ABBEY ELECTRONIC CONTROLS LIMITED
DESIGN ◆ MANUFACTURE ◆ CONSULTANCY

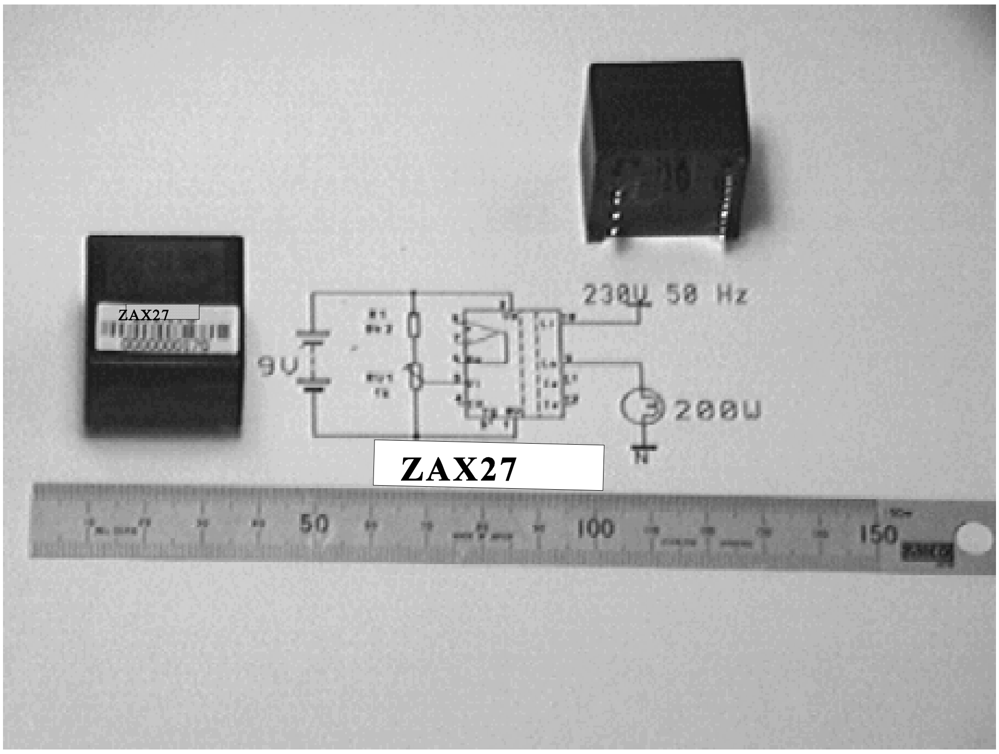
Abbey House
19-21 Fleet Street
Pemberton
Wigan
WN5 0DU
England

THE ART OF CONTROLS

Telephone:
+44 (0)1942 227652
Facsimile:
+44 (0)1942 227653
Web Site:
www.abbeyltd.com

APPLICATION NOTES FOR ZAX27™

ISOLATED MAINS CONTROLLER
(Improved Phase & Burst-Firing Control)
(*Rev. 2.0* November 2003)



This document may be updated at any time without notification. It is therefore advised that a check is made to see if there is a later release copy.

CONTENTS

Figures

Tables

Equations

Introduction

The ZAX27™ is a fully isolated and elegant device for the accurate control of alternating current voltage of any amplitude up to 300V rms. It achieves this through a d.c. control voltage. It exists in two versions, A and B.

The ZAX27A has a built-in triac allowing it to drive loads of up to 3A peak r.m.s. and is therefore a fully self-contained unit. It can be used to drive external triacs or back-to-back thyristors giving it, in effect, unlimited power capability.

The ZAX27B, on the other hand, is optimised for driving thyristor modules and therefore has no in-built triac. It is most useful when it comes to implementing controlled bridge circuits. When an external triac is added to it, it will work in a similar way to the ZAX27A. The ZAX27B does not have the current limit input of the ZAX27A.

Other than these differences, the two units have exactly the same functionality and transfer function and the following explanations, other than where indicated, applies equally to either.

The device operates in two modes, Phase Mode and Burst Mode each with its own unique advantages and disadvantages. Which mode the device operates in is selected simply by the appropriate logic on a single MODE pin. The mode is hot selectable, that is, at any time during operation, the logic on the pin can be changed and the device will change to operating in the selected mode. The ZAX27™ embodies all the functions of the earlier ZAX15 (Burst) and ZAX16 (Phase) with additions and improvements.

An ingenious scheme allows certain pins to perform more than one function simply by applying different voltage levels to the pin. This has allowed the functionality of the ZAX27™ to be expanded without incurring extra I/O overhead.

1.1 Main Features of the ZAX27™

Whichever mode is chosen each ZAX27™ offers the following features:

- Accurate and precise mains control
- Choice of Phase or Burst Mode
- Full electrical isolation of 5kV between the low voltage input and the mains
- Unlimited output power via external triac or thyristor
- Provision for output overload protection
- Internal Overheat shutdown protection
- Soft Start and delayed start
- Control input of 0 - 1V or 0 - 5V for 0 - 100% power control
- Adjustable time base in Burst Control mode
- Input inhibit function
- Fully non committed comparator or operational amplifier
- 4.0V to 6.0V operation
- Wide ambient temperature of –20°C to +60°C
- Hermetically sealed for operation in harsh environments
- Very small size and footprint of only 28 mm x 28 mm x 21 mm
- Plug-able pin-out construction for ease of replacement
- Backward compatibility with ZAX15 & ZAX16

Phase versus Burst Control

Both phase control and burst control are well-established methods for controlling alternating current voltages. Phase control is more versatile and suitable to a wider range of situations than is burst control. It however has the major disadvantage of being intrinsically very noisy. Where the electrical noise generated cannot be eliminated (due to power level, for example) its use may be precluded[1].

Burst control on the other hand does not suffer from noise in the same way as phase control. It can work with full half sine wave cycles. This makes it possible to ensure the turn on point always coincide with the zero crossing point thus eliminating the main source of noise in phase control. Burst control is inherently slower in response than phase control and is only suitable for systems with relatively fairly large inertia such as heaters, some motors, and the like. It would not for example be used in lamp dimming where there would be visible and very much unacceptable (unless of course this is the intention) flickering.

2 Principle of Operation

The principle of operation is quite simple and follows the pattern that makes all well-known components easy to use - predictability, precision, a well-defined output for a defined input. The r.m.s. value of the a.c. output is a computable function of the value of the applied controlling d.c. voltage and the input a.c. voltage. The ZAX27A™ maintains its output as a fixed ratio of the applied input voltage, the ratio being determined by the level of d.c. voltage applied to the device's control pin (5).

The dc voltage achieves this control by regulating the conduction phase (in phase mode) of the switching element of the ZAX27™ or (in burst mode) by proportionally allowing a number of half cycles of mains power to the load. Applications for the ZAX27™ include many mains operated devices that are able to work with phase or burst control. Among these are all resistive and inductive elements as well as some capacitive ones. The control of such elements directly from a microprocessor or micro controller is now possible through the ZAX27™.

2.1 Closed Loop Application

The device has a further advantage in that it can also be used in a fully isolated closed loop design providing even better control than is possible with other controllers that work with similar principles[2]. To aid in such applications, it has an integral, fully uncommitted, operational amplifier that can be used as an error amplifier or comparator.

2.2 Output Inhibit

The ZAX27A has an in-built fully isolated load current regulation input that can be configured to limit either the peak or average load current. On the low voltage side, the ZAX27™ has an inhibit input which prevents any output from it when the pin is taken high, whatever the voltage is on the control input. If this pin is high or tied to Vcc at power-up, it will disable the soft-start and the output will be on immediately[3].

1 Abbey Electronics offer a range of suitable EMC filters for use with phase control up to 100A.
2 Refer to suggested applications on page 8.
3 This feature is only available on release 3 version of the ZAX27A.

2.3 Overheat Shut Down

There is also the inclusion of an in-module overheat shut down facility. If the module's internal temperature should rise too high it will automatically shut down until it has cooled down to an acceptable limit before turning on again automatically. For this feature to be effective the thermal overload must not be too severe, otherwise the temperature will rise faster than the thermal sensor could react leading to internal failure.

2.4 Soft Start Facility

The ZAX27™ has a soft-start feature which will gently ramp up the power output from 0% to 100% over a period, typically 20 seconds. Should the control not be set to provide 100% power, the soft-start will ramp at the same rate but stop at the current power setting.

The soft-start is active only at power up and following removal of an inhibit signal. Refer to paragraph 3.1.3 for information on how to disable the soft-start.

Applications such as motor speed control, automatic brightness control, regulation and pre-regulation of the supply to transformers in both linear and switch mode power supplies are among the many uses that the ZAX27™ can or has been put to.

In addition to the supply pins, the ZAX27A™ only needs three other pins (1 for input and 2 for output) connected to be fully functional.

Some application examples are given beginning on page 17.

3 Pins Details

Pins 1 to 8 are the Low Side pins and are identical on both the ZAX27A and B. The High Side pins are however different. The ZAX27A™ has 5 pins on the high voltage side making 13 pins in all. Pin 13, the bias pin, is a later addition and is rather oddly placed between pins 9 and 10 in order to avoid a complete renumbering of all pins thus maintaining compatibility with existing designs.

The ZAX27B™ has 6 pins on the High Side making 14 pins in all.

3.1 Low Side Pins

These pins are common to both versions of the ZAX27™

3.1.1 DC Power Supply Pins (1 & 2)

A stable dc supply of 5V nominal should be applied to pin 2 with respect to pin 1. All parameters are quantified assuming this voltage. In applications where the control voltage is derived from V_s (such as the examples on pages 17 and 19) the Supply Voltage Rejection Ratio[4] (SVRR) is theoretically 0%. If the control voltage is independent of the supply, then the SVRR is theoretically 100%.

3.1.2 Mode Pin (3)

4 Defined as $\Delta V_{rms}/\Delta V_s$

A low logic on the mode pin 3 puts the ZAX27™ into its burst mode whilst a high logic will put it into the phase mode. This pin should not be left floating as it may otherwise be in an indeterminate state.

3.1.3 Inhibit Pin (4)

The inhibit pin suppresses any output from the ZAX27A™ when a logic high is applied to its input. The pin is also used to modify the input range of the module. It has an internal 10kΩ pull down resistor and can therefore be left unconnected if not used. Since this pin has an internal 10k pull down resistor, all that is required in order to change the input range is another 10k resistor from it to the supply rail.

It is necessary to put a blocking diode in series with this pin, if the 10k pull up resistor is used, to ensure that the pin is not dragged low by the applied inhibit signal. Similarly, the diode will also be necessary in the case of ZAX27A if the current limit feature is used because this pin is internally pulled up by the current limit circuitry.

Following the removal of an inhibit signal, the output will remain inhibited for about 1s after which it will soft-start to the power level set by the control pin 5. This allows a settling time for other devices such as relays and contactors.

Having this pin high at power-up will disable the soft-start feature and force the input into its 0-5V operating mode. Subsequent removal of the high signal from the inhibit pin will allow the pin to function normally as previously described but the soft-start will remain disabled and can only be restored by a power-on reset. This disabling feature is not present on pre-release 3 of ZAX27A.

3.1.4 Control Input Pin (5)

The controlling pin (5) is by default set to a range of 0 - 1 V dc to provide 0 - 100% power control. It can however be changed to a different range of 0 - 5 V dc by applying a 2.5V (or $0.5V_s$) dc to the inhibit pin (4).

In the 0 - 1 V mode the device operates with 51 incremental steps thus providing a resolution of about 2%. This increment will be imperceptible and the resolution satisfactory in many applications. In fact it may be necessary for loads that are not very responsive.

If for any reason these performance figures are not satisfactory, the 0-5V mode may be used. This provides 256 incremental steps and an average resolution of about 0.4%.

3.1.5 Operational Amplifier (Pins 6,7 & 8)

Pin 6 is the output whilst pins 7 and 8 are the inverting (-) and non-inverting (+) inputs respectively.

The rest of the pins are different for ZAX27A and B respectively.

3.2 High Side pins ZAX27A™

3.2.1 Output (Pins 9 & 10)

Interchangeable mains input and output. These are the terminals of an internal triac and are therefore not polarity sensitive.

3.2.2 Current Overload Input (Pins 11 &12)

These pins are the inputs for implementing current limiting on the ZAX27A. Refer to Figure 7 on page 17 for details on how to implement current limiting.

3.2.3 Bias (pin 13)

The bias pin is a later provision on the ZAX27A™ to allow reliable operation with AC supplies below 150V. With the bias it is now possible to operate with any AC supply down to 12V or less. A bias resistor should be connected between pins 9 & 13 for this purpose. Its value is determined as follows.

$$R_B(k\Omega) = \frac{V_{rms}}{2.0mA}$$

Equation 1 Calculating for the bias resistor.

3.3 High Side pins ZAX27B

The 6 pins on the high side are conveniently grouped as follows.

3.3.1 Synchronisation (pins 9,14)

These are pins for the synchronisation which the ZAX27B requires to properly time its switching with the external supply. A bias resistor, R_B, should be connected in series with one of these inputs. The value of R_B is determined according to Equation 1 above.

3.3.2 Thyristor 1 Drive (pins 10,11)

The ZAX27B can drive 2 external thyristors in a synchronised manner. Pins 10 and 11 are drive pins for the first thyristor. One pin should be connected to the anode and the other connected to its gate via a blocking diode.

3.3.3 Thyristor 2 Drive (pins 12,13)

The ZAX27B can drive 2 external thyristors in a synchronised manner. Pins 12 and 13 are drive pins for the second thyristor. One pin should be connector to the anode and the other connected to it gate via a blocking diode.

4 Technical Specifications (absolute maximum ratings)

4.1 Low Voltage Side

Supply Voltage, V_s	5.0 ±0.8	V
Max Supply Current	30	mA
Control Input Range	0 - 1 (or 0 - 5)[5]	V
High Logic (pins 4 & 5)	> 3.6[6]	V
Low Logic (pins 4 & 5)	< 3.0[7]	V
Supply Voltage Rejection	≤ 0.5	%/V
Temperature Coefficient	≤ 0.25	%/°C
Maximum Input (all pins)	Up to 2 x V_s	

4.2 Error Amplifier:

Input Offset Voltage	±5	mV
Bias Current	0.25	µA
Input Offset Current	±50	nA
Common Mode Input Range	0 - 5	V
Output Range	0 – 3	V @ 5 mA
Gain	≥ 2.5 x 10^4	

4.3 High Voltage Side

Isolation Voltage[8]	5	kV
Mains Supply Range[9]	12 - 300	V 50 Hz
ZAX27A		
Continuous Load Current	1.0	A rms
Maximum Peak Load Current	3.0	A rms
Non Repetitive Surge	15	A (≤ 10 ms)
Maximum Load[10]	300	W
Minimum Load	10	W
ZAX27B		
Maximum Drive current	100	mA
Maximum Peak Drive current	1.0	A (≤ 10 ms)
Operating Temperature	-10 to +60	°C
Overheat Shutdown	90	°C
Overheat Reset	60	°C
External Dimensions	28 x 28 x 21	mm

5 See paragraph 3.1.4 on page 7
6 Or (3.6*V_s/5) if supply voltage is not 5V
7 Or (3*V_s/5) if supply voltage is not 5V
8 Between all pins 1 to 8 tied together and pins 9 to 12 tied together.
9 For the ZAX27A a bias resistor on pin 13 is required only for voltages below 150V. The ZAX27B always requires a bias resistor on either pin 9 or 14.
10 Refer to derating curve on page 16.

5 PHASE MODE (Pin 3 high)

Equation 2 below gives the normalised transfer function governing the input/output ratio when the ZAX27™ is used in the phase mode.

$$TF(V_i) = \frac{V_{load}}{V_{mains}} = \sqrt{\frac{(2\cdot\pi\cdot(v_i - v_o) + \sin[2\cdot\pi\cdot(1-(v_i - v_o))]}{2\cdot\pi}}$$

Equation 2 Normalised Transfer Function for ZAX27™.

V_{load} and V_{mains} are both in rms
$\mathbf{v_i}$ is the control dc input and $\mathbf{v_o}$ is a circuit constant.

V_o is effectively an offset voltage caused by components' as well as manufacturing tolerances. It can either be allowed for as detailed in paragraph 5.1 on page 11 or can be trimmed out by other external methods.

Equation 2 might look rather cumbersome but, as can be seen in Figure 1, it is quite easy to use. As a further aid, a table is given on page 11 (Table 1) of this document giving the transfer function for a normalised input of between 0 to 1 V[11] in increments of 10 mV.

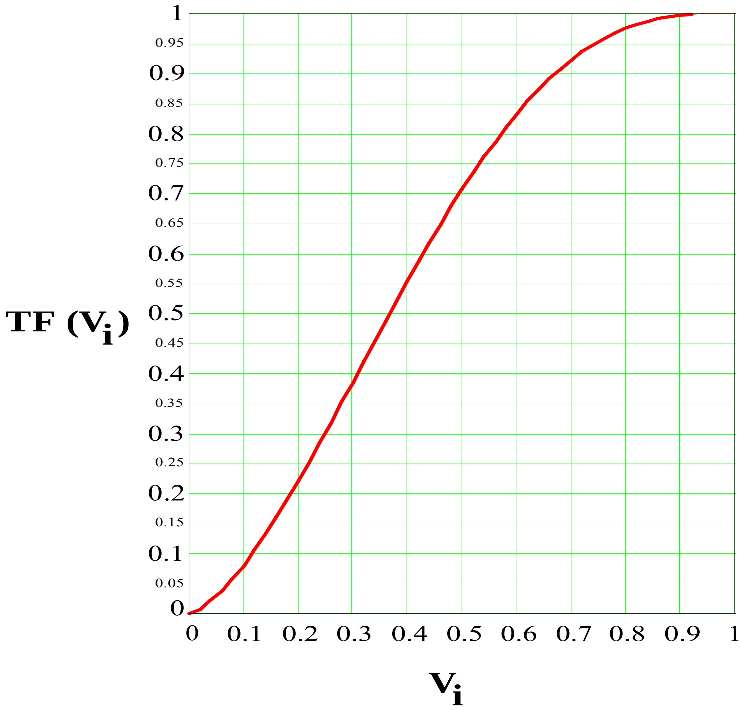


Figure 1 Curve of normalised Transfer Function for the ZAX27™ in its Phase Mode (v_o = 0).

[11] Multiply Y-axis by 5 for 0-5V input.

Table 1 Transfer Function (TF) table for ZAX27™ with $V_o = 0$.

	0	.01	.02	.03	.04	.05	.06	.07	.08	.09
0	0	0.003	0.007	0.013	0.020	0.029	0.038	0.047	0.058	0.069
0.1	0.080	0.092	0.105	0.118	0.132	0.146	0.160	0.175	0.190	0.205
0.2	0.221	0.236	0.252	0.269	0.285	0.301	0.318	0.335	0.352	0.369
0.3	0.386	0.403	0.420	0.436	0.453	0.470	0.487	0.504	0.521	0.537
0.4	0.554	0.570	0.586	0.602	0.618	0.633	0.648	0.663	0.678	0.693
0.5	0.707	0.721	0.735	0.748	0.761	0.774	0.787	0.799	0.810	0.822
0.6	0.833	0.843	0.854	0.864	0.873	0.882	0.891	0.900	0.908	0.915
0.7	0.923	0.930	0.936	0.942	0.948	0.953	0.959	0.963	0.968	0.972
0.8	0.975	0.979	0.982	0.985	0.987	0.989	0.991	0.993	0.994	0.996
0.9	0.997	0.998	0.998	0.999	0.999	1.0	1.0	1.0	1.0	1.0

5.1 Compensating for v_o

Making allowance for v_o when using the table is very simple. Typically v_o is about 10 mV or less. The exact value for a device can be determined by plotting its curve for a few points. For a lot of applications however, it can be ignored without suffering any significant errors.

For example, if a device's v_o is 25 mV, say, and a control voltage of 0.4 V is applied to it, the output ratio will be given by that of,

$$V_{control(effective)} = 0.4 - 0.025 = 0.375$$

which is half way between 0.37 an 0.38. Extrapolating between the two therefore gives a transfer ratio of ,

$$\mathbf{TF}_{(0.375)} = 0.512$$

Ignoring v_o in this case would have resulted in an error of 8.2%.

6 BURST MODE (Pin 3 low)

Equation gives the simple expression governing the transfer function when the ZAX27A™ is in its burst mode.

$$P_{av} = k \cdot v_i \cdot P_{\max}$$

Equation 3 Transfer Function for the ZAX27™ in Burst Mode.

Where

P_{av} is the average power to the load, **v_i** is the control d.c. input which can be varied from 0 to 1V. **k** is a circuit constant (nominally unity), P_{max} is the maximum available power to the load.

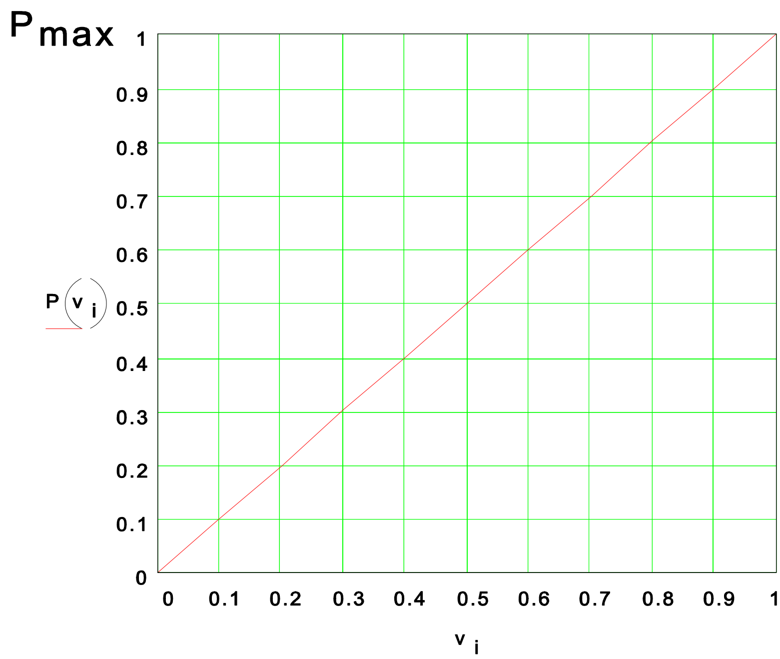


Figure 2 Transfer Function for ZAX27™ in Burst Mode.

The d.c. voltage achieves this control by "burst" firing the switching element of the ZAX27™ on and off within a defined time frame or time base. Within this time base (nominally 1 second), the ZAX27™ switches its output on and off with a fixed mark/space ratio determined by the value of **v_i** as shown in Equation 1 and Figure 2.

The ZAX27™ is also zero-crossing switching. This means it will only switch its output on or off when the mains is passing through its natural zero. This virtually eliminates any noise that could be associated with mains switching and it is this single fact that may make the ZAX27™ a must in many applications.

The ZAX27™ only switches on and off once within a time base period. Furthermore, the minimum conduction period is determined by one half cycle of the mains which, for a 50 Hz mains, is 10 milliseconds. This means the resolution[12] of the ZAX27™, when operating with a time base of 1 second, is 1% which is very good. On the other hand, switching on and off once every second may be too slow for some applications.

[12] **Resolution** in this case is defined as the ratio of the minimum incremental conduction period divided by the time base.

Provision is therefore made for variable time base on the ZAX27™. The minimum time base is 100 ms which allows a maximum of 10 half sine waves and provides therefore a resolution of 10%.

The mode pin (3) on the device serves the dual purpose of allowing the time base to be varied thus increasing or decreasing the reaction time of the ZAX27™ but correspondingly reducing or increasing the resolution. For example, reducing the time base to half a second will increase the reaction time to half a second but this also reduces the resolution to 2% which is still good enough for most applications. If an application only needs a resolution of, say, 10%, the time base could be decreased to 100 ms offering a faster reaction time.

The mode pin thus provides means for optimising the speed/resolution parameters for any given design if these matter. To change the time base a dc voltage should be applied on to the mode pin as follows:-

0V (Default)	---->	100 ms
98 mV	---->	200 ms
196 mV	---->	250 ms
294 mV	---->	500 ms
392 mV	---->	1s
≥ 490 mV	---->	2.5s

The tolerance band in each case should be kept well within 39 mV in order to ensure that the intended time base is selected. This tolerance is the sum total of the dc error and any ripples that might appear on the pin. If a voltage that can not be reconciled to any of the above is applied to the mode pin, one of two things will happen; the time base will remain at the last valid time base or (less likely) set to the default.

The above voltages are ignored in the phase mode and their presence have no effect at all on the device's operation.

Figure 4 shows the simplest possible configuration for the ZAX27A™. R1 and R2 are chosen to give the required control voltage and, provided V_s is stable, the ZAX27A™ will maintain a constant input/output ratio.

6.1 Current Limiting

For current limiting, choose R3 to develop a voltage of between 2.0 and 2.1V at the required current. The current limiting operates at both halves of the mains cycle.

Using R3 for current limiting this way is suitable only for low power applications due to inevitable power dissipation in R3. For higher power than this, it may be necessary to use a current transformer instead.

C1 can be added as an integrating capacitor for average load current protection. The terminal impedance at pin 4 is 10kΩ. The recommended value for an integrating capacitor is between 0.47µF to 10µF depending on whether averaging is required within a cycle or over several cycles.

When pins 11 and 12 are used for current limiting, the inhibit pin (pin 4) can only be used for output inhibit by configuring it as shown in Figure 3 below. If the 0 - 5 V input range is required the necessary 2.5V or $0.5V_s$ should be imposed directly onto pin 4. Keeping in mind that the input resistance is 10kΩ a single resistor of 10kΩ to V_s from pin 4 will be sufficient.

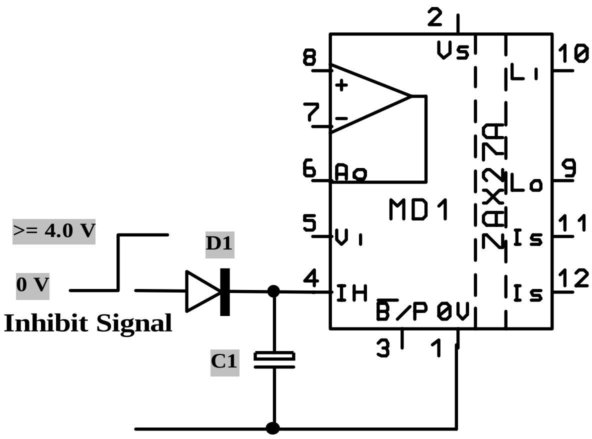


Figure 3 Using the inhibit pin when load current limiting is used.

Figure 8 below shows how the output drive capability of the ZAX27A™ can be easily boosted. In this case the drive capability is limited only by the triac's rating. The circuit shown for example will drive a 48 kW load. Note that snubbering provision is not shown in any of the examples and some EMC suppression measure will also need to be taken depending on the load and topography of the construction.

As further demonstrated in Figure 9, the ZAX27A™ is not restricted to driving single phase loads but can easily be configured also for multi phase loads. The illustrated example is for a three phase application and it is obvious how this can be extended to other number of phases. Multi phase applications have particular advantages such as improved power delivery, frequency multiplication allowing smoother operation of machinery or lower smoothing requirements.

It will be noticed in this example that there are three non-committed operational amplifiers which may be used to carry out other circuit control functions.

Figure 11 shows a typical closed loop application of the ZAX27A™ (phase mode). It is an untried suggested circuit, therefore some development work may be necessary. The ZAX27A™'s amplifier is used as an error amplifier to compare the reference set by R1,D5 with a sample of the output voltage. It then controls the supply to the transformer to maintain a constant output d.c. supply irrespective of load and mains supply variations.

As wide variations of mains supply is no problem the circuit is also suitable for automatic mains supply adjustment for appliances designed for global usage.

Another advantage of this application is that it automatically compensates for transformer load regulation problems, an important consideration in the design of power supplies.

When used as a pre-regulator at the front end of a linear supply, a very high efficiency linear supply can be realised whilst producing savings in reduced heatsink size and overall volume.

Since the ZAX27A™ gets its own supply from the circuit's output, a starter may be required in the form of C4,R6. Note that TX1 will need to be a *low gauss* transformer specially wound to limit the very high magnetising current which phase control tends to induce. Most transformer suppliers/manufacturers can supply these.

7 Accessories

A stripboard style printed circuit board dedicated for ZAX modules is available which can be used either for prototyping or for constructing small ZAX projects. With this board, many on-board functions such as power supply, attenuation/amplification and similar functions can be easily implemented. Necessary discontinuities in tracks can be created using standard spot-face cutters which are conventionally used with strip boards.

Abbey Electronics
www.abbeyltd.com
Tel: +44 (0)1942 227652
Fax: +44 (0)1942 227653

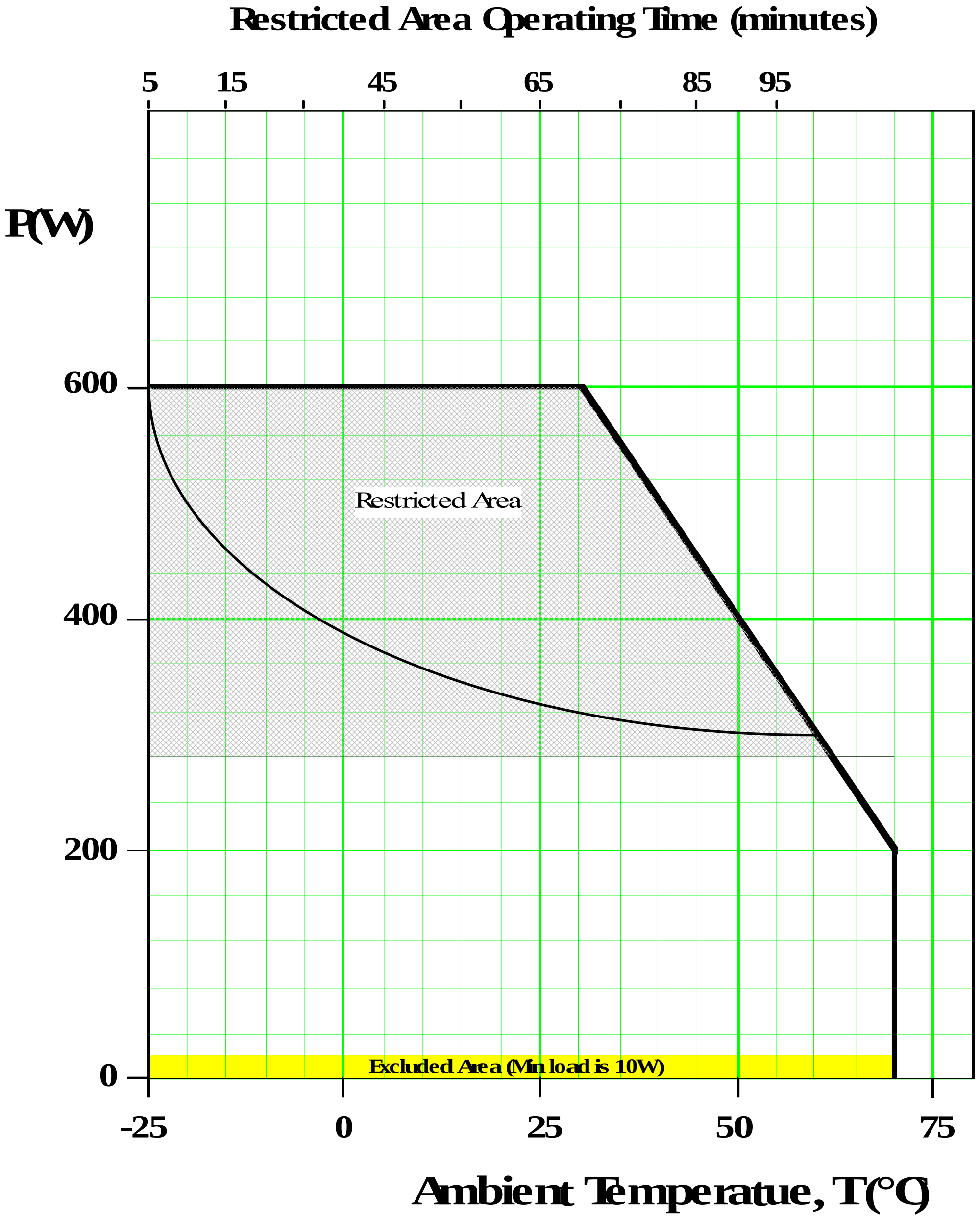


Figure 4 Derating curve for ZAX27A™

Figure 4 is a derating curve provided to assist in ensuring that the ZAX27A™ is used within its capability. The inset exponential curve gives a guide as to how long the device may safely be used in the restricted region and applies only for T_a of 25°C and 25% duty cycle or less.

8 ZAX27A Application Information

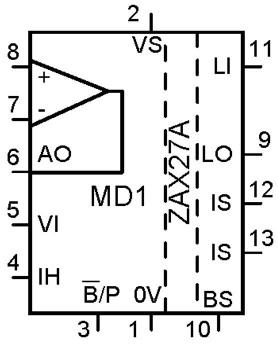


Figure 5 ZAX27A

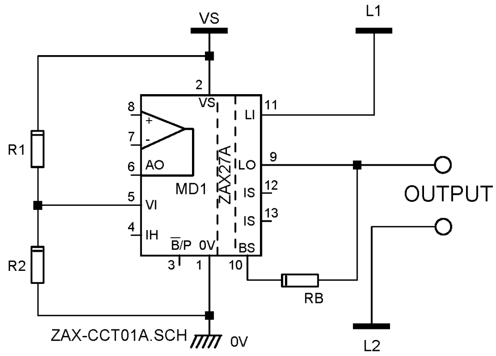


Figure 6 Basic configuration - refer to Equation 1 on page 8 for calculation of R_B

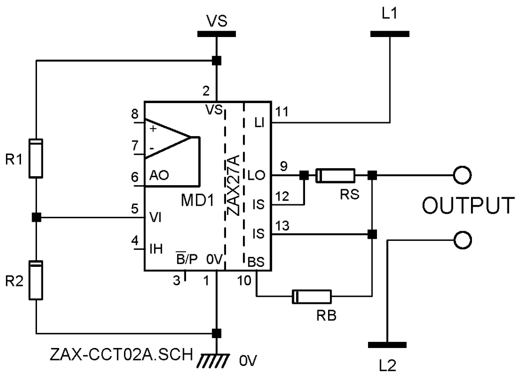


Figure 7 With current limiting

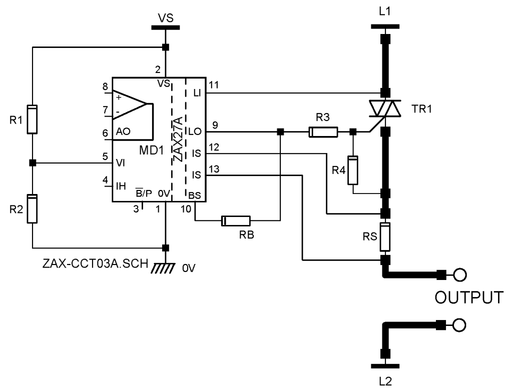


Figure 8 Driving an external triac for current boosting

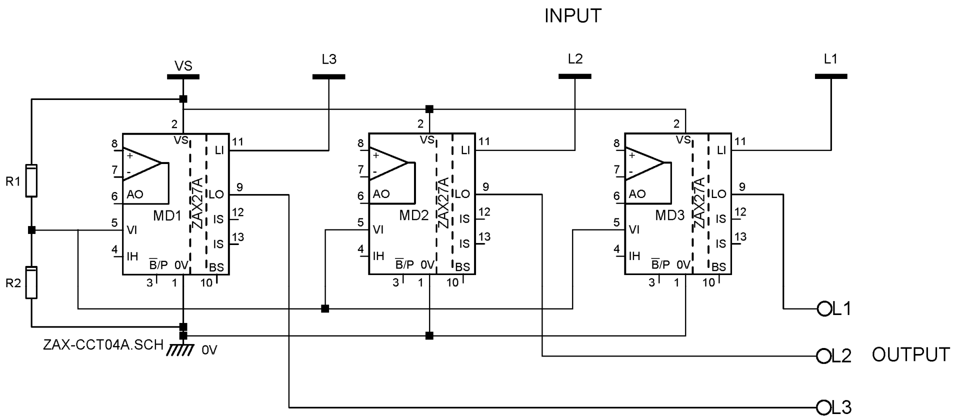


Figure 9 Driving multiphase loads

The inhibit pins can also be paralleled but, if using the high resolution phase mode keep in mind that the combined input resistance of these pins will be 10k/*n* where *n* = number of modules. Hence a pull-up resistor of 10k/n will be required.

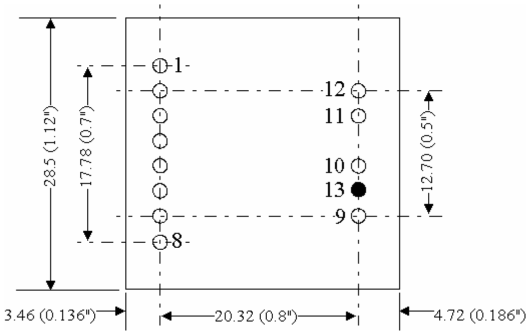


Figure 10 PCB layout (Footprint) details for ZAX27A.

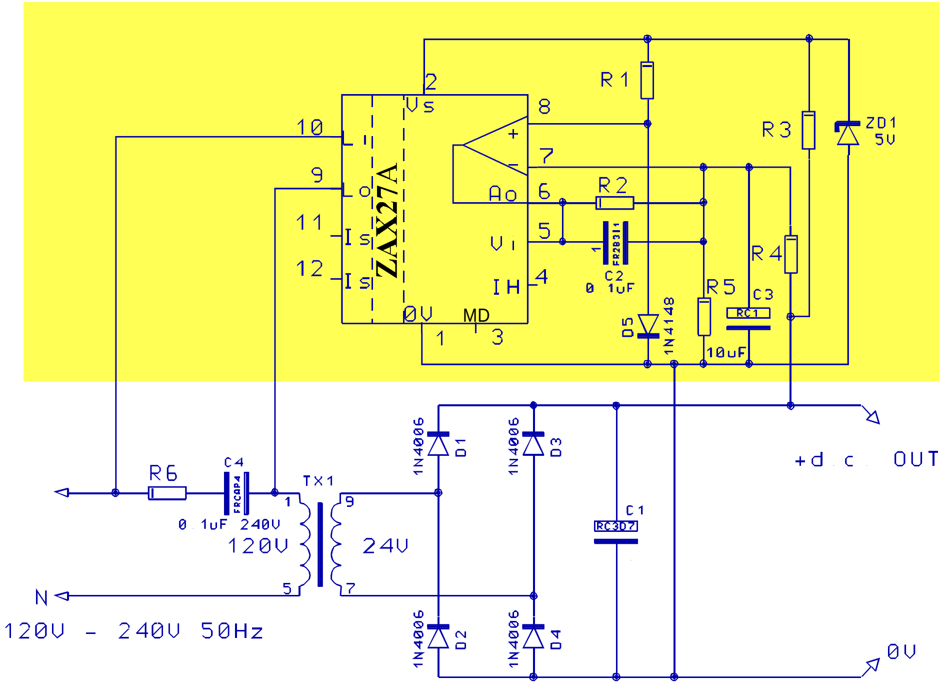


Figure 11 Suggested circuit for regulating the output of a d.c. power supply.

9 ZAX27B Application Information

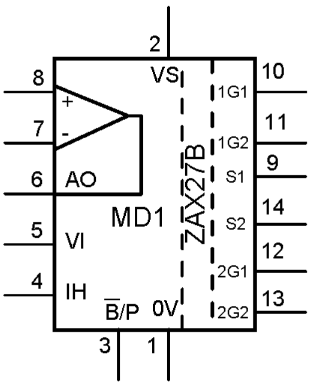


Figure 12 ZAX27B

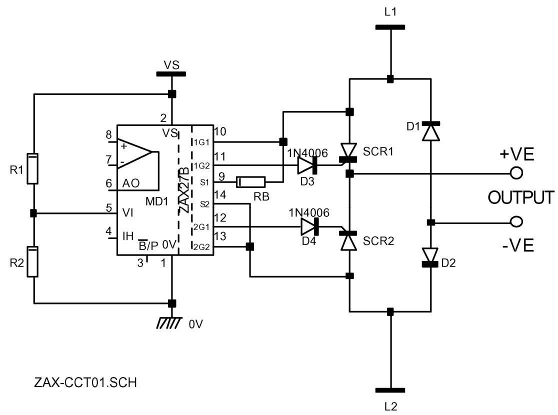


Figure 13 Driving a controlled bridge rectifier with a pair of common cathode thyristors.

Refer to Equation 1 on page 8 for calculation of R_B

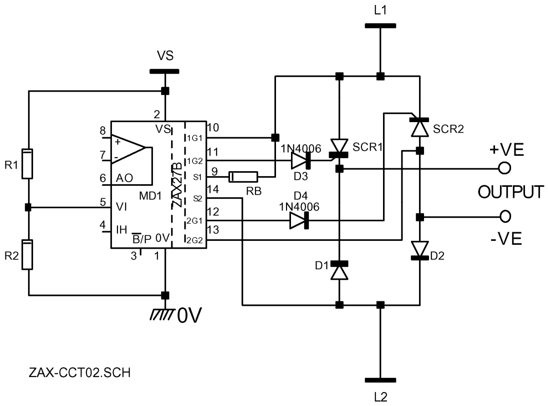


Figure 14 Driving a controlled bridge rectifier with a pair of series connected thyristors

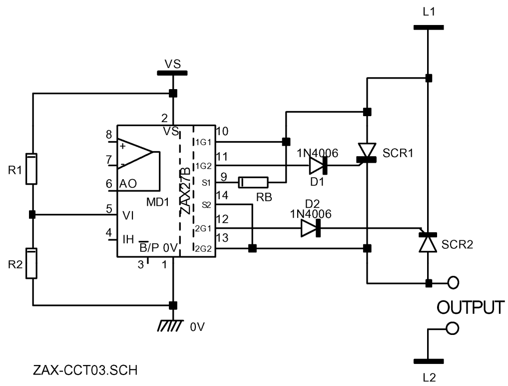


Figure 15 Driving a pair of back-to-back thyristors

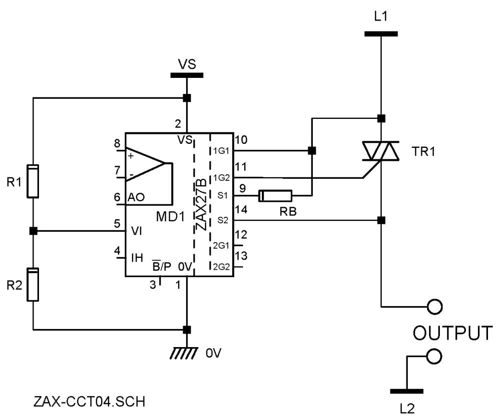


Figure 16 Driving a triac (pins 12 & 13 may be left open or paralleled with 10 & 11)

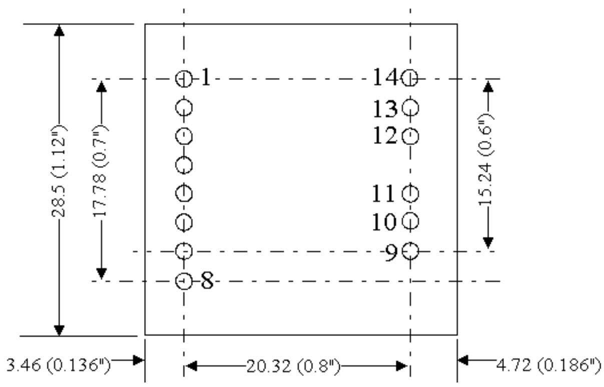


Figure 17 PCB layout (Footprint) details for ZAX27B

10 Accessory diagrams

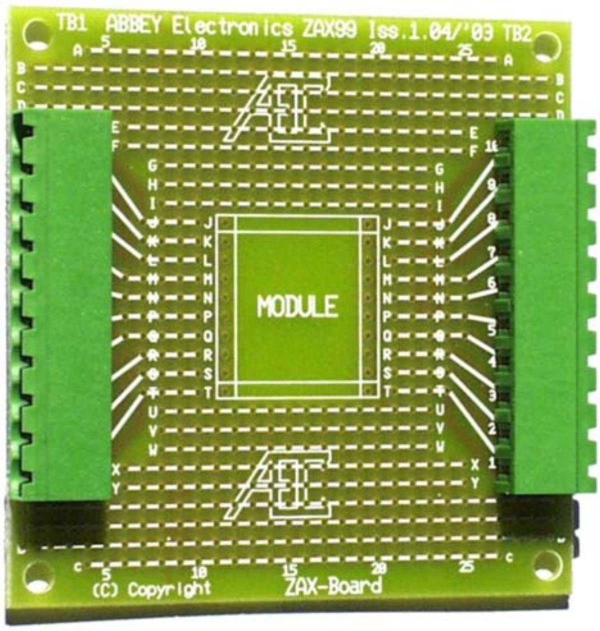


Figure 18 ZAX-Board

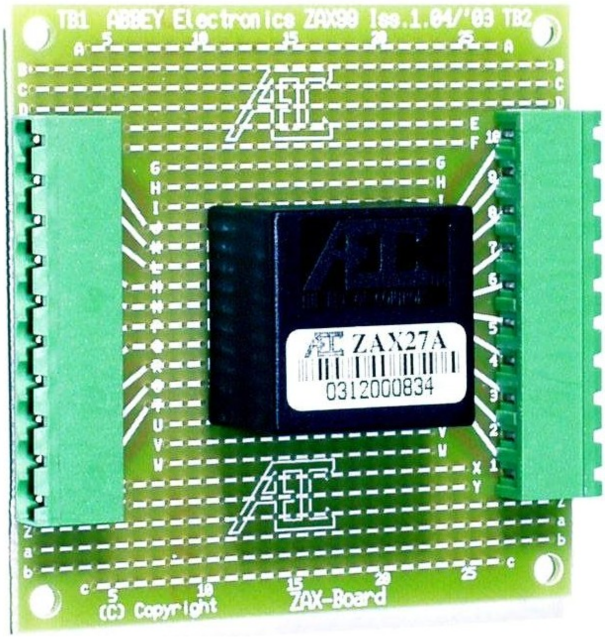


Figure 19 ZAX-Board with a module on it.

The ZAX-Board is a convenient accessory for prototyping with any ZAX module and can be used just like a stripboard. It is 80mm x 80mm and is equipped with 2 10-way connectors.