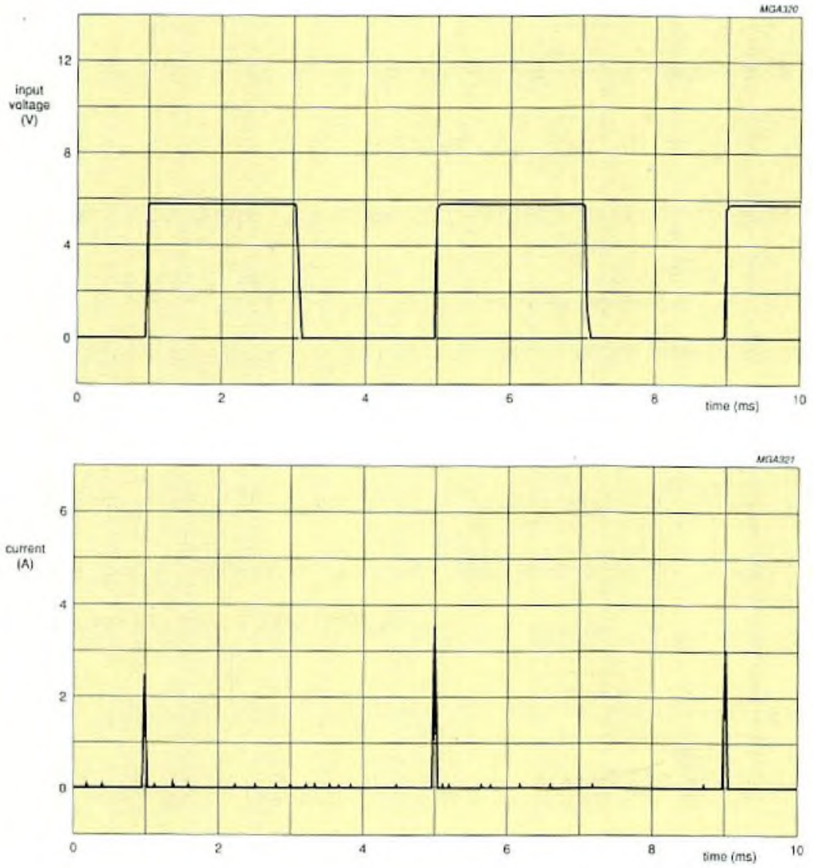


Fig.13 Drain-source voltage and current when TOPFET is overtemperature in a PWM system

Overvoltage protection

Figure 14 shows a simplified circuit diagram of the TOPFET overvoltage protection. If V_{DS} exceeds a level of 50 V while the device is in the off-state, the output Power MOS will turn on to limit V_{DS} by clamping and thus prevents its breakdown.

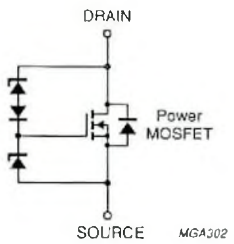


Fig.14 Simplified TOPFET overvoltage protection circuit

Overvoltages due to Inductive Loads

The overvoltage protection of the TOPFET prevents avalanche breakdown of its power MOSFET during inductive load turn-off. Provided that the energy to be handled by the TOPFET during clamping does not cause T_j to rise too far, an external freewheel diode is not needed. The turn-off of a 15 mH load is shown in Fig.15. For repetitive switching (e.g. PWM drives) an external freewheel element is generally recommended. This is because the accumulation of clamping energy with each turn-off makes the average dissipation too high. This energy E_{clamp} lost in the TOPFET at each turn off can be calculated from:

$$E_{clamp} = \frac{1}{2} L I^2 \left(\frac{V_{(CL)DS}}{V_{(CL)DS} - V_{batt}} \right)$$

where

$V_{(CL)DS}$ = TOPFET drain source clamping voltage
V_{batt} = battery voltage
L = load inductance
I = load current at the moment of turn-off

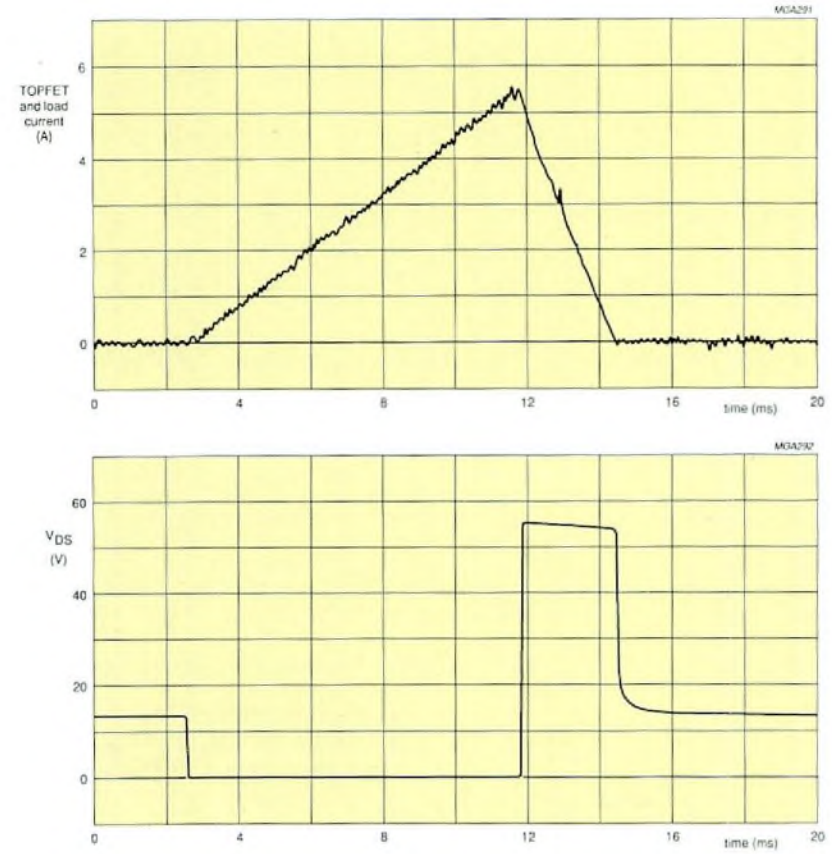


Fig.15 TOPFET driving 15 mH inductor

Figure 16 shows an equivalent circuit diagram for that situation, in which the TOPFET is subjected to a voltage transient coming via the supply rail. The transient is represented by the voltage source $V_{pulse}(t)$ with an internal resistance R_i. The TOPFET's current during clamping is limited by the sum of internal pulse resistance R_i and load resistance R_L. As with inductive load turn-off, the TOPFET limits its V_{DS} below its avalanche breakdown level. The clamping energy to be handled by the TOPFET should not cause excessive rise in T_j. If it does, a clamping element, which can handle this energy, has to be connected between the drain and source of the TOPFET. The clamping voltage of such an element must be below that of the TOPFET. For on board systems in motor vehicles ISO TR7637 (DIN 40839, part 1,2) specifies exponentially shaped test pulses for simulation of typical voltage transients. With its overvoltage protection function, the TOPFET is protected against test pulses 2 and 3 b at all severity levels, even under short-circuit load conditions (i.e. the TOPFET current during clamping is only limited by the internal resistance R_i of the test pulse). Figure 17 shows the TOPFET current I_D and drain-source voltage V_{DS} versus time when test pulse 2 is applied.

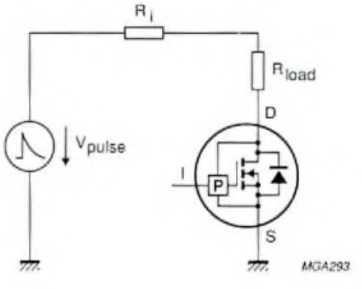


Fig.16 Equivalent circuit diagram for supply line transient

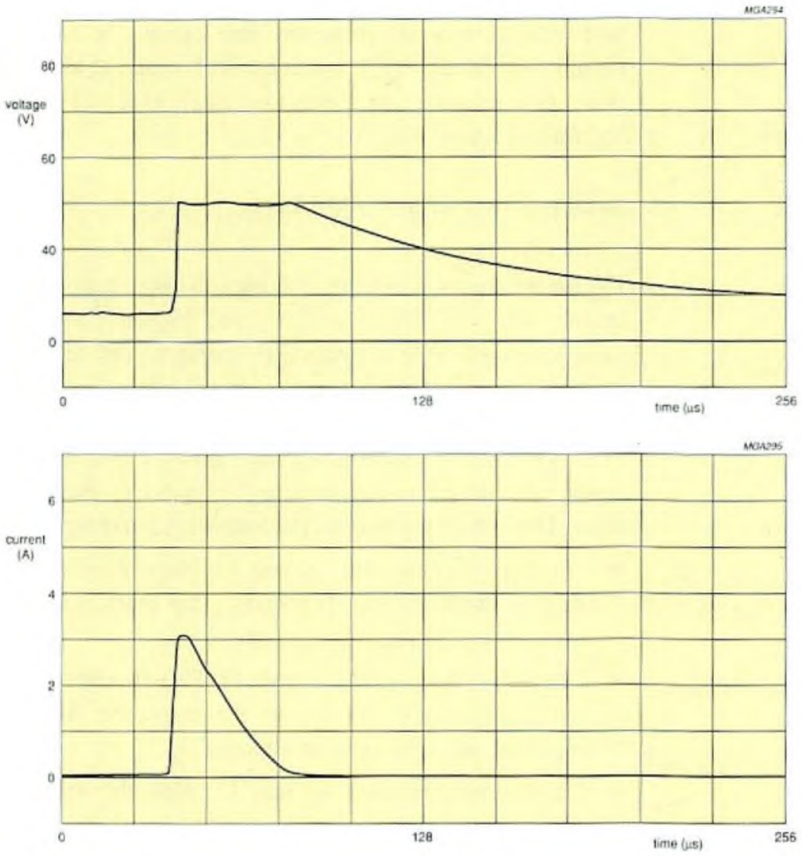


Fig.17 Supply line voltage transient
R_i = 10 Ω; pulse peak voltage V_s = 100 V;
pulse width T = 0.2 ms

APPLICATIONS

TOPFET as a low side switch

Static driving

As with discrete logic-level and standard power MOS transistors, the nominal on state resistance $R_{DS(ON)}$ of TOPFET is reached when V_{IS} = 5 or 10 V. With the three-pin version of TOPFET, the external driver stage has to charge and discharge the power MOSFET gate and supply the internal protection circuits. For the first generation TOPFET, the high-level input voltage V_{IS} must be at least 4 V under any condition for correct operation of all protection functions. The maximum input current I_{IS} flows if there has been a fault and the TOPFET is in the latched condition. In this state, first generation TOPFETs have an ohmic input resistance R_{IS} of typically 5 kΩ with a minimum value of 3 kΩ. The driver stage must be capable of applying at least V_{IS} = 4 V under this condition. The TOPFET will be off if V_{IS} is < 1 V. Considering their requirements, push-pull driver configurations should be preferred for driving first generation TOPFETs. The bus driver output stages of the HC/HCT family and all output stages of the AC/ACT family meet the requirements stated. A further TOPFET version is planned which can be directly controlled by standard microcontroller port outputs.

Pulsed driving

The dynamic switching characteristics of the first generation of TOPFETs are mainly determined by as R_{IS} of typically 5 kΩ between the input pin and the power MOS gate. Pulsed mode applications, with switching frequencies up to 10 kHz, are possible. Figure 18 shows average load current versus duty cycle measured for a PWM control at 10 kHz, a load inductance of 3.2 mH, a load resistance of 2 Ω and a battery voltage of 13 V. An external free-wheel diode was connected across the load. There is an almost linear dependency of average current from duty cycle in the range from 10% to 90%. This shows that the first generation of TOPFETs can be used for pulsed mode applications, although they are not optimized for this purpose. Compared with a discrete power MOSFET, a limited switching speed and an increase in dynamic power dissipation has to be taken into account. The following TOPFET versions for higher switching speeds are planned:

- 3-pin device with a lower R_{IS} allowing for switching frequencies above 20 kHz
- 5-pin device with the full switching speed of a discrete power MOSFET.

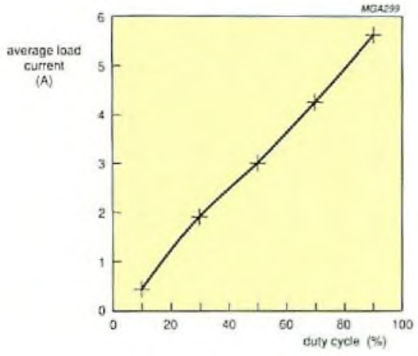


Fig.18 Average current versus duty cycle

TOPFET as a high-side switch

The major factors involved in using TOPFETs as a high-side switch are the same as those for a standard MOSFET. These are:

- providing a gate drive voltage 5 or 10 V higher than the supply voltage
- level shifting the control from ground referenced to source referenced.

The normal methods of creating the necessary gate voltage include charge pumps and bootstrap circuits. These methods are still applicable but care is needed to ensure that maximum V_{IS} is not exceeded. The extra current needed to supply the protection circuits has also to be considered. It's worth noting that, if the TOPFET has turned itself off, the source will be close to ground. So the extra current needed by the TOPFET in this mode can be provided by the main supply. A typical bootstrap arrangement is shown in Fig.19.

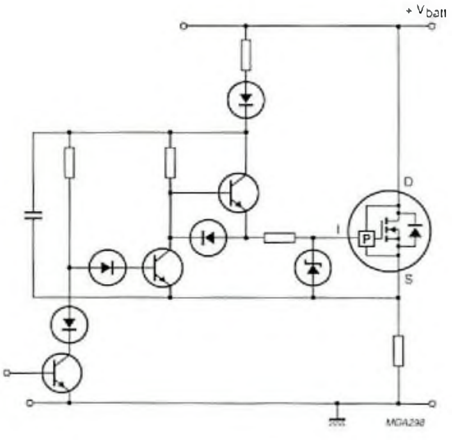


Fig.19 Bootstrap drive for high side TOPFET

Level shifting the control signal by pull-up resistors will still work well. However, care should be taken to ensure that the TOPFET is turned off by pulling the input down to the source rather than to ground. This will prevent V_{IS} falling below −0.3 V.

Bridge drives with TOPFETs

Static driving

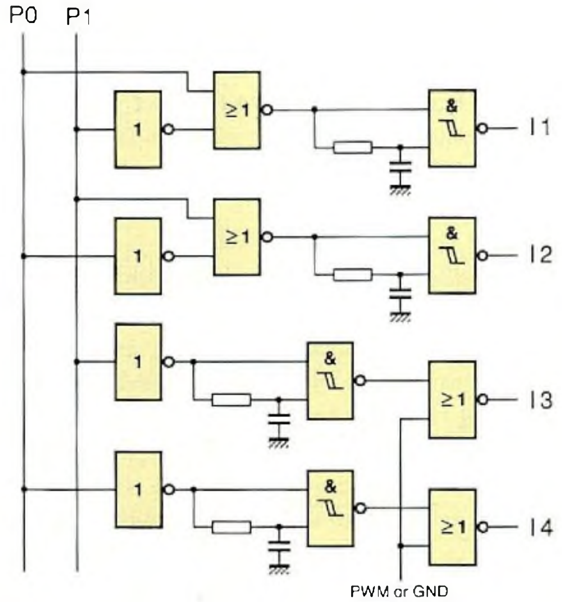
Figure 20 shows a complete bridge drive circuit for DC motors using TOPFETs as low- and high-side switches. Due to the TOPFET protection features, the bridge is protected against any short-circuit condition (i.e. motor terminals shorted or any motor terminal connected to V_{batt} or to ground). It's also protected against a stalled motor condition and against overvoltage spikes on the supply lines. The circuit consists of the following building blocks:

- A charge pump circuit delivers a voltage above V_{batt} for driving the High Side TOPFETs. This block is built up around two Schmitt Trigger inverters.
- The driver stages T1/T2 and T5/T6 will either apply the charge pump voltage to the respective TOPFET input or pull this input to source.
- Level shift transistors T3 and T7 allow the respective driver stages to be controlled with logic level signals referenced to ground.
- An interface circuit (shown in Fig.21) provides control of the four switch signals I1 to I4 by two input signals P0 and P1. The latter can be delivered by, for example, two port outputs of a microcontroller. The truth table in Fig.21 shows the behaviour of the bridge due to P0 and P1. Turn-on delays for each switch are designed in, to avoid the simultaneous conduction of either TOPFET 1 and TOPFET 3 or TOPFET 2 and TOPFET 4.

As with discrete power MOS transistors, no external freewheeling diodes have to be used across the switches because the internal inverse diodes of the TOPFET output power MOS will perform this function.

Pulsed driving

The bridge circuit shown in Fig.20 can also be used for PWM driving. The PWM signal can be applied to a low-side switch while the respective high-side switch is permanently on. Figure 21 shows how the PWM signal can be fed to the low-side switches via the interface circuit. For the first generation TOPFETs, the maximum switching frequency is limited to about 10 kHz. At this switching frequency the reverse recovery behaviour of the internal inverse diodes of the TOPFETs is satisfactory. The connection of faster, external freewheel diodes is, therefore, not necessary.



State	I1	I2	I3	I4	P0	P1
Braking	H	H	H	H	L	L
Rotation Direction 1	L	H	L	H	L	H
Rotation Direction 2	H	L	H	L	H	L
Running down	H	H	L	L	H	H

MGA296

Fig.20 Bridge circuit with TOPFETs

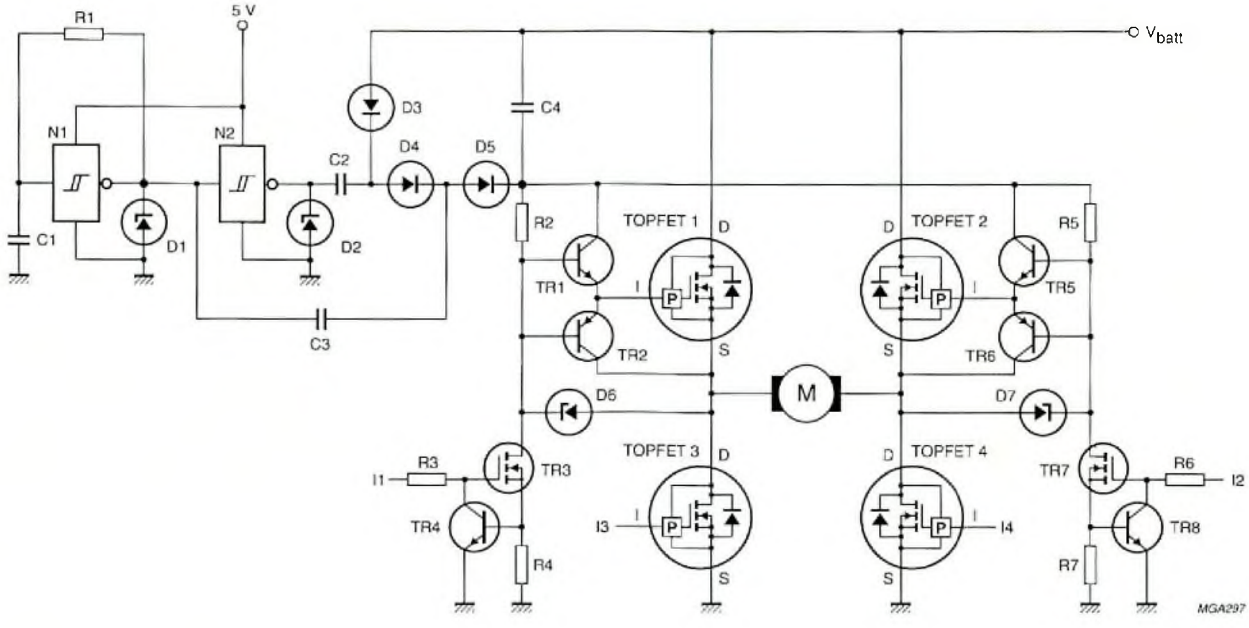


Fig.21 Microcontroller interface for bridge drive circuit

SPECIAL CONSIDERATIONS

Inductive load turn-off

Although the overvoltage protection feature of a TOPFET can be used to turn off an inductive load, designers should be aware that the circuit was intended to handle intermittent phenomena, and not the continuous use associated with PWM control of inductive loads. The overvoltage clamp circuit of a TOPFET will cause a high negative voltage to be applied to the load, quickly resetting the current. Dissipation in the power switch will be high during this time and the effects of it on junction temperature, T_j should be assessed. Methods for calculating the rise in T_j, during inductive load turn-off, are given in Ref.2. These techniques use information about the transient thermal impedance of a device to estimate the rise in T_j at times throughout the turn-off period. From this it's possible to find the peak rise in T_j. This peak when added to T_j prior to turn-off should be less than 150 °C if the best reliability is to be achieved. Table 2 gives figures for the current with various sizes of inductor which will cause T_j, of the three sizes of TOPFET to rise to 150 °C. The calculations assume that T_j before turn-off was 25 °C and the supply voltage is 13 V.

TABLE 2

Currents for 125 °C rise in T_j

TOPFET	Inductor value 1 mH	10 mH	100 mH	
BUK100	10.3	5.1	2.9	A
BUK101	16.7	8.5	4.6	A
BUK102	31	15	8	A

Paralleling TOPFETs

In parallel operation, TOPFETs have the same basic advantages over bipolar transistors as discrete Power MOS transistors, such as positive temperature coefficient of $R_{DS(ON)}$ and no second breakdown. Also the basic design points that have to be taken into account when paralleling Power MOS transistors are still valid for TOPFETs. In addition, the following points have to be considered for TOPFETs.

In contrast to a discrete Power MOS transistor, a 3-pin TOPFET requires a minimum input voltage V_{IS} to ensure correct function of its protection circuits at a certain DC input current, I_{IS}. So for parallel operation of *n* TOPFETs the driver stage has to source a current of *n* × I_{IS}. For the first generation TOPFET, and further 3-pin versions for higher switching speeds, the use of an individual driver for each TOPFET maybe advantageous.

Reverse operation of TOPFETs

For reversal of drain and source terminals the TOPFET performs in the same way as a discrete Power MOS transistor. The internal inverse diode of its output Power MOS transistor becomes forward biased and a current will flow that is limited by the load resistance. This diode has the typical characteristics of a Power MOS inverse diode. The reverse recovery behaviour of the internal inverse diode is sufficient to use it as a freewheel diode in bridge circuits up to the maximum switching frequency of the 3-pin TOPFET (10 kHz for the first generation TOPFET). Thus no external connection of faster diodes is necessary. A zener diode is directly connected between the input and source terminals of the TOPFET for ESD protection. This diode will conduct when $V_{IS} < -0.5$ V. Thus the reversal of input and source terminals must be avoided.

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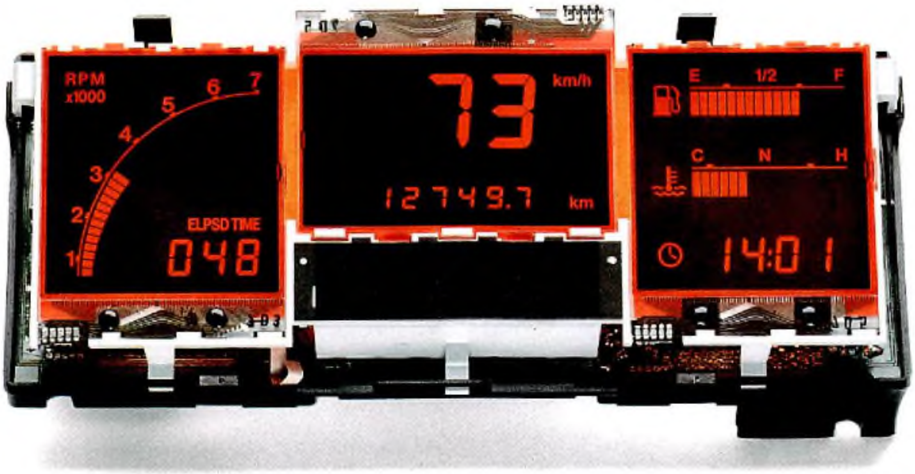
1. Schultz, Warren June 1987. 'Drive techniques for high side N-channel MOSFETs', PCIM.
2. Hammerton, C.J. 'MOSFETs control inductive loads in automotive applications', Philips Semiconductors.

Chip-on-glass – for LCD modules with totally integrated driver

WIM STIJNS

In applications such as telephones, pagers, printing equipment, consumer articles, EDP and automotive products, manufacturers are increasingly turning to LCDs to fulfil their display needs. They know that LCDs not only offer a very clear display, they also give their equipment an elegance that is popular with the end user.

To simplify installation and to offer better reliability, LCDs are often supplied as LCD modules which have built-in drive circuitry. But with conventional LCD modules, the addition of drive circuitry adds considerably to the thickness of the display – a key factor in displays for portable equipment. Chip-on-glass is a new way of making LCD modules with a very thin profile and enhanced reliability.



Car dashboard display using chip-on-glass modules

In a conventional LCD module, the driver IC is mounted on a PCB at the rear of the LCD, more than doubling the overall thickness of the display. The drive connections are made using either fixed-pins or elastomer connectors. With these connectors, several bonds are required for every drive input to the LCD. And since LCDs generally require a large number of drive inputs (even when multiplex drive techniques are used), the quality of these bonds is a critical factor determining reliability.

Chip-on-glass modules have the driver IC(s) mounted directly on an overlapping edge of one of the glass plates that make up the LCD. The resulting module is a totally integrated display, less than 3 mm thick, with all connections from the driver IC to the LCD completely isolated from the environment. Since each connection requires only one bond, reliability is optimized. What's more, by using I²C-bus[1] compatible driver ICs, the number of external connections is minimized.

THE CHIP-ON-GLASS CONCEPT

The idea of mounting the drive circuitry on the glass plate of an LCD has been around for some time, but until now, it's been difficult to make chip-on-glass modules on a large scale. For many years our technologists have searched for a mass production technique for bonding crystalline silicon on amorphous glass in a way that offers high mechanical strength and resistance to severe environmental conditions. Now Philips Components is successfully making large numbers of chip-on-glass modules for the mass market.

A significant factor in the progress of chip-on-glass was the development of TAB'ed (tape automated bonded) chips. A Philips innovation, TAB allows high lead-count chips to be automatically bonded onto polyamide (flexfoil) tape for mounting in low-profile surface-mount packages. The technique is already used in the manufacture of many of Philips' and other manufacturer's LCD driver ICs.

The treatment of ICs for TAB makes them ideal for chip-on-glass. After conventional IC fabrication, the bonding pads are plated with gold bumps which allow them to be bonded directly to contact pads on the flexfoil by mounting the chip upside-down in what's known as 'flip-chip' geometry. ICs with "bumped" pads are also suitable for mounting on a glass substrate. To make chip-on-glass modules, we've substituted the thermocompression process used to mount bumped ICs on flexfoil by a process using conductive glue to bond the chip directly to conductive tracks on glass. Tests show that this process results in a highly reliable bond.

CHIP-ON-GLASS MANUFACTURE

The procedure used to make chip-on-glass modules, closely follows that used in the manufacture of conventional LCD cells. Figure 1 highlights the steps in manufacture that are unique to chip-on-glass manufacture.

LCD cell production

In a chip-on-glass module, one of the two glass plates that make up the LCD is extended to allow room for a driver IC to be mounted and connected. As with conventional LCDs, ITO (indium/tin oxide) electrode patterns are made on the facing surfaces of the glass plates. In chip-on-glass LCDs, these patterns are extended to include connector tracks to the driver IC. In addition, connector tracks from the driver IC to an external connector are also made.

For reliable operation, the resistivity of the connector tracks to the driver IC must be lower than that of the ITO connections used within a conventional LCD cell. We apply one of the following technologies to achieve this:

- *thick ITO* – much thicker ITO than for conventional LCDs (120 nm instead of 30 nm) is used for all connections in the chip-on-glass module
- *gold plate* – all ITO connections (made to standard thickness) outside the LCD cell are gold plated – this gives them lower resistance than thick ITO tracks.

Bonding

The driver IC (chip) is bonded to connection pads on the glass plate after LCD cell fabrication but before applying polarizers. Successful bonding requires a glue that:

- forms high-strength bond between the gold bump and the ITO track
- has good electrical conductivity
- requires moderate curing temperature that does not damage the LCD cell
- exerts very little pressure or mechanical stress on the chip or LCD during curing
- is conductive when wet to allow functional testing before curing, so faulty drivers can be removed and replaced without damaging the LCD cell.

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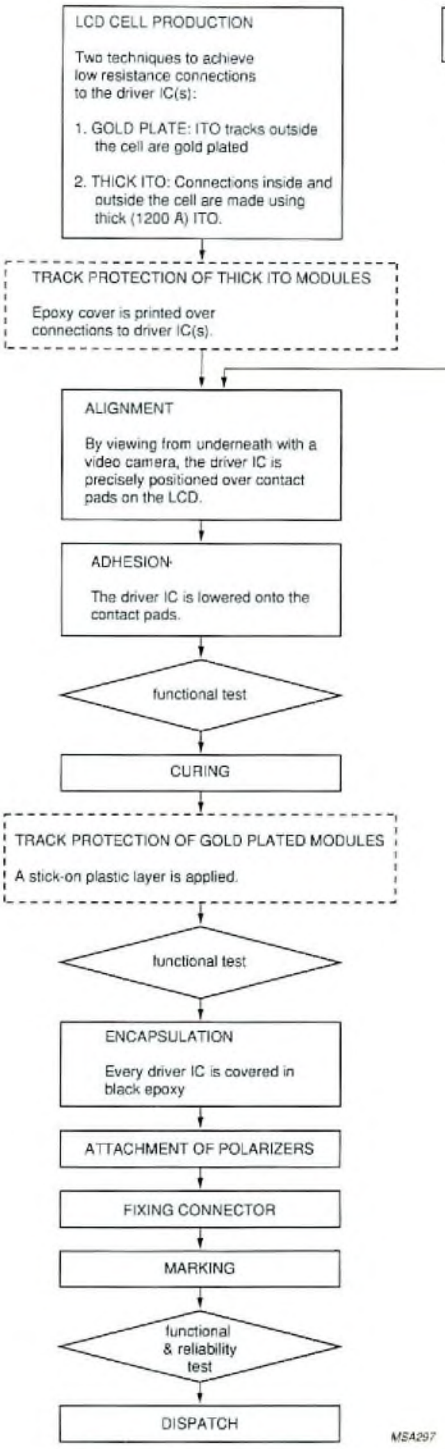
[1] Purchase of Philips' I²C components conveys a license under the Philips' I²C patent to use the components in the I²C-system provided the system conforms to the I²C specifications defined by Philips.



LCD CELL PRODUCTION

Two techniques to achieve low resistance connections to the driver IC(s):

1. GOLD PLATE: ITO tracks outside the cell are gold plated
2. THICK ITO: Connections inside and outside the cell are made using thick (1200 A) ITO.

TRACK PROTECTION OF THICK ITO MODULES

Epoxy cover is printed over connections to driver IC(s).

LCD DRIVER IC

TEST

CONDUCTIVE GLUE

PREPARATION OF THIN LAYER

GLUE APPLICATION:

A driver IC is held by vacuum chuck and dipped into the thin glue layer.

ALIGNMENT

By viewing from underneath with a video camera, the driver IC is precisely positioned over contact pads on the LCD.

ADHESION

The driver IC is lowered onto the contact pads.

functional test

CURING

TRACK PROTECTION OF GOLD PLATED MODULES

A stick-on plastic layer is applied.

functional test

ENCAPSULATION

Every driver IC is covered in black epoxy

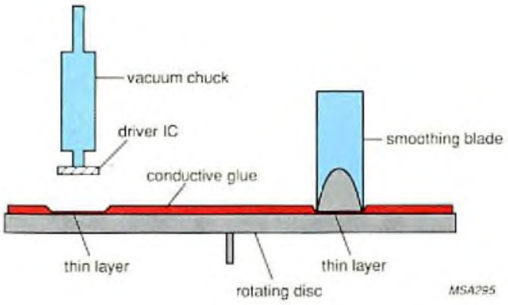
ATTACHMENT OF POLARIZERS

FIXING CONNECTOR

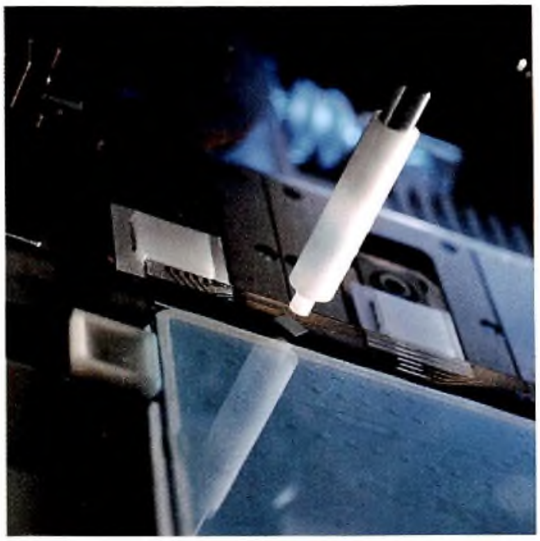
MARKING

functional & reliability test

DISPATCH



Preparing a thin layer of glue



Adhesion

Fig.1 Manufacturing flow diagram for chip-on-glass modules

The glue is applied to the gold bumps in the following manner:

A very thin layer of glue is formed by applying a measured drop to a rotating plate and smoothing the layer with a blade. The chip is removed from its carrier tape, picked up with a vacuum chuck and dipped in the glue to give the gold bump contacts a precisely defined thin coating. The vacuum chuck then moves over the LCD cell, and the chip is precisely aligned with the ITO contact pads by observing it with a magnifying video camera. The vacuum chuck then automatically lowers the chip into position and pushes it onto the contacts with a defined pressure.

With the glue still wet, the driver IC is activated and the display operation is checked by viewing it through polarizers. The connection is then made permanent by curing the glue in an oven. Figure 2 shows the cross-section of a single chip-on-glass connection.

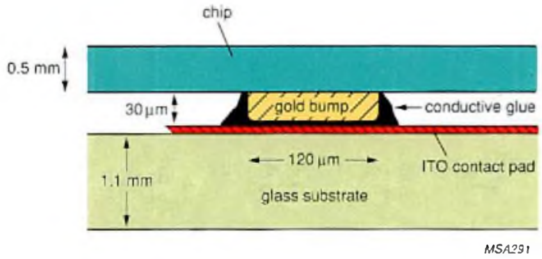


Fig.2 Cross-section of a single chip-on-glass bond

Before the chip-on-glass bond is cured, the module undergoes a full functional test

Protection

All connections outside the LCD cell must be protected from the environment. The method used depends on the connector track technology. Thick ITO chip-on-glass modules are printed with an epoxy layer before the driver IC is bonded. For gold-plated modules, a stick-on plastic cover is applied after curing.

The driver IC and the chip-on-glass bonds are sealed by coating the chip in black epoxy. To prevent light entering the IC and causing increased power consumption (especially important for backlit displays), a small black sticker is glued on the glass, underneath the driver IC.

Final procedures

The polarizers and connectors (see "DESIGN OPTIONS") are attached and the module is marked. The chip-on-glass module is then ready for final test (see "QUALITY ASPECTS").

DESIGN OPTIONS

Chip-on-glass technology sets very few limitations on display design:

- most display designs allow any edge of the display to be used to mount the driver IC
- the design of the display pattern must follow the same criteria as for normal cells and modules. Displays can be made up of seven-segment characters, dot matrix characters or specially designed symbols or words. For more complex applications requiring detailed text and graphics we can make chip-on-glass modules with full-graphic displays
- any type of LCD technology can be used
- up to four driver ICs can be integrated with a display. With specially designed ICs, several drivers can be connected together on an I^2C-bus for *cascaded* operation.

LCD technology

Philips Components makes chip-on-glass LCDs using one of the following technologies:

- **TN** – LCDs using Twisted Nematic (TN) technology produce the familiar black characters against a clear background. They are very effective for direct-drive and low multiplex displays
- **STN** – Super Twisted Nematic (STN) technology is used for displays requiring a high multiplex rate. This technology provides a high contrast display with a wide viewing angle

- **GH** – Guest-Host (GH) displays produce a very bright display with high contrast over a wide, uniform viewing angle. They require a high operating voltage (8.5 V) and are not suitable for multiplex displays. Unlike TN and STN displays, they can only be used in transmissive mode.

Driver IC

For chip-on-glass, only driver ICs with gold-bump contact pads can be used. Choice is therefore restricted to ICs designed for TAB, but with the ever increasing popularity of surface-mount packaging, the number of available driver types is growing rapidly. Table 1 lists the driver ICs we've used so far in chip-on-glass development and manufacture.

Cascaded operation

Although circuit layout is restricted to a single plane, several drivers can be cascaded together on the same I^{2}C-bus to control a single display with a large number of display segments. This is made possible by the design of Philips driver ICs which have sufficient space between the contact bumps for an I^{2}C-bus to be connected underneath.

Figure 3 shows the connections for cascaded operation using two PCF8576 drivers. With this configuration, up to 320 display segments can be controlled at a multiplex ratio of 4:1. The drivers operate at the same slave address on the I^{2}C-bus (input SA0 determines the LSB of this address) and respond simultaneously to commands from the control electronics. Sub-address inputs A0, A1 and A2 are connected on the glass to power lines V_{DD} (+5 V) or V_{SS} (0 V) to define sub-addresses 000 and 001 for the RAM

The LHS540U-22 chip-on-glass module from Philips Components uses a Guest-Host LCD to produce a very bright annunciator display

TABLE 1
ICs for chip-on-glass manufacture

driver IC	no. common/segment lines	possible multiplex rates	connection to microcontroller	cascading on glass	remarks
Oki MSM5298	68 common lines	1:64 to 1:256	–	no	for full-graphic displays
Oki MSM5299	80 segment lines	1:64 to 1:256	4-bit bus	no	for use with MSM5298
Philips PCF2111	2/32	1:2	CBUS (3-line)	no	
Philips PCF8576	4/40	1:1/2/3/4	I^{2}C-bus	yes	
Philips PCF8578	32/8 24/16 16/24 8/32	1:32 1:24 1:16 1:8	I^{2}C-bus	no	for full-graphic displays
Philips PCF8579	40 columns	1:8/16/24/32	I^{2}C-bus	yes	for use with PCF8578

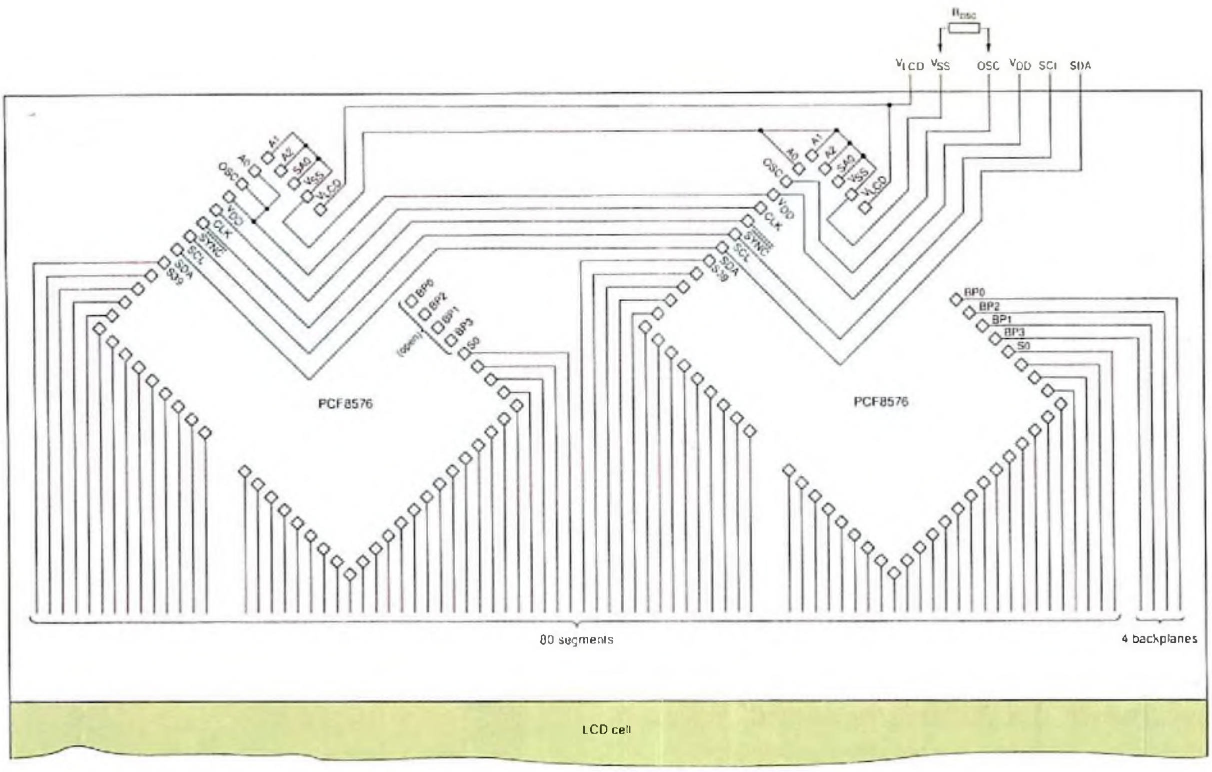


Fig.3 By running interconnection tracks underneath the chips, up to four driver ICs can be cascaded together to control a large number of segments on one display

area in the two chips. Synchronization signal $\overline{\text{SYNC}}$ ensures that the LCD segment drive outputs are synchronized with the relevant backplane outputs. Input OSC sets the internal frequency of one driver IC to a value determined by resistor R_{OSC} which is connected externally. CLK synchronizes the internal clocks of the two ICs. V_{LCD} determines the LCD operation voltage (V_{op}) according to $V_{op} = V_{DD} - V_{LCD}$ and should be set for optimum contrast (for some applications V_{LCD} can be connected to V_{SS} to reduce the number of external connections to five). Inputs SCL and SDA are the I^{2}C-bus connections.

Up to four PCF8576 ICs can be cascaded together on a chip-on-glass module to allow up to 640 display segments to be controlled. When more than one driver IC is used, the resistance of the power lines must be minimized by using gold-plated tracks or with separate connectors for each IC.

Illumination

The back polarizer of the display is given a reflective coating according to the required illumination mode:

- *reflective-mode* – a continuous reflective coating allows viewing by ambient light
- *transmissive-mode* – the back polarizer is left clear and the display must be illuminated from behind
- *transflective-mode* – a thin reflective coating offers sufficient reflection for viewing by ambient light, yet allows backlighting to shine through, so the display can be used in dim conditions.

For transmissive and transflective-mode displays, the following backlighting systems can be used:

- **LED** – several LEDs are mounted in a flat (3-4 mm deep) box including a light guide which distributes the light evenly over the display. LED backlights are available in many colours and produce a bright display when supplied with a low DC current. They have a very long lifetime of up to 1000 000 hours
- **EL panel** – a phosphor impregnated sheet which provides very even illumination when supplied with an AC voltage (typically 100 V (RMS) at 600 Hz). EL panels have a very thin profile but are not as bright as LED backlights and draw more current. They have a typical lifetime of 2000 hours
- **incandescent lamp** – a low cost but bulky illumination system can be made using conventional light bulbs. The display must be carefully designed to avoid uneven illumination.

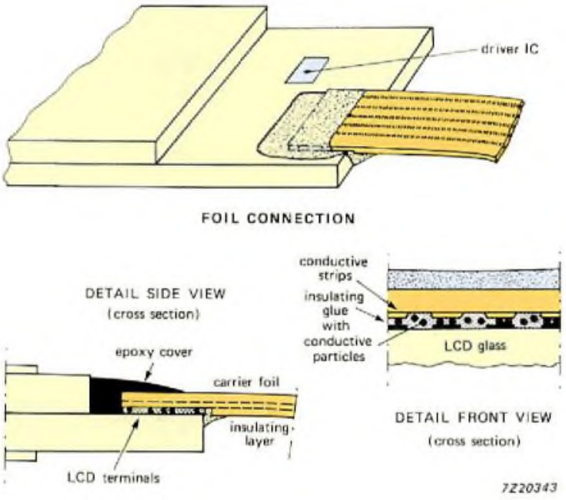
Connectors

The tracks leading to the edge of the glass allow the chip-on-glass module to be connected to a microcontroller. Several methods can be used to make this connection (see Fig.4):

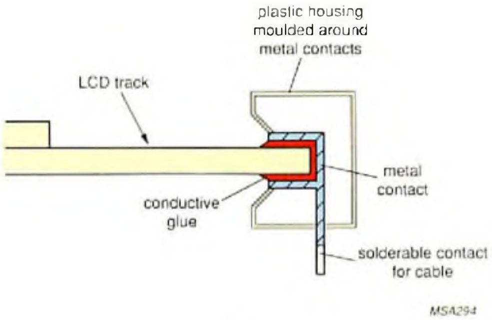
- *flexfoil* – fixed directly on the glass with a hermetically sealed bond, flexfoil offers a highly reliable and flexible connection system
- *fixed-pins* – clipped to the edge of the glass, fixed with conductive glue and sealed with epoxy, fixed-pins offer a very stable and low-cost connection method that is recommended for most applications. The pins can be soldered directly to a PCB or fitted to a suitable interface connector
- *glued-on connector* – glued directly to the edge of the glass and protected by a plastic housing, this type of connector offers an alternative low-cost solution.

Mounting

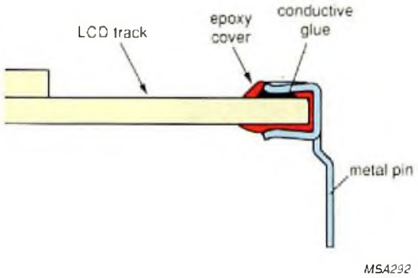
Unlike conventional LCD cells which require bulky connectors to carry a large number of drive signals, the connectors used for chip-on-glass modules are too small to offer any mechanical support. The type of mounting used depends very much on the application but should in general be a plastic bezel that gives even support to the edge of the glass. The bezel should be designed to minimize bending stress during assembly and mounting, and to absorb vibration.



(a)



(c)



(b)

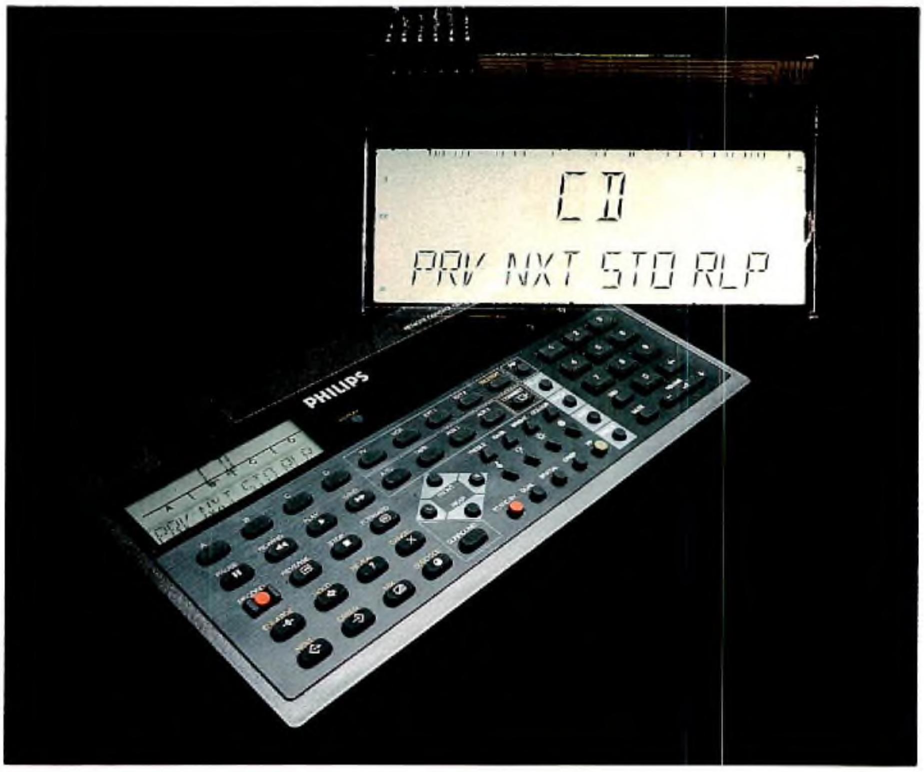
Fig.4 Connection methods for chip-on-glass:
(a) flexfoil
(b) glued-on-pins
(c) glued-on connector

TABLE 2
Product release tests for chip-on-glass modules[1]

test name	test description according to climatic category	
	commercial	extended
high temperature storage (IEC 68-2-2: Test Bb)	+70 °C in dry air for 21 days or +60 °C in dry air for 10 days[2]	+90 °C in dry air for 21 days or +85 °C in dry air for 21 days[2]
low temperature storage (IEC 68-2-1: Test Ab)	−25 °C in dry air for 21 days	−40 °C in dry air for 21 days
damp heat, steady state (IEC 68-2-3: Test Ca)	+40 °C/90% RH for 21 days or +40 °C/90% RH for 10 days[2]	+80 °C/90% RH for 21 days or +60 °C/90% RH for 21 days or +80 °C/90% RH for 21 days[2]
change of temperature (IEC 68-2-14: Test Na)	−25 °C for 30 min. followed by +70 °C for 30 min. repeated × 10	−40 °C for 30 min. followed by +85 °C for 30 min. repeated × 10
low air pressure (IEC 68-2-13)	+25 °C/500 mbar for 2 days	+25 °C/500 mbar for 2 days
high air pressure	+60 °C/5 bar for 1 hour	+60 °C/5 bar for 1 hour
leakage and seal line adhesive strength	+25 °C in freon for 3 hours	+25 °C in freon for 3 hours
vibration (IEC 68-2-6: Test Fc)	10 sweeps from 10 to 150 and back to 10 Hz in X, Y and Z directions at 3 mm peak-to-peak amplitude 10-55 Hz with a constant amplitude of 0.75 mm 55-150 Hz with a constant acceleration of 10 g	10 sweeps from 10 to 150 and back to 10 Hz in X, Y and Z directions at 3 mm peak-to-peak amplitude 10-55 Hz with a constant amplitude of 0.75 mm 55-150 Hz with a constant acceleration of 10 g
bump (IEC 68-2-29: Test Eb)	6 ms/40 g peak repeated × 1000	6 ms/40 g peak repeated × 1000
sulphur dioxide test (IEC 68-2-42: Test Kc)	–	25 °C/75% RH/25 ppm for 10 days
UV light exposure	–	1.1 kW Xenon tube at 20 cm for 100 hours

[1] test conditions for future LCD modules may vary from this table

[2] depending on type



Remote control unit display

QUALITY ASPECTS

To allow customers to make a choice according to application, we supply chip-on-glass modules in two climatic categories:

- *commercial* – for operation under normal environmental conditions
- *extended* – for applications where the display will be subjected to extremes of temperature and humidity.

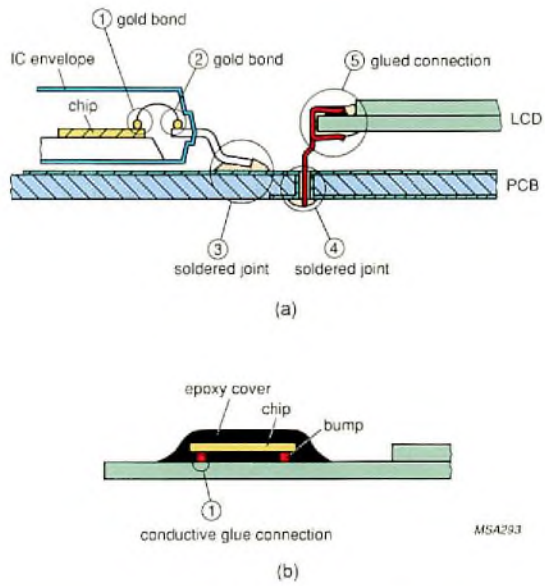
Modules in both climatic categories must pass our rigorous and extensive test procedures, although for some tests the requirements for commercial grade products are less demanding. Table 2 lists the product release tests for chip-on-glass modules.

A STEP FORWARD IN SIMPLIFICATION

The introduction of chip-on-glass LCD modules marks a step forward in the simplification of electronic equipment. Just as LSI technology in semiconductor design has reduced multiboard computer systems to a single chip, so chip-on-glass technology means that a display panel, including drive electronics, can now be incorporated in two pieces of glass. This offers some major benefits to equipment design:

- *very thin profile* – less than 3 mm thick, chip-on-glass LCD modules can be mounted wherever the designer sees fit
- *very high reliability* – even the simplest LCDs use a large number of picture elements to make up their display, and need a large number of drive connections. The reliability of these connections often determines the overall reliability of the display system. In conventional LCD modules with PCB mounted drivers, every drive connection needs five bonds to connect the driver IC to the LCD (see Fig.5). With chip-on-glass, drive signals are connected with a single bond between the driver chip and the relevant ITO conductor on the glass. This low bond-count gives chip-on-glass modules much greater reliability. What's more, in chip-on-glass modules, all the drive electronics is totally sealed from the environment. Both mechanical and environmental tests show that the driver connections made with chip-on-glass technology are more reliable than those in conventional LCD modules
- *easy to connect* – with a minimal number of external connections (especially when using I^2C-bus) needed to control the display, both labour and material costs are minimized in installation
- *simplifies backlighting* – with the drive electronics mounted to one side of the LCD, the back of the display is completely free to allow any type of back-lighting system to be used.

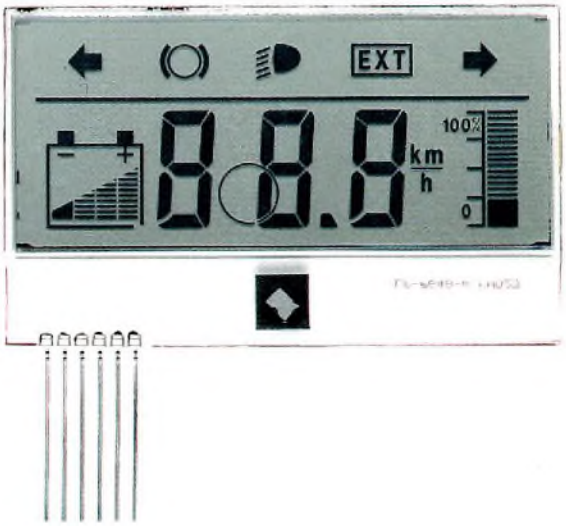
Philips Components chip-on-glass modules are used for car dashboards, annunciator panels, audio-visual remote control units, wheelchairs and many other applications. Contact your local Sales Organisation to find out how chip-on-glass can offer the best solution to your display needs.



(a)

(b)

Fig.5 Chip-on-glass technology reduces the number of LCD-driver bonds from five, in conventional PCB mounted modules (a), to a single bond (b)



Wheelchair display

Abstracts

The KMZ110BH family of magnetoresistive-sensor modules for angle and rotation measurement

Universally acknowledged as a highly effective means of measuring both linear and angular displacement, Philips' magnetoresistive sensors now feature in several series of ready-to-use, active sensor modules. Their advanced hybrid circuitry includes laser-trimmed sensors and temperature compensation. What's more, as they perform contactless measurements, operation is wear-free thus ensuring high reliability and long operating life. The module range includes types with digital output to display or control rotation/linear (or detect the presence of a reference mark), and analog types for angle measurement.

TOPFET – a new concept in protected MOSFET

Philips Semiconductors' range of BUK100 TOPFETs (Temperature and Overload Protected Field-Effect Transistors) are the world's first MOSFETs to include integrated short-circuit, overtemperature and overvoltage protection. Requiring no additional protection components, they reduce circuit complexity and improve reliability in a wide range of general industrial and automotive applications such as the switching of lamps, motors and solenoids. TOPFETs can be driven directly from conventional logic-level FET driver circuitry, and so can be used as direct replacements for MOSFETs in existing equipment, as well as in new designs.

Chip-on-glass – for LCDs with totally integrated driver

With the driver IC bonded directly to one of the two glass plates of an LCD cell, chip-on-glass modules are the most compact displays available. And since every connection to and from the driver IC is made using a single, environmentally sealed bond, chip-on-glass modules are far more reliable than conventional modules with PCB mounted drivers. Philips Components has recently perfected techniques to make high-quality chip-on-glass modules on a commercial scale. This article shows how chip-on-glass modules are made and outlines the options available when designing a new display.

Die KMZ110BH-Familie – magnetoresistive Sensormodule für Winkel- und Drehzahlmessungen

Allgemein als hocheffiziente Hilfsmittel zur Messung von Linear- und Winkelbewegungen anerkannt, bieten die magnetoresistiven Sensoren von Philips jetzt bei mehreren Serien bedienungsfreundliche, aktive Sensormodule. Die Hybridschaltung enthält lasergetrimmte Sensoren und verfügt außerdem über eine Temperaturkompensation. Da die Messungen berührungsfrei durchgeführt werden gewährleisten sie damit eine hohe Zuverlässigkeit und lange Lebensdauer. Die Modulreihe umfaßt Versionen mit digitalem Ausgang zur Anzeige oder Steuerung von Rotations- und Linearbewegungen (oder zur Erkennung einer Referenzmarkierung) sowie analoge Versionen zur Winkelmessung.

TOPFET – ein neues Konzept für den Schutz von MOSFETs

Die TOPFETs (temperatur- und überlast-geschützte Feldeffekt-Transistoren) der Reihe BUK100 von Philips Semiconductors sind die ersten MOSFETs der Welt, in denen ein Kurzschluß-, Übertemperatur- und Überspannungs-Schutz von vornherein integriert ist. Damit sind keine zusätzlichen Bauelemente zu ihrem Schutz erforderlich. Die Schaltungen können weniger komplex gebaut werden, so daß ihre Zuverlässigkeit bei zahlreichen allgemeinen Anwendungen in der Industrie und der Kfz-Technik, zum Beispiel beim Schalten von Lampen, Motoren und Elektromagneten, gesteigert wird. TOPFETs können direkt von konventionellen FET-Treiberschaltungen mit Logikpegeln angesteuert werden und können somit die MOSFETs in vorhandenen Schaltungen und in neuen Schaltungsentwürfen unmittelbar ersetzen.

Chip-on-glass – für LCDs mit vollintegriertem Treiber

Da ihre Treiber-ICs direkt auf eine der beiden Glasplatten der LCD-Zelle gebondet werden, sind Chip-on-glass-Module die kompaktesten Displays, die zur Zeit erhältlich sind. Da außerdem jede Verbindung zum Treiber-IC mit Hilfe einer einzigen, gegen Umwelteinflüsse hermetisch abgeschlossenen Bondierung hergestellt wird, arbeiten Chip-on-glass-Module weitaus zuverlässiger als herkömmliche Module, deren Treiberbausteine auf Leiterplatten montiert sind. Philips Components hat vor kurzem die Technik zur Fertigung von hochwertigen Chip-on-glass-Modulen im kommerziellen Maßstab vervollkommnet. In diesem Beitrag wird die Herstellung von Chip-on-glass-Modulen beschrieben; ferner werden die zur Verfügung stehenden Möglichkeiten dargestellt, die sich für die Entwicklung eines neuen Displays ergeben.

La famille KMZ110BH de modules de capteurs magnétorésistants pour mesure angulaire et de rotation

Universellement reconnu comme un moyen de mesure de déplacement tant linéaire qu'angulaire de grande efficacité, les capteurs magnétorésistants de Philips figurent actuellement dans plusieurs séries de modules de capteurs actifs, prêts à l'emploi. Leur ensemble de circuits hybrides élaboré comprend des capteurs ajustés au laser et la compensation de température. Etant donné qu'ils effectuent des mesures sans contact, ils ne connaissent pas d'usure due au fonctionnement et offrent par conséquent une grande fiabilité et une longue durée de vie. La gamme de modules renferme des modèles à sortie numérique pour affichage ou commande de mesures de rotation/linéaires (ou dépistage de présence de repère de référence) et des modèles analogiques pour mesures angulaires.

TOPFET – un nouveau concept en matière de MOSFET protégés

La gamme de TOPFET (Temperature and Overload Protected Field-Effect Transistors = Transistors à effet de champ (TEC) protégés contre les températures excessives et les surtensions) sont les premiers MOSFET au monde à court-circuit, protection contre température excessive et surtension intégrés. Ne nécessitant pas de composants de protection supplémentaires, ils réduisent la complexité du circuit et améliorent la fiabilité dans un large éventail d'applications industrielles générales et automobiles, comme la commutation de lampes, de moteurs et de solénoïdes. Les TOPFET peuvent être pilotés directement à partir d'un ensemble de circuits de commande classique TEC à niveau logique et peuvent ainsi se substituer aux MOSFET aussi bien dans les équipements existants que dans les nouvelles réalisations.

'Puce sur verre' – pour les diodes électroluminescentes avec excitateur totalement intégré

Avec le CI excitateur adhérant directement à l'une des deux plaques de verre d'une cellule LCD, les modules 'puce sur verre' constituent les afficheurs les plus compacts que l'on puisse acquérir. Etant donné que chaque connexion dans l'un ou l'autre sens avec le circuit intégré d'excitation est réalisée à l'aide d'une simple liaison étanche scellée, les modules 'puce sur verre' sont beaucoup plus fiables que les modules classiques avec excitateurs montés sur cartes à circuit imprimé. Philips Components a récemment perfectionné les techniques de production de modules 'puce sur verre' de haute qualité, sur une base commerciale. Cet article montre comment sont réalisés ces modules et expose les options qui s'offrent lors de la conception d'un nouvel afficheur.

La familia de módulos con sensor magnetorresistivo KMZ110BH para medición de ángulos y rotación

Reconocidos universalmente como un medio muy eficaz para la medición de desplazamientos lineales y angulares, los sensores magnetorresistivos Philips se presentan ahora en varias series de módulos sensores activos listos para su utilización. Su avanzada circuitería híbrida incluye sensores ajustados para láser y compensación de la temperatura, y como además realizan las mediciones sin contacto, su funcionamiento está libre de desgaste, lo que garantiza una elevada fiabilidad y larga vida de servicio. La gama de módulos incluye tipos con salida digital para presentación o control de rotación/movimiento lineal (o para detección de la presencia de una marca de referencia), y tipos analógicos para medición angular.

TOPFET – un nuevo concepto en MOSFET protegido

La gama de semiconductores Philips BUK100 TPFET (transistores de efecto de campo protegidos contra la temperatura y las sobrecargas) son los primeros MOSFET del mundo que incluyen protección integral contra cortocircuitos y excesos de temperatura y de tensión. No precisan componentes de protección adicionales, reducen la complejidad del circuito y mejoran la fiabilidad en una amplia gama de aplicaciones industriales y de automoción tales como la conmutación de lámparas, motores y solenoides. Los TOPFET pueden ser excitados directamente por circuitería FET de nivel lógico convencional, por lo que pueden utilizarse como sustitutivos directos de los MOSFET en los equipos existentes, así como en los de nuevo diseño.

'Chip-on-glass' – para pantallas de cristal líquido (LCDs) con excitador completamente integrado

Con el circuito integrado del excitador unido directamente a una de las placas de vidrio de una celda de cristal líquido (LCD), los módulos de 'chip-on-glass' son las pantallas más compactas que existen. Y, en vista de que todas las conexiones del y al circuito integrado del excitador se efectúan utilizando una sola unión sellada herméticamente, los módulos 'sobre vidrio' son mucho más fiables que los módulos convencionales con excitadores montados sobre una placa de circuito impreso (PBC). Philips Components ha perfeccionado recientemente técnicas para fabricar comercialmente módulos de 'circuito sobre vidrio'. Este artículo muestra cómo se fabrican los módulos 'chip on glass' y describe las opciones existentes para el diseño de nuevas pantallas.

Authors

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Jan Lont was born in Deventer, The Netherlands in 1958 and after completing his studies in physics at the University of Groningen, joined Philips Components, Mitcham, England in 1986, as an assistant marketing manager in the Tube Division. In 1988 he moved to Philips Semiconductors, Hamburg, Germany, where he was initially involved in application work on silicon infrared image sensors. Since 1990 he has been International Product Marketing Manager for the semiconductor sensor group.

Wim Stijns was born in Brunssum, The Netherlands in 1961. He graduated in 1985 at the Higher Technical School of Heerlen and subsequently joined Philips LCDs in the same town. Starting as a test support engineer for the Innovation Group, he went on to provide customer support as an applications engineer, and recently became product manager for LCD modules.

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