Proposed SSR Technology Questions
Answers to Proposed Questions

1) What fundamental attribute distinguishes a Relay from a Switch? What element (component) in the SSR is responsible for this attribute, what SSR specification represents this attribute, and what are the typical values for this specification?

   Electrical Isolation between input and output. The optocoupler provides electrical isolation. Input to output isolation voltage specification. I/O isolation values are between 1500 VAC and 4000 VAC.

2) Define the difference in switching means between an Electromechanical Relay (EMR), a Solid State Relay (SSR), and a Hybrid Relay (HSR). For a 25 amp application, which type device has the least initial cost, and which has the highest initial cost?

   EMRs utilize electromechanical means with moving parts. SSRs are all solid state and have no moving parts. HSR relays combine both technologies. An EMR has the least initial cost while HSR have the highest initial cost.

3) What SSR characteristic prevents it from being applied in applications requiring Safety Interlocking (complete disconnect), and what are the typical AC values for this parameter at 25 C ambient, with and with out an RC snubber network?

   Off-state leakage current prevents SSRs use in circuits requiring a complete disconnect. Typical leakage values are 5 to 15 mArms with snubber, and < 1 mA without snubber.

4) What semiconductor components constitute the output of a typical DC output SSR, and what components constitute the output of an AC output SSR?

   Transistors are used in DC output relays, including FETs, while thyristors, triacs and SCRs, are used in AC output SSRs. Inverse series FETs can be used to make AC output SSRs, but are very expensive.

5) Define or describe ‘zero voltage turn on’ (or zero voltage switching/synchronous operation) and ‘random turn on’ (or instant turn on/asynchronous operation). What element (component) in the SSR determines this feature’s functionality?

   Zero voltage turn on refers to a control circuit which after the presence of a control signal, only permits the relay’s output to switch on load current if the AC line voltage is inside of a preset value near the zero voltage point. Random turn on refers to a control circuit that energizes the relay’s output irrespective of the value of the AC line voltage at the time of turn on command. The optocoupler(s) design and selection determine the zero or random function.

6) What term or specification quantifies ‘zero voltage turn on’, and what are typical values for this specification.

   ‘Window’ voltage or ‘inhibit’ voltage. Upper limits of this value vary from manufacturer to manufacturer, but are generally over the range of 15 to 40 volts. Note: the actual minimum value that the relay may turn on at (the so called lower value of the window) is determined by the coupler forward voltage drop combined with the gate current characteristics of the output devices and series impedance in the trigger circuit. This value is typically from 2 to 10 volts and is referred to as trigger voltage.

7) What 3 load attributes determine the use of zero verse random turn on SSRs in a given application?

Inrush current/cold filament effect; Power Factor; Required response time (phase control).

8) Define or describe the term ‘power factor’ including the range of numerical values associated with the specification. Provide a typical range of power factor values for resistive loads, and a typical range of values for reactive loads.

Power Factor is the cosine of the phase angle between voltage and current with numerical values between 1.0 (purely resistive) and 0.0 (purely reactive). Note: the cosine of 0 degrees is 1.0, and the cosine of 90 degrees is 0. Loads, which are resistive typically, have Power Factors between 1.0 and 0.8, while reactive loads are generally less than 0.8. However, the range of 0.9 to 0.7 may contain either type load. Note: whether a load is considered as resistive or reactive load is determined by the nature of the load itself, not the Power Factor.

9) List the recommended range of power factor values for the application of zero turn on and random turn on SSRs.

Zero voltage is recommend for use on loads with Power Factors from 1.0 to 0.8. Random relays are recommended for loads from 0.5 to 0.1. Either may be used for loads 0.8 and 0.5, depending on the actual application.

10) Describe ‘phase angle control’ and ‘integral cycle control’, and determine the type of SSR function appropriate for each application (zero or random).

Phase angle control refers to a control technique that provides a means of varying power to a load by altering the point in an AC half cycle where load current is permitted to flow through the relay. Each successive half cycle is varied in the same manner. More current can be provided to the load by increasing the portion of each half cycle that the relay is in the on-state.

Integral cycle control refers to a control technique that provides a means to vary power to a load by providing increasing or decreasing amounts of complete AC half cycles of load current. More half cycles effectively provides more power to the load.

Random turn on relays are used for phase control circuits because the turn on point is determined by the timing of the control to the relay’s input. Zero turn on relays are used in integral cycle control because they provide an easy means of achieving full half cycles of current. Note: it is possible to use random turn on relays in integral cycle control circuits by timing the control signal with the zero crossing points of the AC line.

11) What is the typical turn on response time for zero turn on SSRs? For random turn on SSRs?

Response time for zero turn on relays is one half AC cycle (8.33 mS for 60 Hz and 10 mS for 50 Hz). Random relays respond in less than 0.1 mS for any line frequency.

12) With respect to the AC line frequency and load characteristics, when does an AC output SSR switch off current to the load. What element (component) provides this feature and why? How would this feature be of benefit in an application?

AC output SSRs using thyristors shut off at the zero current point. The thyristor itself is responsible for this attribute due to the bi-stable nature of the component and its ability to remain latched in conduction so long as current above its holding current value continues to flow through it.

This feature is very beneficial because it eliminates transients resulting from breaking the flow of current, especially in reactive loads.

13) What are the two main functional electrical elements of an optical coupler? How is the input to the coupler energized?

The two main elements are the emitter diode on the coupler's input, and the detector/switch on the coupler's output. The input LEDs are energized with DC current, typically from 2 to 10 mA DC.

14) Name the 2 basic types of control inputs available in SSRs. With respect to question (13) above, how is current from an AC input SSR provided to the optical coupler?

SSRs are available with either AC or DC input controls. In the case of AC input SSRs, the AC signal is rectified and filtered with capacitors to provide a DC signal. In some cases, this rectification is full wave and in others it is half wave rectification. AC input SSRs are slower to switch on due to the time it takes for the AC signal to be converted to a useful level DC current to the coupler input LED.

15) What is a 'regulated input circuit', why is it incorporated in SSRs, and what advantages/disadvantages does it offer?

A regulated input circuit refers to an input circuit design that contains circuitry to deliver a more or less constant amount of current to the coupler input LED and visible input status indicator if included. This circuit provides a greater amount of LED drive current at lower input voltage levels, while providing a means of dissipating and thereby limiting excessive LED currents at higher input voltage levels.

Regulators are available for regulating either DC or AC input voltages over a wide range of values. However, one drawback is in applications that have limited control circuit current less than 3 mA DC. This limitation is fundamentally a problem with the coupler input current requirements verse the actual regulator itself.

16) What is 'output voltage drop', what are typical values for this parameter, how does it relate to power dissipation in the output assembly?

Output voltage drop is the residual voltage across the semiconductor's main terminals while conducting load current and is due to the impedance of the semiconductor material in the on-state combined with its junction drops and any ohmic resistance of mechanical interconnections. Power dissipation in the output assembly is determined by the product of the forward voltage drop and forward load current (e.g.: 1.2 volts x 10 amps = 12 watts).

17) Define 'output breakdown voltage' (or blocking voltage), list typical values, and describe how this parameter relates to off-state leakage current.

Output breakdown voltage is the voltage that can be applied across the relay's output terminals in the off-state without partial or full load current conduction. Breakdown voltage is determined either by the value of voltage that results in arcing or complete conduction, or is in excess of a specified value of leakage current. Typical values of breakdown voltages would be 600, 800, 1000, 1200 volts peak. Note: for AC output SSRs, output breakdown voltages are specified with peak AC values. i.e.: 600 volts peak is 424 VAC (424 x 1.414 = 600).

Output breakdown voltage is normally associated with the output semiconductor, but any internal component in the SSR that is subjected to the line voltage, such as opto coupler, bridge diodes, snubber capacitors, etc., may breakdown.

Breakdown voltages are directly related to leakage currents. The leakage current is specified at a defined applied output voltage and vice versa. Current in excess of the specified value or at the specified value, but below the prescribed voltage, is considered as a breakdown.

18) What relationship exists between output breakdown voltage and output voltage drop of the output?

With respect to the output semiconductor, generally as you increase breakdown voltage, the forward voltage drop increases. The reason for this is that the normal means of increasing breakdown voltage is to increase die thickness, which results in a higher on-state impedance/voltage drop. Note: one of the major compromises made in the design of an SSR pertains to this aspect of the output. It is desirable to increase breakdown voltage for transient immunity. However, since increased breakdown voltage often results in higher voltage drops, more power is created in the output semiconductor raising its temperature for a given application. Increased temperature makes the device more susceptible to dv/dt, di/dt, surge current and I squared t failures.

19) What is ‘dv/dt’ and how does this parameter apply to AC output SSRs? What functional failure can be attributed to dv/dt?

Dv/dt is the rate of rise of voltage across the SSR’s output. The normal failure mode is for the relay to go into load conduction or fail to stop conducting load current. Often, the relay’s output will half wave.

20) What is the difference between ‘static dv/dt’ and ‘commutating dv/dt’? With respect to load types, when does each apply and what are typical SSR specifications/values for each parameter?

Static dv/dt is also known as turn on dv/dt because a static dv/dt failure is when the relay should remain off, but goes into conduction as a result of a sudden change in voltage (e.g.: initial application of line voltage). Commutating dv/dt or turn off dv/dt occurs when the SSR is expected to stop conducting load current but continues to carry load current as a result of a high rate of rise of voltage at the moment of turn off due to a large voltage/current phase shift associated with reactive loads..

Both failures are a result of junction capacitance in the SCR or triac. A sudden change in voltage across the semiconductor’s main terminals results in an internal current flow sufficient to charge the junction capacitance. This current flow, if sufficient, will cause the device to avalanche into conduction without a gating signal, or remain conducting if in the on-state.

Static dv/dt failures can occur with any SSR if the voltage across its output is low (typically 0), and then suddenly increases at a very high rate as when power is first applied to the SSR’s terminals. Commutating dv/dt failures are exclusively associated with turn off of inductive loads where there is a significant phase shift due to the power factor of the load. While conducting, the SSR has a voltage across the semiconductor equal to the forward voltage drop, typically 1.2 volts, and then must rise to value of the line voltage when turning off. If there is a significant phase shift, the voltage may be as high as peak line voltage.

Static dv/dt is associated with all types of loads/applications. Commutating dv/dt is only associated with inductive loads. Typical values for each are 200 v/uS or more for static dv/dt, and 50 v/uS for commutating dv/dt. Note: it common to only publish static dv/dt values in data sheets…..

21) How does an RC snubber network effect dv/dt? Is there any relationship between snubber values and off-state leakage currents?

RC networks are placed across SSRs outputs to increase both static and commutating dv/dt capabilities of the relay. The voltage across a capacitor can not be changed instantaneously, so a sudden increase in voltage results in current flow through the snubber network which appears as a low impedance to the voltage source, loading and dropping the voltage, thus reducing the rate of rise of voltage the semiconductor sees. Larger capacitors result in greater reduction of dv/dt, requiring larger wattage resistors to withstand the current and protect the capacitor from destruction.

RC snubber networks add AC off-state leakage current to any SSR where they are included. The leakage current value is directly related to the size of the capacitor. The larger the capacitor value, the greater the dv/dt rating is improved, but the leakage current also increases proportionally. Note: the largest component of AC off-state leakage of an SSR incorporating an RC network is due the RC network.

22) What relationship exists between dv/dt and the physical size of a thyristor, and why?

The dv/dt capability of a semiconductor is related to junction capacitance. The greater the capacitance, the lower the dv/dt. Larger dies have larger junctions and therefore greater junction capacitance. Therefore, the dv/dt values of large dies are generally lower than smaller dies.

23) Define ‘thermal impedance’ and describe how it pertains to the performance of SSRs. What are typical values of thermal impedance for SSRs?

Thermal impedance is the inverse of thermal conductivity and represents the value of the resistance of materials to heat energy transfer through them. Lower values of thermal impedance mean that thermal energy is more easily transferred through the material and the temperature differential from one end of the material to the other is relatively lower than in higher impedance materials.

Thermal impedance is a critical aspect of the design and application of SSRs. The thermal impedance of an SSR represents the relay’s ability to transfer internally generated power in the output of the SSR out of the relay and into an external heat sink. The lower the thermal impedance, the lower the operating temperature of the relay for any given application. The lower the temperature, the more reliable the SSR.

Typical values of thermal impedance for SSRs vary from as high as 15 C/W for PCB mounted relays, down to 0.1 C/W for panel mounted power relays. Typical value for a 50 amp panel mounted relay would be 0.25 C/W. The difference in die temperature internally to the base plate would then be calculated by multiplying the load current times the forward voltage drop time the thermal impedance.

24) How is output power dissipation calculated in the SSR?

Output power dissipation in the SSR is calculated by multiplying the forward voltage drop across the SSR by the load current through the SSR.

25) What is ‘di/dt’? Describe the effects of exceeding an AC output SSR’s di/dt ratings.

Di/dt is the rate of change of current with respect to time through the SSRs output semiconductor. Generally, di/dt becomes a factor in high inrush loads or under short circuit conditions. Typical values are on the order of 10 amps/uS for 25 amp relays.

The consequence of exceeding the relay’s di/dt rating is that a hot spot is created in the semiconductor die material and it melts, destroying the structure and creating a permanent short in the device.

26) There are 2 fundamental SCR designs with respect to gate design: Center gate and Corner gate. Why are they referred to in this manner and what relationship exists between di/dt and these 2 designs? What relationship exists between these 2 designs and dv/dt?

The designs are referred to as center and corner gate because that is physically where the gate circuit and contact point are located on the die. Generally, it is accepted that the di/dt ratings of center gate dies are slightly higher than corner gate dies, because the area immediately adjacent to the die where conduction begins is greater than for corner gate devices. The reverse is generally true for dv/dt….that is, corner gate dies generally have slightly higher dv/dt ratings because junction capacitance associated with the gate area is somewhat lower.

27) What is I squared t? How is it calculated? How is it different from di/dt?

I squared t is the fusing current for the output semiconductor. It is a calculated value based upon the manufacturer's published single cycle surge current for the device. It is intended to represent the amount of energy that device can withstand before the silicon melts and fuses open.

I squared t is calculated by determining the peak single cycle surge current (which is typically 10 times the rated continuous forward current), dividing it by the square root of 2 to get rms., squaring that number and then multiplying it by the time for a half AC cycle (8.33 mS for 60 Hz or 10 mS for 50 Hz).

The difference between di/dt and I squared t is that di/dt is a rate of change of current and not necessarily associated with excessive amounts of current and generally results in a shorted die. I squared t failures by definition results in an open device.

28) What is the relationship between I squared t and die design?

I squared t values increase with die size. However since fusing is a result of melting of the silicon, it is also related to operating temperature. Therefore, any increase in temperature including higher power dissipation due to higher voltage drops, or higher thermal impedance, or higher operating ambient temperatures or minimal heat sinks, will tend to reduce the I squared t value in the actual application.

Certain applications with significant inrush currents may require the selection of an SSR based upon the I squared t rating rather than the traditional forward current rating. Also, fuse selection to protect the SSR or load should be coordinated with the relay's fusing rating (protective fuse's rating should be lower than the relay's rating).

29) How are SCRs electrically connected to provide an SSR output? How does this compare to the use of a triac?

SCRs are gated by connecting the gates together through the trigger circuit. Triacs are gated by connecting their gate through the trigger circuit to the triac's anode.

30) What are the primary differences between triacs and SCRs? What range of rating values are available for each? What is the relationship of die size to rating?

An SCR is intended to switch DC. Therefore, 2 are required to switch AC, which is accomplished by wiring each SCR in an inverse parallel connection. Triacs are intended to switch AC and are effectively 2 SCRs wired as noted above, but in one package. The integration is done at the die diffusion level and there are not 2 distinct SCR devices in a triac. Voltage drops for triacs are typically 25% higher for a given load current than SCRs.

SCRs are available with breakdown ratings over 1200 volts, where as triacs are limited to 800 volts maximum. Therefore, high voltage AC applications require SCR output relays.

An equivalently rated triac and SCR die similar in size, but since 2 SCRs are required to carry AC current, there is twice the conduction area for SCR SSRs than for triac SSRs. Consequently, thermal performance is better for SCR relays as is di/dt, dv/dt, inrush current capability and I squared t….in other words, every critical parameter is better for SCR output relays than for triac output relays.

However, the cost of a triac is only slightly higher than an equivalent SCR, but 2 SCRs are required to constitute a relay and therefore an SCR output SSR is more costly than a triac output SSR.

31) When would a triac be suitable, and when would an SCR output be advisable, and why?

Due to their lower cost but reduced capability, triac output SSRs should be applied in lower power and less demanding applications, in particular those with low inrush current requirements and line voltages less than 250 VAC. SCR relays are appropriate for all applications except those with cost limitations. In general, triac output SSRs should be limited to applications with less than 25 amp loads and line voltages under 250 VAC.

32) Name the main elements of the thermal impedance of the SSR.

The main thermal impedance junctions in the SSR are the solder joint between the die and output lead; the output lead itself; the solder between the output lead and the insulator; the insulator itself including bonded cladding material; the solder joint between the insulator and the base plate; the base plate itself.

33) Name the 3 elements of the thermal impedance of the SSR in an assembly.

The 3 main elements constituting the thermal impedance of the SSR application are the impedance of the SSR; the impedance of the thermal interface material between the relay and external heat sink; and the external heat sink.

34) What is the maximum allowable temperature of the SSR's output in degrees C? Where does this limit come from and what effect is there on operating the SSR above this temperature?

Generally, the maximum allowable temperature of the SSR's output is based upon the rating of the output semiconductor's rating. For existing SCRs and triacs, this rating is 125 C maximum die temperature. For transistors, it is generally 150 C maximum die temperature. However, a new generation of SCRs and triacs is being developed that allow operating temperatures up to 140 C or higher die temperatures.

Operating the SSR's output near the maximum limit has the effect of reducing several parameters including dv/dt, di/dt, surge current, I squared t, and most notably, reliability and life expectancy due to thermal fatigue of solder joint issues. Operating the output above the maximum allowed may have the effect of the relay's output latching on due to regeneration of charges in the dies at higher temperatures (the relay goes into thermal run away).

35) What is thermal fatigue and its consequences? How can it be avoided or minimized?

Thermal fatigue is the failure of a material or mechanical connection (typically a solder joint in SSRs) as a result of repeated flexing or expansion and contraction of the materials or connections due to thermal heating and cooling. The effect depends upon the particular connection or material, but in every case, it results in an incorrectly functioning relay. Note: reliability of SSRs is now mostly related to thermal fatigue issues. Operating the SSR at a constant temperature, even if it is higher than ambient, has the effect of extending relay life expectancy.

36) Calculate the expected die temperature for a relay operating in the following conditions and state whether this is an acceptable application of the SSR:

SSR thermal impedance of 0.2 C/W
Output voltage drop of 1.2 volts
Output load current of 12 amps
Thermal interface material value of 0.05 C/W
External heat sink rating of 1.5 C/W
Ambient air temperature of 45 C

Answer = 70.2 C calculated as follows: 0.2 + 0.05 + 1.5 = 1.75 C/W thermal impedance. 1.2 volts times 12 amps = 14.4 watts of dissipation. 14.4 watts times 1.75 C/W = 25.2 C temperature rise. 25.2 + 45 = 70.2 C.

37) Assuming a 50% duty cycle for the application described in (36) above, what would be the expected output die temperature?

Answer = 57.6 C calculated as follows: 25.2 C temp rise on the die times 50% = 12.6 C. 12.6 + 45 = 57.6 C. Note: this is a generally accepted means of calculating the temperature rise based upon duty cycle.

38) Assuming the conditions for the application described in (36) above, and a 125 C maximum allowable output die temperature, what would be the smallest allowable heat sink for the application?

Answer = 5.3 C/W calculated as follows: 125 – 45 = 80 degree allowed temp rise. 80 divided by 14.4 W = 5.55 C/W thermal impedance. 5.55 - 0.2 – 0.05 = 5.3 C/W heat sink rating.

39) Assuming the conditions for the application described in (36) above, what would be the expected base plate temperature of the SSR? Is this allowed or recommended?

Answer = 67.3 C calculated as follows: 1.2 x 12 = 14.4 W. 14.4 W x 0.2 C/W = 2.88 C. 70.2 C – 2.88 C = 67.3 C. Yes, this temperature is less than 80 C which is the recommended maximum allowable base plate temperature. Note: the 80 C value is the recommended maximum, but not the absolute maximum. Each application has to be considered as it pertains to expected life and reliability requirements, etc. Maximum allowed opto coupler temperature is 100 C and this has to be considered in the relay's temperature.

40) What is the range of typical extruded heat sink thermal impedance ratings? What is the general relationship between the thermal impedance rating the heat sink and its surface area?

The typical range of extruded heat sink thermal impedances is 0.3 to 5.0 C/W. Generally, as the thermal impedance is reduced in half, the surface area is increased by a factor of 4.

41) What is the general relationship between thermal impedance and the physical size of a flat aluminum surface?

A 12" x 12" piece of .1" thick natural finish aluminum plate has an approximate thermal impedance of 1 C/W. A plate 24" x 24" has an approximate rating of 0.5 C/W. A 2.0 C/W rating would be a piece of aluminum approximately 6" x 6".

42) What is the effect on the SSRs di/dt rating and I squared t rating as its operating temperature increases?

All surge current related specifications reduce with increased temperature.

43) What is the effect on the SSRs reliability and life expectancy as thermal excursions are increased? Is it better or worse for the relay to operate at a constant 80 C temperature, or change from 25 to 80 and back to 25 every operational cycle?

Increased thermal excursions reduce the life expectancy of the relay due to fatiguing of the solder joints. It is generally preferred to operate a solid state device including a SSR at a constant temperature to get maximum life expectancy.

44) If a customer had an application to control heaters in a molding operation and was experiencing SSR failures determined to be shorts, what is the most likely cause of the failure and what are the 2 possible solutions most likely to address the reliability problem?

The most likely cause is di/dt failure causing shorted dies due to the repetitive current surges. The 2 best solutions to minimize the failures is to incorporate either a higher rated SSR or larger heat sink. The higher output rated SSR will have better di/dt capability, and a larger heat sink will reduce die temp

45) Define and describe EMI and its possible effect on SSR performance.

EMI is electro magnetic interference and refers to the radiated and conducted electrical noise/transients that may interfere with the proper operation of electrical and electronic equipment. EMI is generated by electrical and electronic equipment as well as natural events. SSRs are subject to EMI in various forms, and may result in improper SSR operation during the duration of the transient. The SSR by the nature of its use and application, is subject to EMI, and may react to it, but should not otherwise be effected or permanently altered by an EMI event.

46) What means are commonly applied to protect solid state devices from transients?

The most common means are using over voltage devices such as MOVs, transorbs or diodes (for DC) to shunt transients around the concerned devices. RC networks are also employed as by pass filters.

47) How does an overvoltage device such as a transorb or MOV react to a transient verses an RC network? Why and when would you apply either device?

Overvoltage devices switch on and maintain a voltage determined by the rating of the component and bypass current through them sufficient to maintain that voltage. Energy absorbed in the component is converted into heat which must be dissipated.

RC snubber networks present a low impedance to electrical noise depending upon the value of the capacitor and bypass the entire electrical event through them.

The major difference in effect is that the overvoltage devices react to amplitude, while RC networks react to rate of change of voltage.

48) What is the fundamental difference between a transorb and a MOV? What is the failure mode for each device?

A MOV is a ‘metal oxide varistor’ which is made from a metal oxide material, typically zinc oxide, and it dissipates energy in the grain structure of the device. They switch into conduction relatively slowly, but can dissipate large amounts of energy.

Transorbs are made from traditional semiconductor silicon material and are very fast to switch. They can handle large amounts of power, but only for short periods of time.

MOVs fail into a shorted condition, while transorbs typically fail open.

49) How does SSR output emissions differ from EMI susceptibility in SSRs?

Emissions are the noise that the SSR creates as a result of it switching load current on and off which is then injected into the power lines. Susceptibility refers to the relay’s reaction to transients carried on the power lines or in the air which contact the relay.

50) How are output emissions measured? What means are available to minimize or reduce them? What effect do these means have on the component selection and component parameters, and on the SSR design?

Conducted emissions are measured with a special metering system which covers a range of frequencies and compares the noise carried on the power lines with and without the relay's contribution. Radiated emissions are measured in a similar manner except that a radio receiver is employed to detect the radiated transmissions. It is common that all such measurements are taken in a shielded room.

The largest contributing factor to the AC output SSR's emissions is the switching on at the beginning of each half cycle. This turn on, which can result in a voltage spike between 3 and 12 volts, is the result of the various semiconductor junction drops in the trigger circuit and output semiconductor, as well as the required gate current for the output and series impedance in the gate circuit. Reducing the circuit impedance, or reducing the Igt value of the output device(s), reduces the turn on trigger spike and consequently, reduces emissions. Note: the most effective means of reducing the turn on trigger spike is to gate the output device with DC current through a source independent of the AC line. Devices such as this have been referred to as "class B" type relays because they are intended to meet the Class B emissions standard verses the class A standard.

51) What is the predominant failure mode of SSRs? How can failures of this sort be minimized?

The most common failure mode of an SSR is a shorted output, either half wave or fully shorted, caused by excess current flow or over temperature. The most common end of life failure is an open circuit as a result of thermal fatigue of solder joints.

In general, the best means to avoid such failures or prolong the life of an SSR is to operate it at the lowest possible temperature and avoid large temperature excursions. Applications that have repetitive current surges should incorporate SSRs with larger output dies to accommodate the heating caused by the surges.

52) What is the determining factor for long term life expectancy of an SSR? How does this differ from infant mortality and what are the likely causes of a relay failure in the first few days, weeks or months of operation?

Life expectancy is largely determined by thermal fatigue of solder joints. Infant mortality is associated with faulty components or assembly procedures, or with improper application of the SSR.

53) What is the best type of relay for a 3 phase resistive load application? Inductive load application? Why?

3 phase resistive loads should be switched with zero turn on SSRs. Inductive loads must be switched with random turn on SSRs due to the delay in turn on phase to phase with zero turn on, which can result in a locked rotor condition for motors, damaging the SSR and or load.

54) How does a packaged 3 phase SSR differ from 3 individual single channel relays? How does a dual SSR differ from 2 individual single channel relays?

Electrically, there is no difference between 3 individual relays and a packaged 3 phase relay, except that there is no means in a packaged 3 phase relay to control each phase separately.

Electrically, there is no difference between a 2 individual relays and a dual relay. As opposed to 3 phase relays, dual relays have the ability to control each channel individually.

55) Under what conditions if any, can a dual SSR be used to control a 3 phase load?

A dual relay can switch a 3 phase delta wired load by switching only 2 legs of the circuit.

56) How is the total power dissipation calculated for a dual or 3 phase relay application? What about multiple relays mounted on a single heat sink?

Total power is calculated by multiplying the voltage drop on each channel by the current through that channel and then adding the 3 power dissipation numbers together for a total package dissipation. Multiple relays on a common heat sink can be combined in a similar manner to determine overall dissipation. Total power dissipation can then be used to determine heat sink size.

57) What will happen if you place a DC line voltage on an AC output SSR? How might this be applied in a beneficial manner?

The relay will block the DC voltage and switch the DC current to the load when an input signal is given to the SSR. However, it will not shut off the current to the load when the input signal is removed. The relay latches on DC and the line must be opened to get the SSR to reset. This presents the possibility of using an AC output SSR as a latching relay in a DC circuit.

58) What precautions should be taken when applying an SSR to switch the primary of a transformer?

Transformer loads represent the worst case application for an SSR due to phase shift of the load, current surges and back EMF voltages. It is generally suggested that a SSR applied to a transformer primary should carry a voltage rating and current rating at least twice the transformers nominal rating.

59) What is minimum load current? What is a typical value of minimum load current for an AC output SSR? How would you determine if a relay was appropriate for any particular application? How would you determine if there was a compatibility problem? What role if any does a snubber network play in a low current application? What can be done about it?

Minimum load current is the least amount of current that the SSR will switch on and continue to carry with a nominal output voltage drop. Load currents less than this value may not be switched by the SSR. Typical minimum load currents are 50 to 100 mA rms.

One means of determining that there is a potential compatibility problem, aside from published specifications, is that the forward voltage drop across the relay will be in excess of the specification. Another means is that the load does not fully turn on or operate correctly. This is due to excess voltage drop in the SSR because it is not able to turn on fully.

A RC snubber network adds leakage current to the SSR. In cases where loads are very light, the snubber leakage current can become a significant percentage of the total load current. E.g.: a SSR with snubber leakage current of 10 mA would be 25 % of a 40 mA relay coil or solenoid. Generally, that is enough current to keep the load latched on. The best choice in such a case would be to employ a SSR with out a RC network, or at least an SSR with a small RC network. The alternative is to add a parallel bypass shunt resistor around the load to decrease the leakage current component going through the load.

60) What is an I/O module and how does it differ from a common SSR?

An I/O module is a normal SSR in a package designed to fit into a mass mounting system that permits interchangeability of functions. I/O modules are available in both outputs and inputs. An output module is exactly identical to a normal relay function. An input module is a relay that is intended to transfer status information as opposed to switching loads.

61) What difference if any is there between an OAC module and a SIP type SSR?

The only difference is in the packaging. There is no functional difference.

62) What considerations should be given to applying a plug in PCB mountable module in a solder in application?

The major consideration is that the plug in modules may not withstand the soldering/cleaning operation without damage.

63) What is the effect of moisture on a typical SSR? What parameter of the SSR is effected to the greatest extent?

Most SSRs are not designed to work in 100% humidity applications. Standard conditions are 98%. Condensed moisture may or may not effect the relays operation depending the amount of conductive contamination present in the moisture or on the surface of the relay.

The most significant effect on the SSR parameters pertains to the isolation from input to output and input/output to the base plate. In the worst case, a fault can result from input to output or output to ground.

64) Discuss the inclusion/exclusion of encapsulation materials (epoxy) on the design and application of SSRs.

Epoxy is a mixed blessing in SSRs. The advantages are mechanical integrity, moisture protection, insulation resistance and some improvement in thermal performance due to increased surface area. The major disadvantages are that it is expensive, creates significant mechanical stress due to thermal expansion and contraction, and tends to combust when subjected to sustained electrical arcs. Overall, unpotted SSRs are more reliable when applied in normal installations.

65) What is the recommended mounting screw torque for a typical panel mount SSR? What are the likely effects of under tightening and over tightening?

Normal mounting screw torque is 15 to 20 inch-pounds. Under tightening may result in increased thermal impedance between the SSR's base plate and the external heat sink, thus raising the relay's operating temperature and reducing its reliability. Over tightening the screws can deform the relay's base plate and result in the same problems as under tightening.

66) What are the 3 basic types of thermal interface materials commonly placed between the SSR and an external heat sink? What are their advantages/disadvantages with respect to each other?

The three common materials are: Thermally conductive compound such as Dow Corning 340; Aluminized thermal interface pad; Phase change material.

The conductive compound is readily available, but difficult to apply and control. Applied thickness of this material is critical to proper function. Aluminized pads are the easiest to employ, but are not as effective filling surface voids or imperfections. Phase change material is harder to use than pads, but easier than compound. It is the most expensive of the 3 materials, but it is far more effective as a thermal interface with thermal impedances on the order of 0.05 C/W or less.

67) What is the recommended input and output screw terminal torque specifications for typical panel mount SSRs? What is the effect of under tightening and over tightening?

The recommended torque for #6 input screws is 8 to 12 inch-pounds. The recommended torque for #8 output screws is 10 to 15 inch-pounds. The effect over tightening either screw is that the threads may fail or the screw break, leading in either case to improper operation. Loose screws on the input can lead to intermittent operation, but loose screws on the output can cause intermittent operation or significant heating of the connection and eventual failure including combustion.

68) What is ‘DBC’, where and why is it used in SSRs, and what advantages does it offer verses other materials?

DBC stands for Direct Bond Copper. In some cases, this material is also referred to as DCB or ‘fused copper’. DBC is a material/process that bonds copper sheeting to flat pieces of ceramic (Al2O3). It is used to produce electrical insulators used in high power applications requiring electrical isolation between the heat source and the metal heat conducting materials, such as the power output assemblies in SSRs.

The main attributes of DBC are that it mechanically strong due to the copper bonding and can therefore be somewhat thinner in thickness, thus reducing thermal impedance.

69) What is the practical limits on current flow through fast-on connectors and why?

For standard .25 inch connectors in ambient temperatures up to 80 C, 25 amps is the limit due to contact resistance heating. Higher currents up to 40 amps can be carried in lower ambient temperatures if care is taken to insure positive contact between male and female connections.

70) What is the difference between input to output isolation voltage and insulation resistance? Which parameter is specified in SSRs?

Input to output isolation voltage is the AC voltage that can be applied between the input circuit and output circuit without a breakdown. A breakdown is defined as current flow in excess of a specified value determined by Safety agencies such as UL and CSA. The UL requirement for breakdown is no more than 1 mA rms. of current. In practice, once leakage current exceeds 100 uA, the insulating material avalanches and an arc occurs.

Insulation resistance is a measure of DC impedance between input and output circuits measured in ohms with measurement voltage typically specified at 500 VDC.

SSR’s input to output isolation is typically specified in voltage, not impedance. However, if measurements were taken, common values would be in the range of 10 to the 8^{th} to 10 to the 12^{th} ohms.

71) What is input to output capacitance and why is it important in certain applications?

Input to output capacitance is the stray capacitance created in the circuit due to the PCB and its components. In most cases, the capacitance is on the order of 8 pico farads. I/O capacitance is significant only with respect to whether electrical noise carried on the power lines is coupled into the control circuits.

72) What is creepage distance and clearance distance internal to the SSR’s construction?

Creepage distance and clearance distances are measured over the surface and line of site distances between components and conductive surfaces in the input circuit to the output circuit, and both circuits to the metal base of the SSR.

73) Name the 4 basic types of opto couplers used to manufacture AC output and DC output SSRs

Optically coupled transistors, optically coupled SCRs, optically coupled triacs, and photovoltaic couplers (used in FET output DC relays).

74) What are ‘Rgk’ resistors? Where are they used and why?

Rgk resistors are resistors connected between the output SCR(s) or triac’s gate and cathode. Generally, they are used to provide a current shunt around the gate, thus increasing the current necessary to turn the output device on.

Assuming constant value trigger circuit impedance, this means a higher turn on or trigger voltage. The increased voltage effectively raises the noise immunity of the SSR. The resistors also have the effect of increasing dv/dt ratings due to the resistor's ability to discharge some of the output device's junction capacitance.

However, Rgk resistors are a mixed blessing because in the event of an open gate connection, the resistor will be subjected to load current when the trigger circuit is energized, and since the resistor is not sized to carry load current, it will fail catastrophically. This failure can often result in combustion because of the line voltage sustaining an arc.

Rgk resistors also have the effect of increasing conducted output emissions because they raise the trigger or turn on voltage value, the main contributor to SSR emissions.

75) Calculate the expected turn on (trigger) voltage of AC output SSR using SCRs and trigger circuit with the following parameters:

Igt = .05 mA (both SCRs)
Vgt = 0.7 volt (both SCRs)
Single opto coupler with 1.0 Vf drop
Trigger circuit impedance of 68 ohms.
No Rgk resistor.

Answer = 5.8 volts calculated as follows: .05 mA x 68 ohms = 3.4 volts trigger circuit drop. 0.7 x 2 = 1.4 volt SCR gate drop(s). 3.4 v + 1.4 v + 1.0 v coupler drop = 5.8 volts.

Note: this turn on or trigger voltage value constitutes the lower value of the zero turn on 'window'.

76) What is the suggested upper operating ambient temperature for SSRs and why is this limit important?

The upper limit is generally 80 C. However, this may be higher or lower depending upon power generated in the SSR during operation. Although the output semiconductors are capable of operating up to 125 C, the optocoupler are generally limited to 100 C. The 80 C limit is based upon the typical co-heating of the couplers caused by the output device and the 100 C limit.

77) What are the 2 main parameters to consider in selecting a fuse to protect an SSR?

Continuous current and fusing current are the two main parameters that must be considered in fuse selection.

Continuous current is self-evident: the fuse's rating must me greater than the highest normal current flow through the relay, yet below the relay's maximum rating. Note: this maxim may require the selection of a relay with a higher output rating than the load requires in order to accommodate available fuses.

Fusing current is calculated as a current/time relationship. For a fuse, this typically is given as a percentage of rated continuous current for a length of time. The fusing rating of the fuse must be less than the fusing rating of the relay, or the relay will not be protected as intended. To compare the fuse rating to the relay's rating, an effective I squared t value must be calculated for the fuse. E.g.: for a 10 amp AC fuse with a 200% /1 second rating, the effective I squared t value would be 20 x 20 x 1 = 400 amp squared seconds. The I squared t rating of a standard 10 amp SCR output SSR is 416 amp squared seconds, just slightly above the fuse's effective rating. In this case, as fuse with a lower rating or a relay with a higher rating would be preferred.

78) What are the typical values of RC snubber networks?

Snubber circuits for SSRs contain resistors in the range of 10 ohms to 200 ohms, but are typically in the 47 to 100 ohm area. The wattage of the resistor must be selected to accommodate the network's capacitor value, but are typically 0.5 watt. The resistor's role is to limit the surge current into the capacitor to just under the capacitor's maximum capability. This is done to afford the greatest rate of change of voltage protection provided by the capacitor without damaging the capacitor in normal use. Note: since the capacitor appears to be a short when voltage is first applied, the resistor will see the entire line voltage, so the voltage breakdown rating of the resistor must be at least the maximum line voltage rating for the relay it is protecting. Also, the voltage coefficient of resistance of the resistor should be considered in the selection of the type of resistor.

Snubber circuits for SSRs contain capacitors in the range of 0.010 to 0.22 microfarads, but are typically in the .033 to .10 microfarad range. Power dissipation of the capacitor must be considered in conjunction with the capacitor dielectric and snubber resistor value. Capacitors must be AC rated and capable of withstanding at least the relay's maximum specified voltage rating. Note: generally speaking, thickfilm capacitors can not handle as much power dissipation as discrete type devices and their use should be limited accordingly.

79) What is the relationship between AC leakage current through a RC snubber network in a SSR, and the AC line frequency?

Leakage current is proportional to frequency and capacitance and increases with frequency and capacitance. Leakage at 400 Hz will be substantially higher than at 50 or 60 Hz. As a result, a relay that includes an RC network and is designed for 50/60 Hz operation, may not be suitable for 400 Hz operation even though the semiconductor switching function of the relay performs satisfactorily.

80) How does the output current rating of a PCB mounted SSR differ from a panel mount SSR?

A panel mounted SSR has a number of thermal impedance's to consider including internal, thermal interface and external heat sink. A PCB mounted SSR has a number of internal elements contributing to its thermal impedance, but for simplicity, these are combined and this permits a direct relationship between output current and ambient temperature. Note: the thermal impedance for a typical single in line SSR is on the order of 12 to 20 C/W, Vs panel mounted SSRs which are on the order of 0.1 to 5.0 C/W.