

Light dimmer circuits

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Some light dimmer history

Light dimming is based on adjusting the voltage which gets to the lamp. Light dimming has been possible for many decades by using adjustable power resistors and adjustable transformers. Those methods have been used in movie theatres, stages and other public places. The problem of those light controlling methods have been that they are big, expensive, have poor efficiency and they are hard to control from remote location.

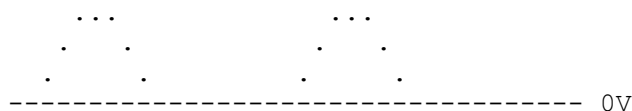
The power electronics have proceeded quickly since 1960. Between 1960-1970 thyristors and triacs came to market. Using those components it was quite easy to make small and inexpensive light dimmers which have good efficiency. Electronics controlling also made possible to make them easily controllable from remote location. This type of electronic light dimmers became available after 1970 and are nowadays used in very many locations like homes, restaurants, conference rooms and in stage lighting.

How modern light dimmers work ?

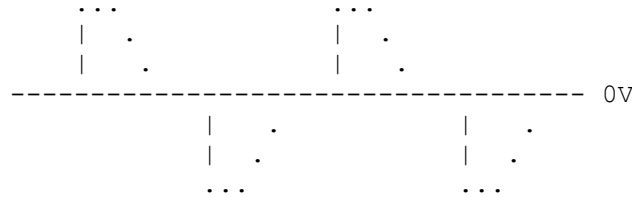
Solid-state light dimmers work by varying the "duty cycle" (on/off time) of the full AC voltage that is applied to the lights being controlled. For example, if the voltage is applied for only half of each AC cycle, the light bulb will appear to be much less bright than when it get the full AC voltage, because it get's less power to heat the filament. Solid-state dimmers use the brightness knob setting to determine at what point in each voltage cycle to switch the light on and off.

Typical light dimmers are built using thyristors and the exact time when the thyristor is triggered relative to the zero crossings of the AC power is used to determine the power level. When the the thyristor is triggered it keeps conducting until the current passing though it goes to zero (exactly at the next zero crossing if the load is purely resistive, like light bulb). By changing the phase at which you trigger the triac you change the duty cycle and therefore the brightness of the light.

Here is an example of normal AC power you get from the receptacle (the picture should look like sine wave):



And here is what gets to the light bulb when the dimmer fires the triac on in the middle of AC phase:



As you can see, by varying the turn-on point, the amount of power getting to the bulb is adjustable, and hence the light output can be controlled.

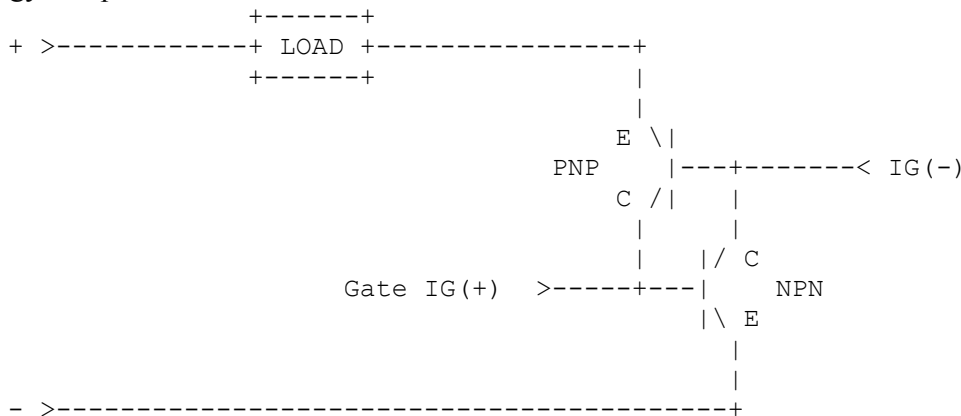
The advantage of thyristors over simple variable resistors is that they (ideally) dissipate very little power as they are either fully on or fully off. Typically thyristor causes voltage drop of 1-1.5 V when it passes the load current.

What are thyristors and triacs

A Silicon Controlled Rectifier is one type of thyristor used where the power to be controlled is unidirectional. The Triac is a thyristor used where AC power is to be controlled.

Both types are normally off but may be triggered on by a low current pulse to an input called the gate. Once triggered on, they remain on until the current flowing through the main terminals of the device goes to zero.

Both SCRs and Triacs are 4 layer PNPN structures. The usual way an SCR is described is with an analogy to a pair of cross connected transistors - one is NPN and the other is PNP.



If we connect the positive terminal of a supply to say, a light bulb, and then to the emitter of the PNP transistor and its return to the emitter of the NPN transistor, no current will flow as long as the breakdown voltage ratings of the transistor are not exceeded because there is no base current to either.

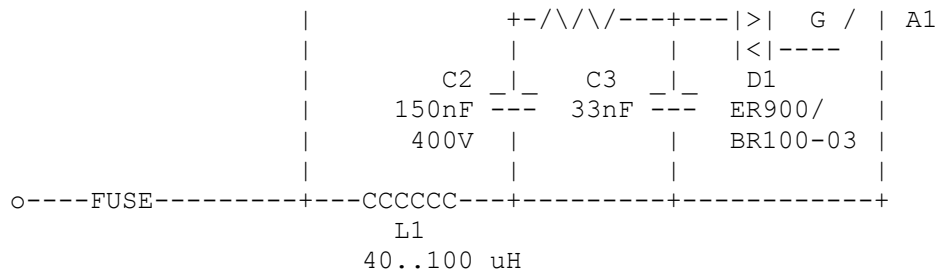
However, if we provide some current to the base of the NPN ($IG(+)$) transistor, it will turn on and provide current to the base of the PNP transistor which will turn on providing more current to the NPN transistor. The entire structure is now in the on state and will stay that way even when the input to the NPN's base is removed until the power supply goes to 0 and the load current goes to 0.

The same scenario is true if we reverse the power supply and use the $IG(-)$ input for the trigger.

A Triac works basically in a similar manner but the polarity of the Gate can be either + or - during either half cycle of an AC source. Typically the trigger signals used for triggering triacs are short pulses.

Incandescent lamp physics

A typical incandescent lamp take power and uses it to heat up a filament until it will start to radiate light. In the process about 10% of the energy is converted to visible light. When the lamp is first turned on, the resistance of the cold filament can be 29 times lower than it's warm resistance. This characteristic is good in terms of quick warmup times, but it means that even 20 times the steady-state current will be drawn for the first few milliseconds of operation. Lamp manufacturers quote a typical figure for cold lamp resistance of 1/17 th of the operational resistance, although inrush currents are generally only ten times the operational current when such things as cable and supply impedance are taken into account. The semiconductors, wiring, and fusing of the dimmer must be



Potentiometer P1 in this circuit is used for controlling the dimmer setting. The trimmer P2 is used for setting the dimming range (how much light can be dimmed maximally). When the circuit is tuned, the P2 should be adjusted so that then P1 is in it's maximum resistance setting (light most dimmed) the light bulb is just dimmed completely out. This adjustment makes sure that the dimmer circuit dims smoothly from zero to maximum setting. If P2 is tuned to too much dimmed preset position, the circuit does not dim nicely up from light off setting or the operation when P1 is in it's maximum value is unpredictable. If you have adjusted P2 to too low value, you just can't dim the light bulb completely off (in some times this can be an intentional setting, for example in theatrical lighting where preheat is used).

Component list:

- C1 150 nF 400V capacitor (preferably X rated capacitor)
- C2 150 nF 400V
- C3 33 nF 400V
- D1 ER900 or BR100-03 diac
- P1 500 kohm linear potentiometer
- P2 1 Mohm trimmer
- R1 2.2 kohm 1/2W
- R2 6.8 kohm 1/2W
- TH1 TIC226D triac (400V, 8A, Igt/lh<10/<60mA)
- L1 Filtering coil 40-100 uH, 4.5A or greater current handling capacity
- FUSE 5A fast

When building thw circuit remeber to put a small heatsink to the triac TH1, because without proper cooling it can't withstand the full dimmer 1 kW power (around 4.4A of current). If you don't put the heatsink, the maximum available power from the circuit is around 300W. The coil L1 must be able to withstand continuous current of at least 4.5A and it can have any value between 40 and 100 microhenries. For C1 I would recommend a good quality 150 nanofarad capacitor designed for mains power applications (propably an X-rated capacitor), because a low quality capacitor does not withstand in this kind of place for too long time.

Safety issues on building the circuits

Because light dimmers are directly connected to mains you must make sure that no part of the circuit can be touched when it is operating. This can be best dealt by building the dimmer circuit to small plastic box. Remeber to use potentiometer with plastic shaft and install it so that no potentiometer metal parts are exposed to user.

Remeber to make circuit board so that the traces have enough current carrying capacity for the maximum load. Make sure that you have enough separation between PCB traces to withstand mains voltage. Remeber to install correct size fuse for the circuit. The fuse shield be ast acting (F) if you want to give any protection to TRIAC (do not use FF or T types). Make sure that all components can handle the voltages they face in the circuit. For 230V operation use at least 400V triac (600V better). The capacitor which is connected between the dimmer circuit mains wires should be a capacitor which is rated for this kind of applications (those are marked with letter X on the case).

Remeber to use coil type which can handle the full load current without overheating or saturating. Use capacitors with enough high voltage rating. Make sure that the TRIAC has enough ventilation so that it does not overheat at full load. For safety reasons it is a very good idea to put an overheating protector to the light dimmer circuit to protect the dimmer circuit against dangerous overheating caused by poor ventilation or slight overloading, because a fuse does not provide a good protection in this kind of cases.

Even though the light can be completely turned off using triac or thyristors, those components are not generally considered to be reliable enough to be used as light switches which remove the dangerous voltages from the light circuit when needed. In small light dimmer there is typically a switch which is built into the light dimmer control potentiometer. In large dimming systems the switching is typically done using a separate contactor or relay.

Tips on selecting components

Triacs and thyristors are sensitive to overcurrents. When dimming normal light bulbs, short circuits caused when filament burns are quite probable. For this reason, light dimmers must have their own fuse which protect it against failures in this kind of situation.

Thyristors have a defined overcurrent handling capacity and the fuse must be selected so that it burns before the thyristor in overcurrent situation. This typically means that the thyristor/triac must have a current rating of 2..5 times bigger than the rating of the fuse in order to be sure that the fuse burns before thyristor/triac in case of short circuit. The fuse type must be also fast enough to burn in this case before the thyristor/triac. In some cases it might be necessary to use special fuses to be able to protect the components effectively.

The thyristor must have a high enough surge current rating also for normal operation. For example in case of normal light bulb dimming of a light bulb with cold filament is turned on at 90 degrees after zero crossing (means at maximum line voltage peak), the peak current can be 20 times bigger than the nominal current of the lamp.

Radio frequency interference details

The modern thyristor (Triac or SCR) dimmer has one fairly severe drawback in its performance in that it dims by switching on the current to the load part-way through each mains cycle. Cutting the leading smooth-part off a mains cycle produces a current with a very rapid turn-on time which generates both mains distortions and EMI. Chokes are included in dimmers to slow down the rapid switch-on (rise time) of the chopped current. The longer the rise time the less EMI and mains distortion produced.

Turn on of the triac in the middle of the phase causes fast voltage and current changes. A typical thyristor/triac starts to fully conduct at around 1 microsecond time after triggering, so the current change is very fast if it not limited in any way. Those fast voltage and current changes cause high frequency interference going to mains wiring unless there are suitable radio frequency interference (RFI) filter built into the circuit. The corners in the waveform effectively consist of 50/60Hz plus varying amounts of other frequencies that are multiples of 50/60Hz. In some cases the interference goes up to 1..10Mhz frequencies and even higher. The wiring in your house acts as an antenna and essentially broadcasts it into the air. Cheap bad quality light dimmers don't have adequate filtering and they cause easily lots of radio interference.

Dimmer circuits typically use coils that limit limit the rate of rise of current to that value which would result in acceptable EMI. Typical filtering in light dimmers causes the current rise time (current rises from 10% to 90%) to be in range of 30..50 microseconds. This gives acceptable results in typical dimmer applications in home (typically this limitation is made using 40..100 uH coil).

If the dimmers are used in places where dimmer is a serious problem for sensitive sound equipments (theatres, TV-studios, rock concerts etc.) a slower current rise time would be preferred. Typically the current rise time in light dimmer packs made for stage applications have a current rise speed of around 100..350 microseconds. If noise is a big problem (TV studios etc.), even slower current rise times are sometimes asked. Those current rise times up to 1 millisecond can be achieved with special dimmers or suitable extra coil fitted in series with the dimmer.

The coil itself does not typically solve the whole problem because of the self-capacitance of the inductor: they typically resonate below 200 kHz and look like capacitors to disturbances above the resonance frequency. That's why there must be also capacitors to suppress the interference at higher frequencies.

If your dimmer circuit cause interference, you can try to filter out the interference by adding a small capacitor (typically 22nF to 47 nF) in parallel with the dimmer circuit as near as possible to the electronics inside the circuit as possible. Keep in mind to use a capacitor which is rated for this kind of applications (use capacitors marked with X). Keep in mind that the filter capacitor and it's wiring make a resonance circuit with certain resonance frequency (typically around 3.6 MHz with 0.1 uF capacitor). The capacitor does not work well as filter with the frequencies higher than the resonance frequency of the circuit.

Power harmonics caused by dimmers

All phase control dimmers are non-linear loads. A non-linear load is one where current is not in proportion to voltage. The non-linear load on dimming systems is caused by the fact that current is switched on for only part of the line cycle by a phase control dimming system. This non-linear load creates harmonic distortion on the service feeder.

Harmonics are currents that occur at multiples of the power line voltage frequency. In Europe where line frequency is 50 Hz the 2nd harmonic frequency is 100 Hz; the 3rd harmonic is 150 Hz, and so on. In North America where line frequency is 60 Hz the 2nd harmonic frequency is 120 Hz; the 3rd harmonic is 180 Hz, and so on.

Excess harmonic currents cause conductors and the steel cores of transformers and motors to heat. Odd-order harmonic currents (specifically the 3rd harmonic) add together in the neutral conductor of 3 phase power distribution systems. The 3rd order harmonic current present on the neutral is the arithmetic sum of the harmonic current present on the three phase conductors (this also applies to the 9th, the 15th and so on harmonics). Harmonics could theoretically elevate the neutral current to 3.0 times what is present on a phase conductor. With typical phase control dimming system connected to three phase feed, the harmonics normally elevate neutral current to about 1.37 times phase current. If the wires are not properly rated for this, neutral conductor overheating or unexplained voltage drops can occur in large dimming systems.

Sometimes the heating of the distribution transformer can be a problem, because transformers are rated for undistorted 50 Hz or 60 Hz load currents. When load currents are non-linear and have substantial harmonic content, they cause considerably more heating than the same undistorted current. In heavily dimmed system, you might not be able to utilize more than around 70 % of the rated transformer power rating because of harmonic induced heating. Additionally, transformers used to feed dimming systems are subjected to stress because of cold lamp inrush currents (can be up to 25 times normal current). Inrush currents and harmonics can drastically reduce the service life of the service transformer.

Eliminating the effects of harmonic currents in large light dimmer systems normally requires oversizing neutral conductors and derating the service transformer.

In a normal low power light dimmer case you don't have to worry much about the harmonics and transformer loads, because the light load of few hundred watts is clearly just a small fraction of the total transformer load.

Buzzing problems with dimmers

Each good dimmer has a filter choke inside. Those chokes help to filter out electrical noise that often causes hum to be picked up in sound system and musical instrument pick-ups. The slower the current rise is, the less noise is picked by sound system.

The chokes also help to eliminate 'lamp singing' that can cause audible noise to come from the lighting fixtures. Lamps with power rating of 300W or more tend to more or less acoustic noise when dimmed. If this acoustic noise is a problem can be removed by adding a series coil which limits the current rise time to around 1 millisecond.

In providing those filtering functions, the chokes themselves can generate a slight buzz. Fast current changes in the coil can make the coil wiring and core material easily vibrate which causes buzzing noise. A little bit of buzzing is normal with filtered dimmers. If the buzz from dimmer can be a problem it is recommended that the dimmer is placed in the area where this buzz will not be a problem.

As far as the 'bulb singing' concerned, a bulb consists of a series of supports and, essentially, fine coils of wire. When the amount of current flow abruptly changes the magnetism change can be much stronger than it is on a simple sine wave. Hence, the filaments of the bulb will tend to vibrate more with a dimmer chopping up the wave form, and when the filaments vibrate against their support posts, you will get a buzz. If you have buzzing, it's always worth trying to replace the bulb with a different brand. Some cheap bulb brands have inadequate filament support, and simply changing to a different brand may help.

Buzzing bulbs are usually a sign of a "cheap" dimmer. Dimmers are supposed to have filters in them. The filter's job is to "round off" the sharp corners in the chopped waveform, thereby reducing EMI, and the abrupt current jumps that can cause buzzing. In cheap dimmers, they've economized on the manufacturing costs by cost-reducing the filtering, making it less effective.

In very high power dimming systems the wiring going to lighting can also cause buzzing. The fast current makes the electrical wiring to vibrate a little bit and if the wire is installed so that the vibration can be transferred to some other material then the buzzing could be heard. The buzzing caused by the vibration of the wiring is only problem in very high power systems like theatrical lighting with few kW of lights connected to the same cable. Better filtered dimmers can reduce the problem because the filter makes the current changes slower so the wires make less noise.

Why does dimmed lighting sometimes hum, and how can it be corrected?

Because of the way all dimmers deliver power at settings other than full brightness, the filaments inside a light bulb may vibrate when lighting is dimmed. This filament vibration causes the hum. To

silence the fixture, a slight change in the brightness setting will usually eliminate bulb noise. The most effective way to quiet the fixture is to replace the light bulb.

How can I avoid the buzzing the dimmers cause to my sound system ?

There are numerous ways that dimmer noise can get into audio systems and it's largely trial and error in determining what in particular is causing your problem and hence how to fix it. The principle ways are either back up the mains or induced into your audio equipment or cables.

What you hear typically in audio system is common mode noise on the hot and neutral, the spike of turn-on of the scr. The higher the rise time of the current in the dimmer, more noise is sent to the mains wiring. So well filtered dimmer will generate less noise problems.

Reduce the possibility of it coming up the mains by taking a totally separate mains supply from the lighting, if possible get a totally separate power socket (or sockets) run in for sound from wherever the electricity board intake is. If this is not possible, then an isolation transformer stops quite much of the noise on the secondary side (better with shield between coils). So put the sound system on the isolation transformer and tie to earth (ground) almost no problems. This assume that sound wiring is correct, especially shielding is done well and ground loop are avoided.

To reduce the possibility of interference induced to the audio cables, run all non speaker level audio cables as balanced lines (or certainly all of any length). You might have to buy balancing transformers if your kit isn't balanced already. Also keep them as far away physically from any lighting cable runs as you can. Make sure that your system does not have any harmful ground loops. Make sure none of your audio kit is anywhere near the dimmer racks.

Now can I dim up the lights smoothly ?

With many cheap dimmers, the lights "Pop On" rather than dim up smoothly. This problem is usually related to the construction of the dimmer electronics. One technique used in some cheap dimmers to allow dimming up smoothly is to place another potentiometer (trimmer) across the control potentiometer. That trimmer potentiometer is set so that the dimmer works smoothly:

- a)Set "Control" to Minimum light level.
- b)Adjust "Trimmer" to filaments JUST "glow"
- c)Turn off dimmer
- d)Turn on dimmer to see if filaments "glow". IF not... set trimmer up a snit.... go to c)

Continue until minimum voltage/current is supplied to lamps (filaments do not seem to glow at all). When everything is properly adjusted, the dimmer circuit will nicely dim up from the lowest setting up to maximum brightness.

Are those household dimmers usable as stage lighting dimmers ?

If you want to make a multichannel lighting desk, you might sometimes wonder if such nit can be built from cheap household dimmers. Unfortunately most cheap household dimmers are no use for stage lighting. The limitations in this kind of use came from performance, power rating, reliability and interferences.

Typically the cheapest dimmer won't fade up smoothly from zero, but come on suddenly at about 20%. You can fade down smoothly, but once they go off you have to go back up to 20% to make them come on. There are some dimmers which perform better than other.

The cheapest household dimmers are typically not well filtered, so the interference caused by a multichannel dimming board built in this way can easily cause a sound system to buzz.

Then in many cases the power rating of household dimmers can be a problem. Usually the household dimmers have a power rating of around 300W, which is not enough for any powerful stage light which can easily be 500W in power.

Cheap household dimmers do not track with each other well. This means that at the same setting, the lamps on one circuit will appear to be twice as bright as those on the other circuit.

Dimming inductive loads

Normal light dimmers are designed to only dim non-inductive loads like light bulbs and electric heaters. Normal light dimmers are not suitable to dim inductive loads like transformers, fluorescent lamps, neon lamps, halogen lamps with transformers and electric motors. There are special dimmers available for those applications.

If you connect inductive loads to the dimmer the dimmer might not work as expected (for example does not dim that load properly) and can even be damaged by the voltage surges generated by the inductive load when current changed rapidly. Another problem is the phase shift between the voltage and current caused by the inductance. If you use a normal simple light dimmer which is just in series

with the wire going to the load, this will cause that the dimmer circuit will not work properly with highly inductive loads. Special dimmers which have a separate controlling electronics connected to both live and neutral wire and then the triac which controls the current to the load usually work much better with inductive loads.

Often when inductive loads cause problems on normal dimmers, you can eliminate said problems by patching an incandescent "ballast" load in parallel with the inductive load. Usually 100W is enough for many inductive loads. Remember that inductive loads can hum quite noticeably when dimmed and the transformers can heat more because of increased harmonics content in the power coming to them.

Dimming lights with built-in transformers

Fully loaded halogen transformers usually dim quite well. If you are planning to dim halogen light transformers, try only dim traditional transformers, because toroidal core transformers do not usually dim well. Most of the cheap halogen light transformers belong to this category as well as the transformer in for example PAR36 pinspot lights. For this kind of transformer it is necessary that the current after the dimmer is still symmetric, so that there is no DC component formed to the transformer which can cause the transformer core to saturate (and lead to overload and finally destruction of transformer). Some of the cheapest light dimmers might not be very good on symmetry, but good quality light dimmers designed for also inductive loads should not have symmetry problems.

When dimming transformers with in any way questionable type do dimmer for inductive loads, it is a good idea to put a fuse in series with the transformer primary so that it will blow when transformer tries to get too much power from the line. This will protect the transformer from overheating which might be caused because of transformer core saturation (which might be caused by small DC bias caused by not very well operating dimmer). A proper fuse will save transformers from burning out. Anyway a normal transformers which feed light loads are dimmable with good quality dimmer which can handle at least some amount of inductive load usually without much problems. Anyway it should be mentioned that when a transformer is dimmed in this way, it can heat somewhat more than in normal operation (full power without dimming). Other thing worth to mention is that when a transformer is dimmed, it usually produces noticeably more audible noise than in normal operation (noise depends on used transformer).

If your halogen light system uses an electronic transformer then you must very carefully check if it can be dimmed. Some of the electronic transformers are made dimmable and work well with traditional light dimmers. The ones which are not meant to be dimmed can be damaged by the dimming and even damage your dimmer.

Dimming fluorescent lights

If you try to dim fluorescent light on normal dimmer you have to turn the dimmer full on to make the light to turn on and you can only dim it down only down to 30-50% brightness. For anything less than this you will need a special dimmers and special fluorescent fitting.

Dimming electric motors

Typical dimmer packs will supply power to motors and make them run, but the dimmers aren't designed for it. Some dimmers can be damaged by connecting inductive loads to them. And when the triac fails half-wave it takes the motor out too. A good idea to protect motor failures is to use a fuse sized for the motor load in series with the motor. This fuse will probably burn before motor is damaged if it is sized correctly.

Light dimmers designed for inductive loads work quite well with universal or AC/DC type motors. Typically, these have brushes and are used in electric drills, vacuum cleaners, electric lawn edgers etc. With this kind of motors a proper dimmer works well.

The motors used in electronics fans are quite likely induction motor which are not very well controllable. Those motors in most fans are square-law devices, most of the speed control will be at the end of the dial but that would be true with any control. The "dimmers" designed for ceiling fan speed control work quite well and also some normal light dimmers designed for inductive loads. If the dimmer approach not satisfactory, then remember that electric motors are usually is best controlled by a small variac, tapped transformer, rheostat, series light bulbs, etc. which do not mess up the sinusoidal waveform. Even this method does not help in controlling a synchronous motor, which always tries to rotate at the same speed synchronous to mains power.

Dimming switching power supplies

Electronic loads like switching power supplies are not generally designed to be dimmed. If you take for example a typical switching power supply to a normal light dimmer, trying to do that might result to cause damages to the dimmer and/or the power supply itself. The power supply might get damaged because it has never been designed to operate on other waveforms than quite much sinewave (other waveforms can cause current spikes). The dimmer can be damaged by the high current surge what a switching power supply takes when the triac on dimmer starts to conduct in the middle of the phase. The "electronic transformers" used to power the 12V halogen lamps which are very fashionable for indoor lighting. Those "transformers" are small switching power supplies which just chop the mains at about 40kHz, so a small ferrite core can be used for the isolation and the voltage step-down (to 12V RMS).

Generally it not a good idea to try to connect this kind of "transformer" to a normal light dimmer unless that "transformer" is a type which is designed to operate correctly with a normal light dimmer (in that case the fact is said on instructions of the "transformer" or it's case). There are for exapmle some small transformers available which say "dimmable with normal light dimmer", so those can be used without any problems with normal light dimmers.

Other "electronic transformers" I would not try to dim with a normal phase controlling light dimmer to avoid possible equipment damages. Quite many electronics transformers (but not all) which can't be dimmed with normal light dimmer can be dimmed with transistor based reverse-phase type dimmers. I have read success stories on this, but never tried this method myself. If you are planning to use this method, then it is best to check that the electronic transformers you have dim nicely and you have a right kind of dimmer for them.

Some of the more expensive "transformers" incorporate a very neat dimmer functions also, operated by external controls, so with those there is no need for any external dimmer (just controls).

How touch dimmers work ?

The basic dimmer operation principle is the same as in dimmers above. The only difference is how the dimemr is controlled. The rouch controlling is done using a special control IC and touchable metal plate. The dimmer usually has a metal plate which is coupled to the circuit via a high value resistor (>1Meg Ohm). Your body acts a little like an antenna and couples 50Hz mains signal (or 60 Hz depending on country) into the circuitry. The AC signal is fed to a shaping circuit(converted to a square wave) and then usually into a dimmer IC.

A typical touch dimmer has following circuit parts:

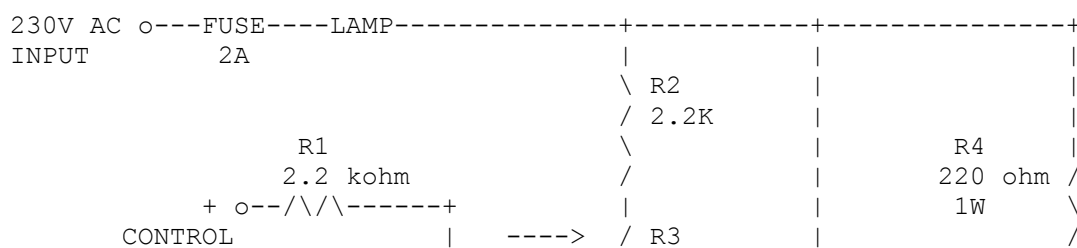
- A special timing circuit which senses if the contact on the touch plate was long or brief. In operation, a momentary touch of the sensor plate with the fingers (50 - 400 ms) will toggle the light ON or OFF depending on its previous state.
- A memory circuit which stores the intensity level of the lights.
- A circuit which generates the pulses necessary to vary the light intensity
- Touch dimmers which typically control the TRIAC in a 45°C to 152°C conductivity region of the mains half period while the IC draws its power from the remaining power up to the 180°C of the half period.

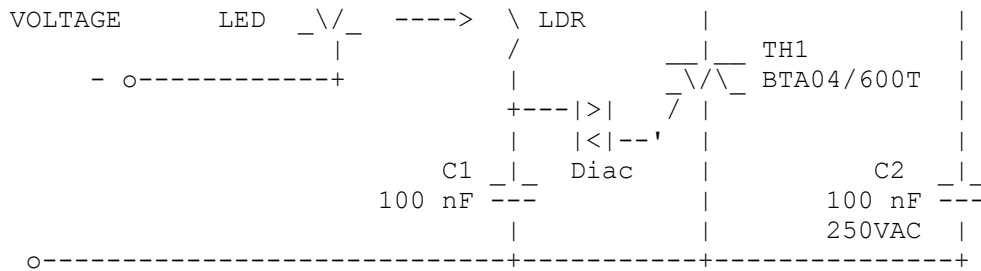
Siemens is one of the companies who supply these IC's (for example SLB-0586). The IC itself will function differently depending how long you touch the plate for.

Advanced dimming systems

Lighting dimmers use phase-control - you switch on at a point on the supply voltage waveform after the zero-crossing, so that the total energy input to the lamp is reduced. The time between zero crossing and switching is controlled by external control interface which is most often 0-10V DC control voltage or digital DMX512 interface.

Simple voltage controlled dimmer





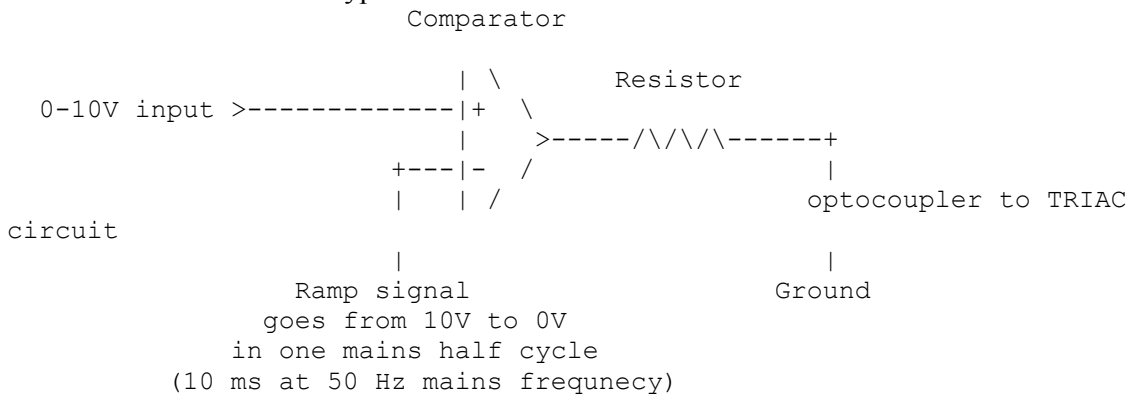
This circuit can control loads up to 2A (460VA). The circuit is basically a normal light dimmer circuit, but the potentiometer is replaced with LDR resistor which changes its resistance depending on the light level. In this circuit a LED powered from control voltage source is used for shining variable intensity light to the LDR, so you must make sure that LDR does not receive light from other sources.

This circuit is basically very simple and not very sensitive on what LDR is used as R2. The disadvantage of this circuit is that the control is not very linear and the different dimmers built around this circuit can have quite varying characteristics (depending mainly on the LED and LDR characteristics). The control voltage is optically isolated from the dimmer circuit connected to mains. If you need a safety solution then remember to have enough distance between the LED and LDR or use a transparent isolator between them to guarantee good electrical isolation. If the dimmer sensitivity is not suitable with the circuit described above, then you can adjust the value of R1 to get the control voltage range you want.

This circuit is a part of an automatic light dimmer circuit published in Elektor Electronics Magazine July/August 1998 issue pages 75-76.

Professional voltage controlled dimmers

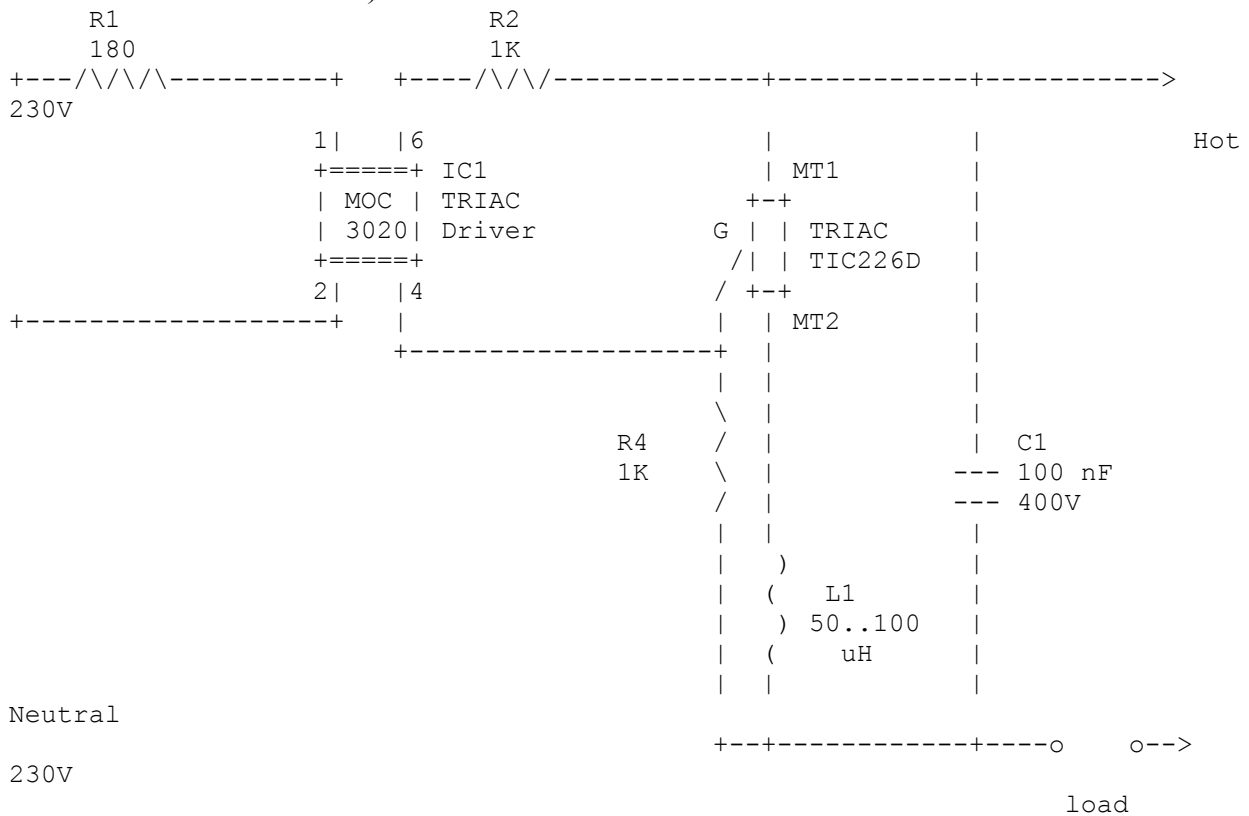
Remotely controlled light dimmers in theatrical and architectural applications typically use 0-10V control signal for controlling the lamp brightness. In this case 0V means that the lamp is on and 10V signal means that the lamp is fully on. A voltage between those values adjusts the phase when the TRIAC will fire. Here is a typical control circuit schematic:



The circuit works so that the comparator output is low when the input voltage is higher than the ramp voltage. When the ramp signal voltage gets lower than the input voltage the comparator output goes high which causes that current starts to flow through resistor to optocoupler which causes the triac to connect. Because the ramp signal starts at every zero crossing from 10V and goes linearly to 0V at the time of one half cycle the input voltage controls the time when the triac is triggered after every zero crossing (so the voltage controls the ignition phase). The necessary linear ramp signal can be generated by a circuit which discharges a capacitor at constant current and charges it quickly at every zero crossing of mains voltage.

You can use your own circuit for triggering the TRIAC or you can use a ready-made semiconductor relay for this (it comes in compact package and provides optoisolation in same package with TRIAC). If you plan to use ready-made solid-state relay you need an SSR WITHOUT zero-crossing switching. You need an inductor in series with the switching element (SSR or triac) to prevent di/dt problems and help to cut down emission of r.f. noise. Values vary typically from 40 uH to 6 mH: they are usually specified in terms of the rise-time of the switch-on edge. Typical home light dimmers use coil of 40..100 uH, which gives 30..50 microsecond rise time. Larger coil values give longer rise time values. Note that the rise time approximation is only rough because the inductors used are non-linear: the inductance varies with load current.

The optocoupled TRIAC triggering circuit can be for example constructed using MOC3020 optodiode and some other component. Here is one example circuit (part of dimmer circuit from Elektor Electronics 302 circuits book):



Most professional stage-lighting dimmers do use solid state relays. They have more in them than you would expect, usually including opto-isolation of the control input. The exact contents are commercially confidential but the operation of voltage controlled version is very similar to the idea described above.

Many professional light dimmers have also extra adjustments available for make them work better in their operating environment. One typical setting is preheat. When preheat is used a small (adjustable) current is always passed through the light bulbs even though the light channel is set off at the lighting desk. This preheat current keeps the lamp filaments warm (but not warm enough to give considerable light output) so that the current surge when lights are turned on again is reduced. This reduced current peak increases the life of the light bulbs.

Another adjustment available in some dimmers is response speed setting. A dimmer's response speed is the time it takes for the dimmer's output to arrive at a new level after it receives the new level setting instruction from the control desk. This time is typically measured in milliseconds. Typical response speeds available on dimmer products are in range of 30..500 milliseconds. A fast response speed is useful in light effects and concert lighting. In studio uses the light need not typically have to change very rapidly, so it might be a nice thing if dimmer goes slowly from old setting to new value. A slower response speed has beneficial effects on lamp life, since the shock to cold filaments will be reduced, as the time period required to ramp then to full brightness is increased.

Some light dimmers have also a setting to adjust the control voltage range. 0-10V controlling is the most common way to do the controlling of small dimmer systems, but there have been also other voltage levels in use. If the dimmer has an adjustment which voltage range it takes, it can be adjusted to work correctly with many different light control desks.

The simplest form of the controlling is that the voltage directly controls the phase when the triac conducts. This works, but is not the best response from the control potentiometer to the dimmer module. For this reason different manufacturers have developed many different response curves from the control voltage to the dimmer output. Here are some of the most common ones:

- Linear: The output phase varies linearly with the input (greatest light level variation between 30% and 70% settings)
- Square: The output power varies linearly with the input (square law ramp standardized by United States Illuminating Engineering Society). At setting of 50% you will see a light level of around 50% of maximum.
- S curve: A modified form of Square with greater control in the centre of the range

- True power: The output power varies linearly with the input voltage so that the lamp get 50% of it's nominal power on 50% setting (used more on industrial control than in light dimming)
- Exponential ramp: Light output varies most in the contro range of 70% to 100%
- Relay: The output switched to the full when the input exceeds 25% of the full control voltage (with some equipment the limit is 50%)

Nowadays some advanced commercial dimmers support many of those control voltage response curves so that the user can set the dimmer to use the mode which is the most convient for the user in the particular application.

Phase controlling using microprocessor

If you want a digital control of light dimmer you can use a simple microcontroller to do the phase controlling. The microcontroller has to first read the dimmer setting value through some interface (commercial digital dimmers use DMX512 interface). typically the control value is 8 bit number where 0 means light off and 255 that light is fully on.

The microcontroller can easily generate the necessary trigger signal using following algorithm:

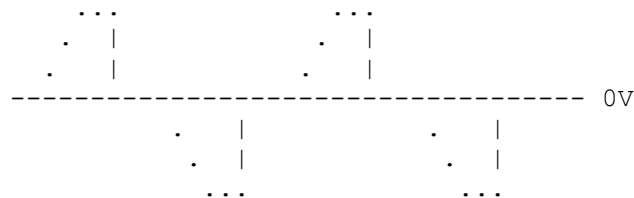
- Convert the light value to software loop count number
- First wait for a zero crossing
- Run a software loop which waits the necessary time till it time to trigger the TRIAC
- Send a pulse to the TRIAC circuit to trigger the TRIAC to conduct

Software loop is quite simple method and useful when you know how long time it takes to execute each microprocessor command. Another possibility is to utilize microcontroller timers:

- You can generate an interrupt at every zero crossings and every timer count.
- At every zero crossing the microcontroller loads the delay value to the timer and starts it counting.
- When the counter time has elapset it generates an interrupt. The timer interrupt routine sends a trigger pulse to the TRIAC circuit.

Reverse phase control

Reverse phase control is a new way to do light dimming. The idea in reverse phase controlling is to turn on then switching component to conduct at at every zero crossing point and turn it off at the adjustable position in the middle of the AC current phase. Tming of the turn-off point then controls the power to the load. The waveform is exact reverse of that is used in traditional light dimmers.



Because the switching component must be turned off at the middle of the AC phase, traditional thyristors and TRIACs are not suitable components. Possible components for this kind of controlling would be transistors, FETs, IGBTs and GTO-thyristors. Power MOSFETs are quite suitable components for this and they have been used in some example dimmer circuits.

Reverse phase controlling has some advantages over traditional dimmers in many dimmer applications. The manufacturers of inverse phase dimmers advertise their products to be more efficient and less noisy. Using proper controlling electronics it is possible to build a reverse phase dimmer without any magnetics or vibrations caused by them.

Because turning on point is always exact at the zero phase there are no huge current spikes and EMI caused by turn on. Using power MOSFETs it is possible to make the turn-off rate relatively slow to achieve quite operations in terms of EMI and acoustical or incandescent lamp filament noise.

Variable transformer as dimmer

One old approach for dimming of lights is do it by using variable transformer (Variac or similar brand) as a dimmer. Some of these are made specifically for this application - they'll fit into a double-size wall box (maybe even into a single-size wall box if you get a small one) and will handle several hundred watts. They're heavy and mechanically "stiff" (compared to a triac dimmer) and not cheap - but they put out a nice, clean 60 Hz sinewave (or very near to it) at all voltages, and don't add switching noise.

Other not so good ideas for dimming

Zero cross switching will minimize noise in switchign and dimming. Unfortunately that appriach is not very practical for lampi dimming. At 60 Hz line frequency, you'd be limited to turning the lamp on and off at discrete 120 Hz intervals. You'd easily end up with a rather nasty 15-20 Hz flickering, unless the dimmer-driver can do some sort of dithering to spread out the flicker spectrum. I've never seen a dimmer of this sort being used.

In some occasions a single diode can be to dim a light bulb when wired in series with the lamp. The diode then passes only the positive or negative half of the mains voltage to the light bulb. If you put a switch in parallel with the diode, you end up having a dimmer wich has two settings: full on and dimmed. Diode will indeed work on small loads, but with larger loads the DC component this diode causes is not good for the distribution transformers in the electrical distribution system (will cause them them to heat up more than in normal use).

European EMC requirements on dimmers

NOTE: The following information is taken from the discussion from sci.engr.electrical.compliance newsgroup discussion at February-March 2000. The facts have not been checked against any standard documents, but I suspect that the information is quite much correct because most of the writers of the articles where experts on the field (for example John Woodgate) and the information makes sense to me.

Harmonics

Mains harmonics are typically tested from mains frequency up to 2 kHz frequency (2.4 kHz in 60 Hz countries). Phase controlled dimmers up to 1 kW do not need to be tested for harmonics. There is no point, because the harmonics are very predictable and there is nothing much the designer can do to reduce them.

Professional (as defined in IEC/EN61000-3-2) dimmers over 1 kW up to 3680 W are also not subject to limits.

Dimmers above 3680 W, which are all professional, come under the future IEC/EN61000-3-12, and it is still being discussed whether they need to have an Rsce (as defined in IEC61000-3-4) limitation or not.

Conducted emissions

Light dimmers need to meet conducted emission standards. Conducted emissions start at 9 kHz for some products and for dimmers the applicable standard for those is CISPR15/EN55015. That standard is applicable to lighting equipments and an accessory for a luminaire (like a light dimmer is).

There is no exception in CISPR15/EN55015 standard (which now applies, rather than CISPR14/EN55014). Dimmers for household use need to meet Class B limits, but Class A should be OK for professional dimmers. The conducted emissions are mostly harmonics and can exist up to megahertz frequecny region.

To meet the conducted emission limits is not very easy, especially for professional dimmers. The choke hardly helps, because a typical filtering self-resonates at around 100 kHz (higher for low-power household dimmers). Above those frequencies the coil does not suppress the high frequency harmonics. This means that it is often necessary to sprinkle quite large (up to 1 uF) capacitors around the circuit to reduce the emissions. In professional dimmers this demands that inductances in the wiring be reduced to a minimum, otherwise the caps and wiring inductances resonate and emissions go up instead of down.

A lot of manufactureres of professional dimmers ground thyristors heat sink, effectivly coupling RF noise into the earth lead. This will reduce the radiated emissions and there might be safety considerations to do that. The downside of the RF (harmonics) coupled to ground wire is that in some cases the inductance of the earth lead is so high that the appliance case carries a noticeable voltage.

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