Simple Solid State Loudspeaker Relay for Audio Amplifiers

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Simple Solid State Loudspeaker Relay (SSLR) for High-End Audio

This simple but very effective SSLR for audio amplifier applications is a bit unusual in that it switches the speaker ground return line, rather than the ‘hot’ side at the amplifier output which is the normal approach. Since it is the ground line that is being switched, gate drive is well within the amplifier supply rails and the mosfet drive circuit is as a result greatly simplified, obviating the need for opto-couplers or photo-couplers, and saving on components, space and cost; the direct drive results in very fast (by conventional relay standards) turn on and turn off times. Furthermore, the distortion using this technique is better than -150 dB reference an output voltage of 130 V pk-pk into 8 Ω; making is eminently suitable for high end applications.

1. Why Use an SSLR?

It is difficult to find cost effective relays that can be guaranteed to switch an amplifier output fault level current without catastrophic damage with 75 V rail and perhaps 30 or 40 A being a worst case scenario when a big amplifier has a short between its output and ground. When a big amplifier output stage fails short to either of its supply rails with a typical 4 Ω speaker load, currents in the order of 20 A can be expected. When operated within the device ratings, SSLR’s can switch fault level currents and voltages indefinitely – and here we are talking about low cost devices that can handle 40 or 50 Amps across 150 V. Importantly, there is *no* wear out mechanism with SSLR’s. There are drawbacks however. There is likely to some small amount of signal leakage, and ‘offness’ of -75 to -85 dB (1 kHz) is typically what is achievable. However, this only takes place when the SSR is in the mute condition (so amplifier ON, but speaker muted) and of course, the volume will have to be turned up for it to be audible – all in all not a serious issue, where the main function is to provide reliable fault condition switching and switch on/off anti thump muting. You also have to consider fail safety – we will return to this point a little later.

2. Minimum Requirements

For reliable operation, an SSLR should meet the following requirements:-

- Handle a fault level current of up to 50A (corresponds to a dead short on the amplifier output)
- Switch in less than 30 µs to cater for a short circuit condition on the amplifier output. This requires very good gate drive to the mosfet.
- Handle heavily inductive loads, with load dump capability of 500 mJ
- Suffer no wear out mechanism(s), unlike relays
- Easily interfaced into thermal protection, offset detection and switch on, switch off mute circuits
- Simple and low cost, avoiding the use of photo-couplers and/or opto-couplers in the *gate drive* (however, as we will see later, opto s can be used very effectively for the over current detection function)
- Recover after the fault is cleared or the system has been reset, thus emulating the behavior of an EM realy – so no fuses or circuit breakers to contend with
- Very reliable, since this speaker protection device stands between the amplifier and an expensive loudspeaker

3. Circuit Description

Referring to Fig 1, M1 and M2 are the main switches, connected back to back such that when ON, they will both conduct current in either direction, and when OFF they will block current flow in both directions. R5 provides a switched current from the Amplifier positive rail – assumed at 65 V in this example - to the gates of M1 and M2. D1 zener clamps the gates to 12 V, and R7 provides a low resistance discharge path for the mosfet gate capacitance to ensure fast turn-off behavior. This design will turn ON in under 5 µs, while the turn OFF time is under 25 µs. Both these figures are about 2 to 3 orders of magnitude faster than a typical power relay. In the OFF condition, the cathode of D2 is pulled to the amplifier negative rail, which effectively leaves the gates of M1 and M2 tied to their sources via R7 and both will therefore be OFF.

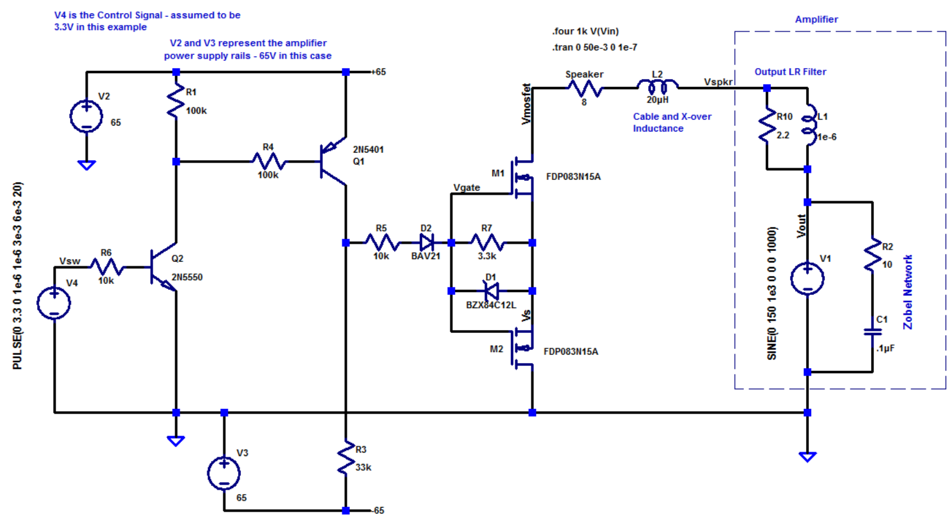

Figure 1 - SSLR Circuit Diagram. Note, this is the driver circuit only, and does not incorporate sensing of latching functions – these will be covered later

Figure 2 details the switching action of the SSLR under normal operating conditions. In the OFF

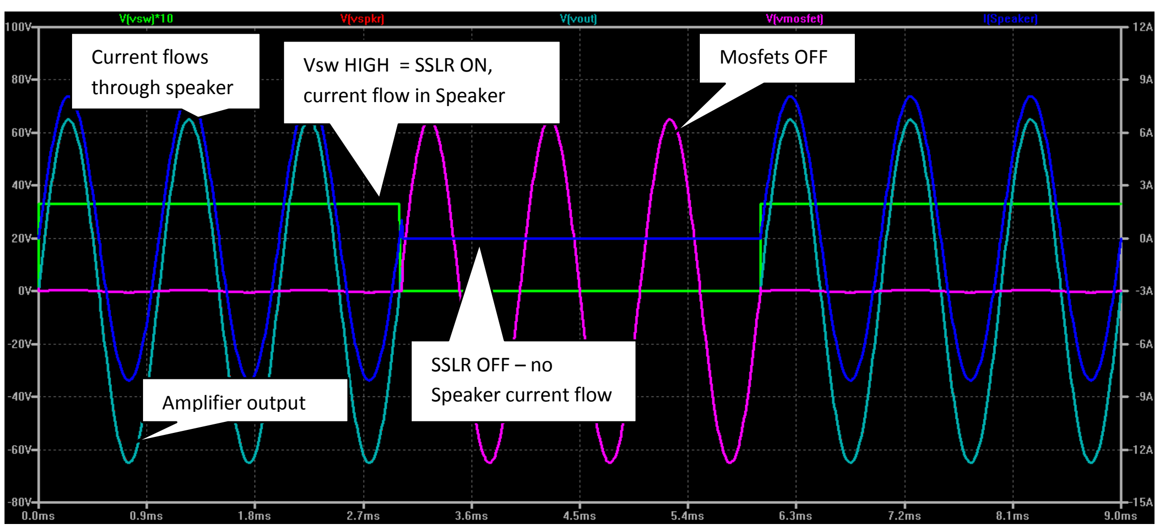

Figure 2 - SSLR Switching (Note Vsw scaled up by 10x to make viewing easier)

condition, the leakage current through the mosfets is about 160 uA ref 65 V peak output – not as good as a mechanical relay of course, but certainly good enough for this application.

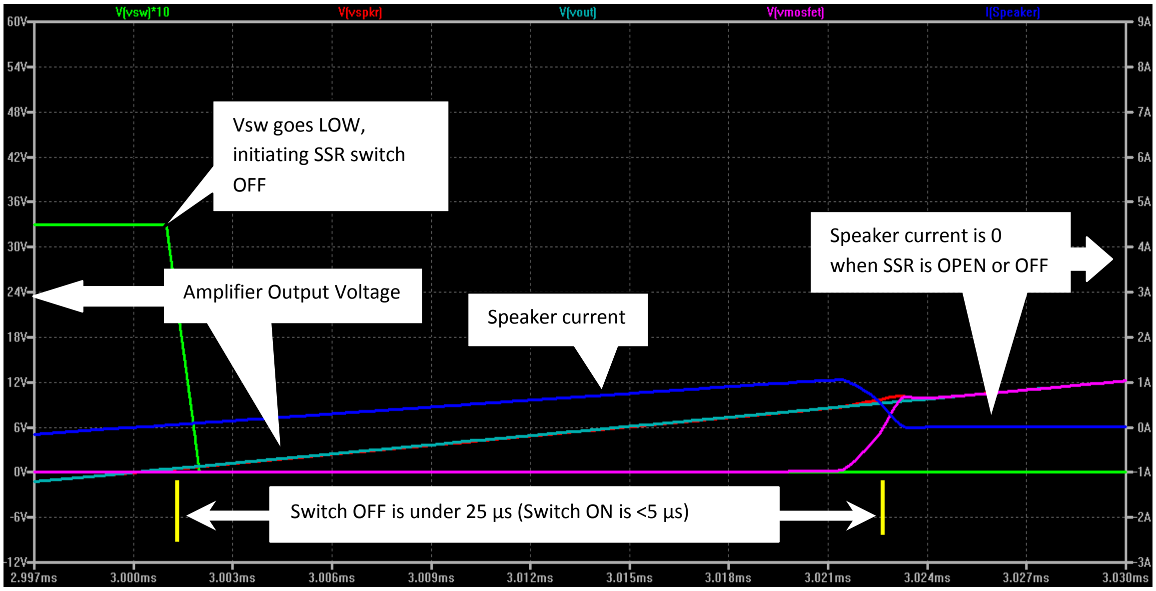

Figure 3 - SSLR Switching Performance – Turn OFF

Fig 3 details the turn OFF cycle, showing that this takes under 25 µs. The turn OFF time is limited primarily by the speed with which the mosfet gate charge can be removed such that Vgs falls below its minimum threshold level. In this design R7 is therefore deliberately selected for a low value to facilitate fast turn OFF.

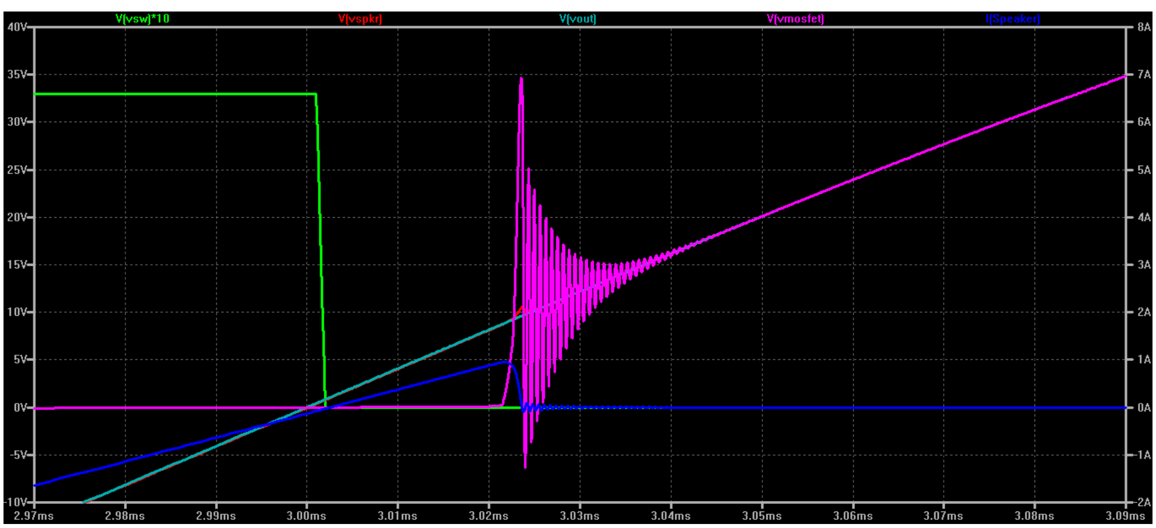

Figure 4 - Turn OFF Ringing

4. Energy Handing Capability

It's important to note that when turning OFF, there will be ringing caused by the tank circuit formed by the cabling plus speaker inductances and the mosfet drain-source capacitance (See Fig 4). Because M1 and M2 are connected in series, the capacitance is low (a few tens of pF), and the ringing frequency thus in the order of 1 MHz and upwards, depending on the specific mosfets being used. A snubber across the mosfets can alleviate this, but you will then have to deal with reduced 'offness'. Fig 4 shows the result with 20 µH of cabling inductance (assuming a short at the speaker end) in series with the SSLR, where the ringing (without any sort of snubber), typically lasts for about 20 ~ 30 µs. For much larger values of inductance and load current, there is enough energy to drive the drain of M1 above the amplifier supply rails. In normal applications, it is quite permissible to allow the mosfet (and here I specifically talk about trench mosfets that are characterized to handle inductive load dump) to avalanche and so dissipate the inductive energy. The recommended devices here have an avalanche rating of over 580 mJ, which means no free wheel clamp diodes are needed for this configuration. If we take a worst case situation of a short at the speaker output and a drain current of 50 A and 100 µH of cabling inductance, the total energy from $0.5*(LI^2)$ = 125 mJ – easily within the devices capability. Of course, if driving a normal load (i.e. no short), the currents will be much lower (peaking under normal conditions at perhaps 10 A) and the inductance higher.

Because of the ground return line switching configuration, gate drive remains well below the amplifier rails, in marked contrast to direct drive designs that switch the hot amplifier speaker output line. When in the ON condition, resistively biased SSLR's that switch the hot side of the amplifier need provide gate bias of about 10 V above and below the amplifier supply rails if they are not to limit output swing at the peaks. Of course, if using a photo coupler to drive the mosfet gates, then this does not apply, and hot side switches have no clipping or headroom output voltage swing issues.

5. Fail Safety

A word about fail safety is in order at this stage. If either of the amplifier rails fails in this design, the SSLR will end up conducting on one half of the signal and blocking the other – a rather problematic situation. For this reason, the SSLR power should be derived *before* any secondary rail fuses. Of course, there is always the possibility that the main bridge or one of the output caps fails, but in my experience, these components are usually very reliable. If the SSLR is being driven from a microcontroller based supervisory system, then it is a simple matter to cater for these eventualities and allow the system to gracefully shutdown.

6. Mosfet Selection

The correct types of mosfets for this application are trench technology types. These are designed for switching applications in SMPS (both PSU and motor control), hot-swap and synchronous rectification. They couple low $Rds_{(on)}$ figures with very fast switching times and are usually rated for inductive load dump, with figures up to 100's of mJ quite normal. Devices can typically switch many 10s of amps and Vds ratings from 30V to 800 V are commonly available, but for audio applications, Vds ratings between 100 and 200 V are the main area of interest. 150 V to 200 V Vds rated components that can switch >50 A and handle high levels of inductive energy load dump are ideal, and for large amplifiers (so 150 W to 300 W), these make perfect speaker SSR devices. Trench mosfets are not used in linear applications, since their SOA in the linear conduction mode is small compared to vertical and lateral types. For general purpose SSLR service for amplifiers up to 250 W, I recommend Fairchild FDP083N15A 150 V or equivalent devices. These feature an $Rds_{(on)}$ of c. 6.8 mΩ, and can switch up to 75 A; using two of them back to back in SSLR configuration yields a total end to end 'contact' resistance of under 15 mΩ. Importantly, they come in a TO-220 package, will easily handle up to 50 A fault current switch across a 150 V and will require no heatsinking for normal operation. For amplifiers of much lower power ratings – e.g. 100 W or less, lower Vds rated devices with lower $Rds_{(on)}$ specifications are available – and they are substantially cheaper.

Fig. 5 below shows the SOA for the FDP083N15A device. Given the switching speed of this SSLR, the fault load current switching capability extends all the way out to the devices 100 µs SOA envelope (highlighted in RED below) – i.e. very significant switching capability, and in all likelihood able to handle any fault condition.

Here is the full data sheet of the Fairchild device FDP083N15A

As a general point, note that not under *any circumstances* can the Vds rating of the mosfets used be exceeded. The devices must be rated to carry the full +- rail voltage, plus some safety margin.

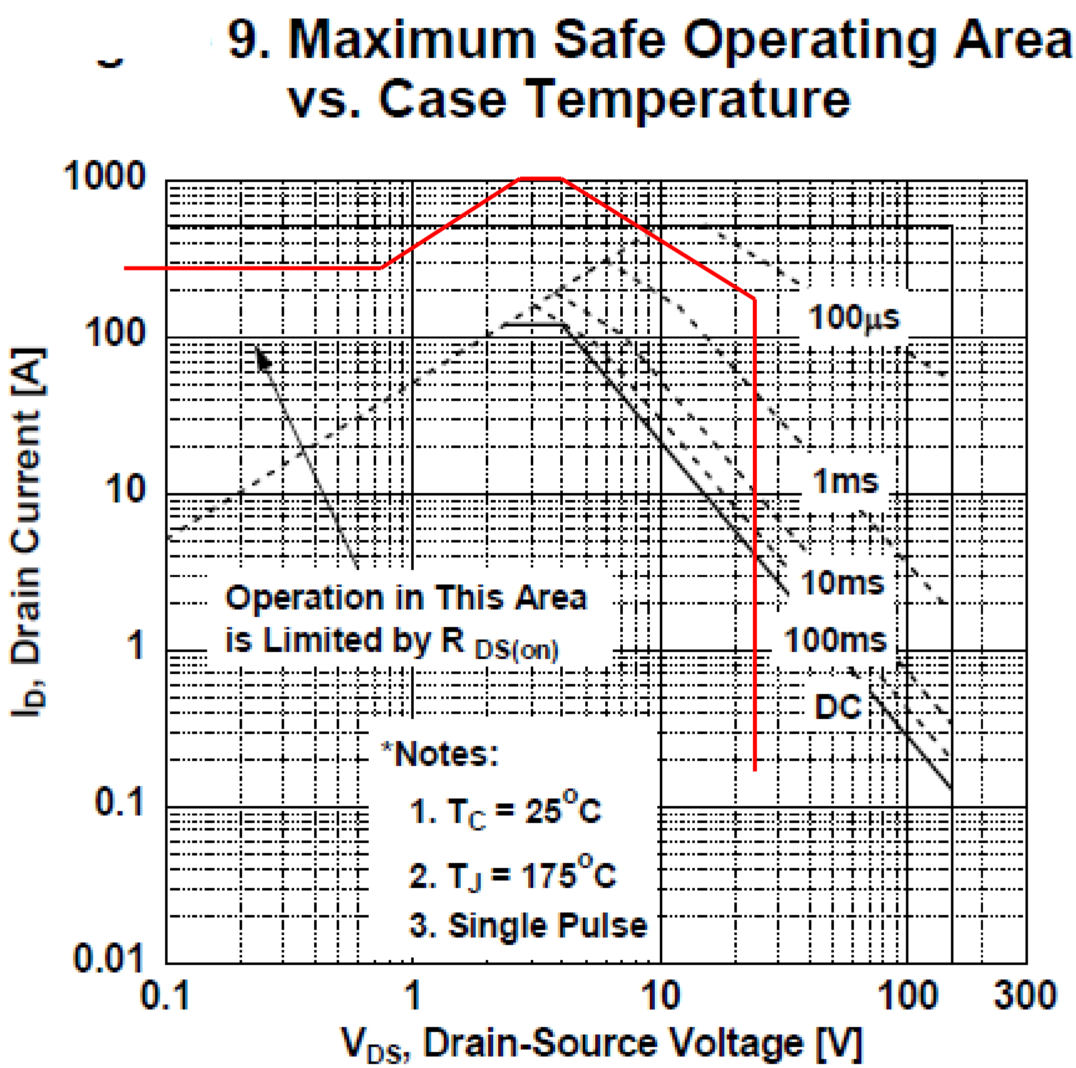

Figure 5 - Fairchild FDP083N15A SOA Curves

6. Distortion Performance

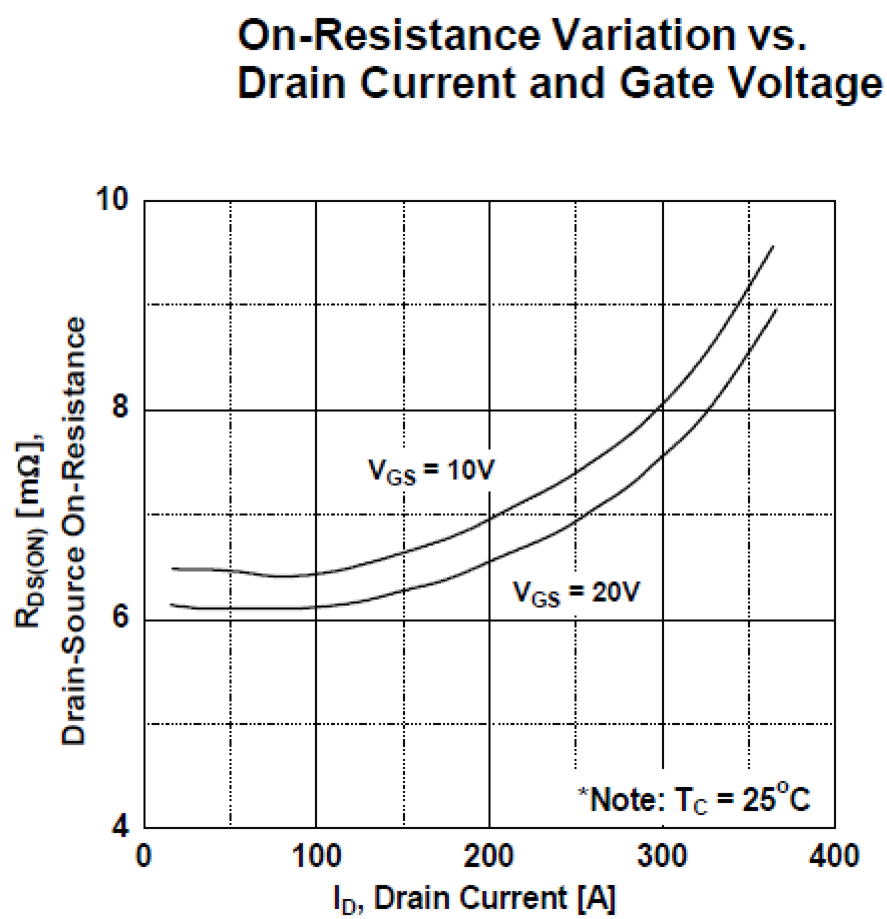

Figure 6 - Fairchild FDP083N15A_F102 $Rds_{(on)}$ Variation with Drain Current

Figure 6 above depicts the variation of $Rds_{(on)}$ vs drain current. I have included this graph because variations in $Rds_{(on)}$ with drain current will lead to distortion. From the graph, you can see that for drain currents of up to 100 A, the variation in $Rds_{(on)}$ is minute. And, since $Rds_{(on)}$ in turn is only a very small fraction of the speaker load impedance, the contribution is essentially zero. Simulations were done to check distortion at the output of the amplifier when switching the load using the SSLR described here, and the figure is less than 1 ppm. For most audio applications this is of absolutely no consequence.

The following few tables show the distortion simulations based on the circuit shown in Fig. 1. As expected, at the amplifier output prior to the output inductor, it is extremely low.

Fourier components of V(vout)
DC component:-4.42763e-010

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]
1	2.000e+04	6.500e+01	1.000e+00	-0.00°
2	4.000e+04	2.431e-10	3.739e-12	48.06°
3	6.000e+04	6.579e-09	1.012e-10	-83.44°
4	8.000e+04	7.043e-10	1.084e-11	135.51°
5	1.000e+05	1.918e-08	2.950e-10	85.21°
6	1.200e+05	1.162e-10	1.788e-12	102.26°
7	1.400e+05	1.853e-08	2.850e-10	163.33°
8	1.600e+05	3.884e-10	5.975e-12	-107.26°
9	1.800e+05	2.162e-08	3.326e-10	-42.31°

Total Harmonic Distortion: 0.000000%

After the inductor, again very low.

Fourier components of V(vspkr)
DC component:3.63033e-009

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]
1	2.000e+04	6.493e+01	1.000e+00	-0.89°
2	4.000e+04	4.815e-08	7.416e-10	-19.16°
3	6.000e+04	1.632e-07	2.513e-09	73.77°
4	8.000e+04	6.698e-10	1.032e-11	38.58°
5	1.000e+05	5.717e-08	8.806e-10	50.86°
6	1.200e+05	1.958e-09	3.016e-11	-50.51°
7	1.400e+05	2.366e-08	3.644e-10	136.45°
8	1.600e+05	3.296e-09	5.076e-11	152.91°
9	1.800e+05	2.408e-08	3.708e-10	30.11°

Total Harmonic Distortion: 0.000000%

If we now look at the signal voltage *across the mosfets* themselves, we see the distortion is 39 ppm. However, since this is 39 ppm across a 100 mV pk (i.e. from $I_{speaker}$ x $Rds_{(on)}$ when the mosfets are ON), this is an extremely small number when compared to the signal at Vout which is 65 V pk. Further, this distortion drops with lower output signals as the mosfet channel resistance modulation is decreased.

Fourier components of V(vswitch)
DC component:3.56668e-005

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]
1	2.000e+04	1.003e-01	1.000e+00	-0.89°
2	4.000e+04	1.575e-06	1.570e-05	-100.73°
3	6.000e+04	3.567e-06	3.556e-05	-2.53°
4	8.000e+04	1.167e-09	1.164e-08	88.61°
5	1.000e+05	5.583e-07	5.566e-06	-4.46°
6	1.200e+05	5.450e-10	5.433e-09	85.69°
7	1.400e+05	1.861e-07	1.856e-06	-6.25°
8	1.600e+05	3.105e-10	3.096e-09	83.48°
9	1.800e+05	8.463e-08	8.437e-07	-8.04°

Total Harmonic Distortion: 0.003932%

Here are two FFT plots, one showing the signal at Vout and the other the FFT of the signal across the mosfet switches when they are turned ON.

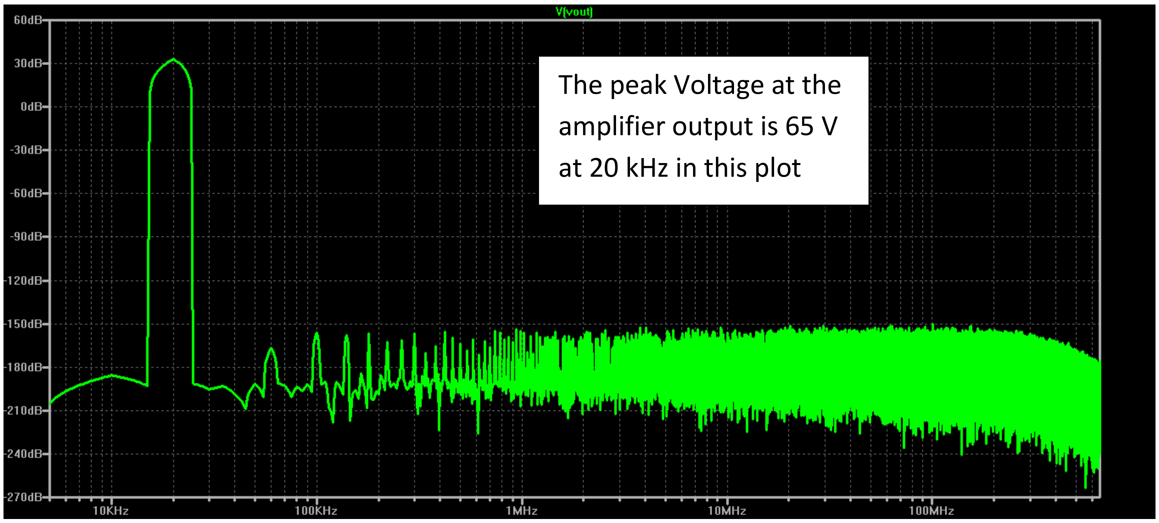

Figure 7 - FFT of Amplifier Output with SSLR ON

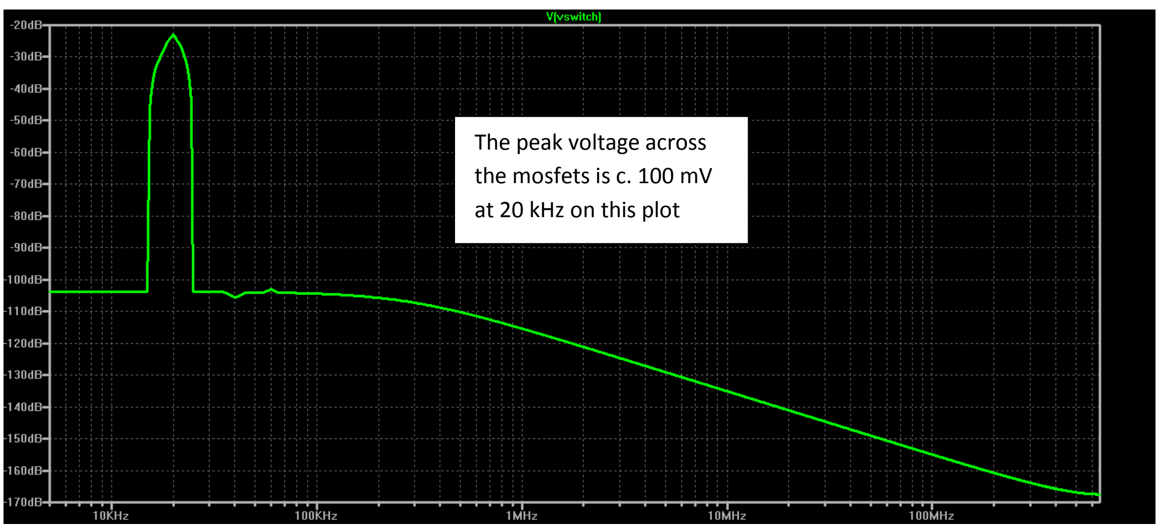

Figure 8 - FFT of Signal Across the SSLR when ON

Finally, here is a plot of the voltage *across the mosfets* when ON with the signal source driving 65 Vpk-pk into an 8 Ω load.

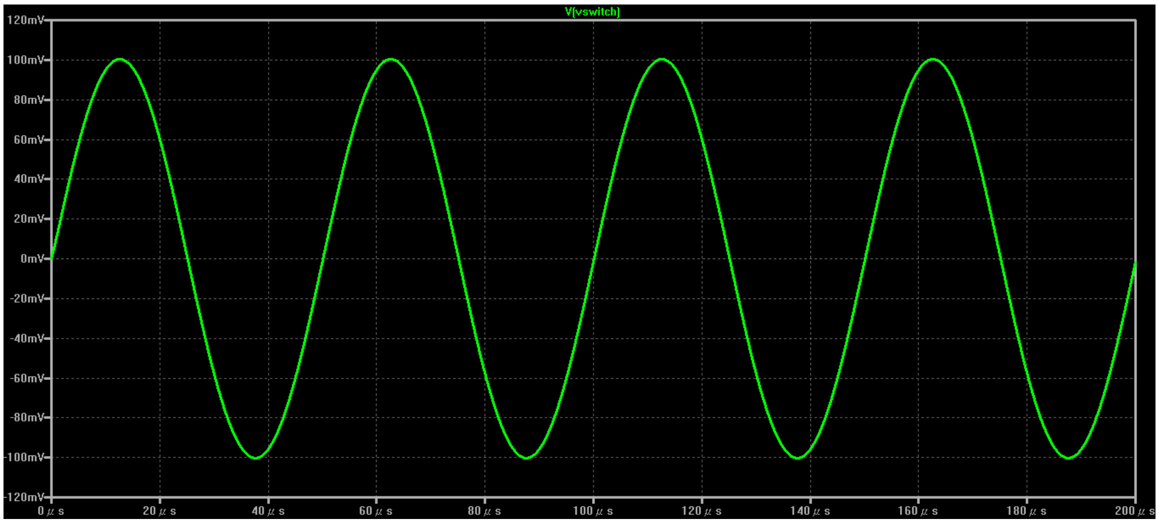

Figure 9 - Voltage Across SSLR at 130 V pk-pk into 8 Ω

Note that for these simulations, I used the IRFP4668 model in LTSpice. The recommended Fairchild parts have about 40% lower $Rds_{(on)}$, lower channel resistance variation with drain current and therefore lower distortion.

7. Solid State Loudspeaker Relay Applications

In this section, we will explore a few ideas on how to apply the SSLR. Because the drive requirements are much more flexible than EM relays, SSLR's lend themselves to some new and unusual ways of providing amplifier protection.

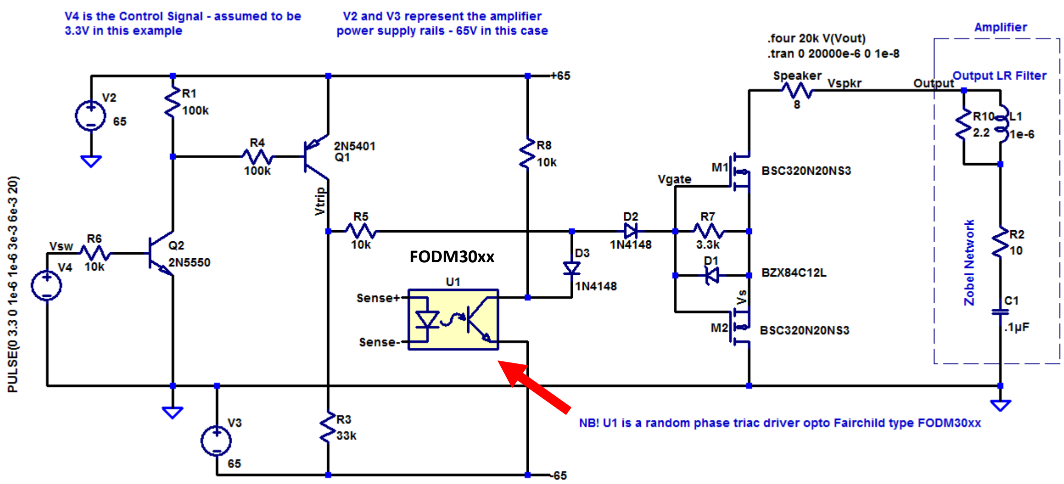

Figure 10 - Practical Protection Circuit. For U1 Details, see Fig 12

It's important when providing over current protection, that the protection is latched – so in the event of a short on the amplifier output is disengaged and remains so until the fault is removed, or, the protection reset by powering the amp OFF and then ON again. In Fig 10, the basic relay driver circuit from Fig 1 has been augmented with U1, a Fairchild random-phase triac driver[1] (FODM30xx family – see Fig. 12). The Sense+ and Sense- pins drive the LED in the coupler, which in turn triggers the triac which remains latched ON. D3 simply provides DC blocking so that in the 'un-tripped' state, normal operation of the SSLR remains unaffected and control is asserted by Q1, which would typically be controlled by speaker mute circuitry, over temperature protection and so forth. When U1 is triggered via the sense connections, D3 is pulled to the -65 V rail, reverse biasing D2 causing the mosfets to turn off, thus protecting both the amplifiers and ultimately the speakers.

In Fig. 11, some ideas on how the SSLR can be interfaced into over current detection circuits are given. U1 in Fig 11 is the same U1 shown in Fig 10.

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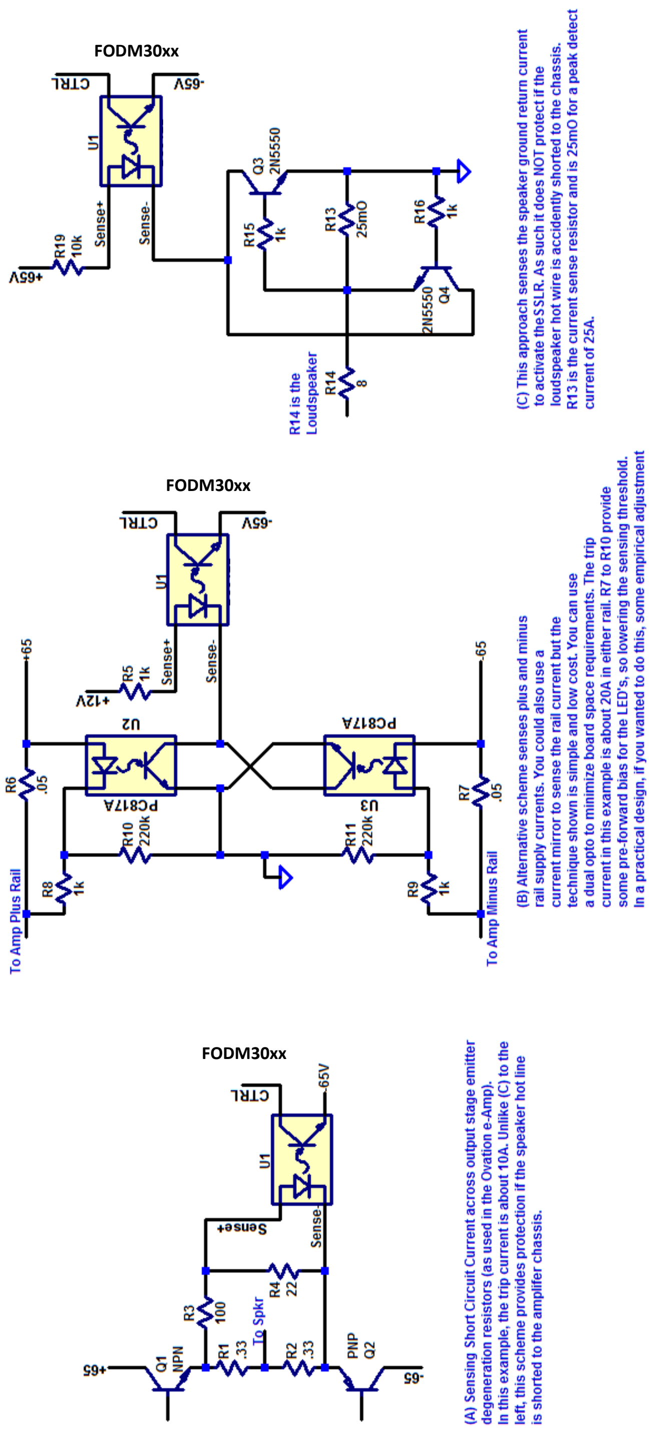
[1] Note that a zero crossing detector triac output opto will NOT work correctly in this application – you have to use a 'random phase' triac output opto

Figure 11 - Ideas on Applying the SSLR to Detect Over Current with Latching

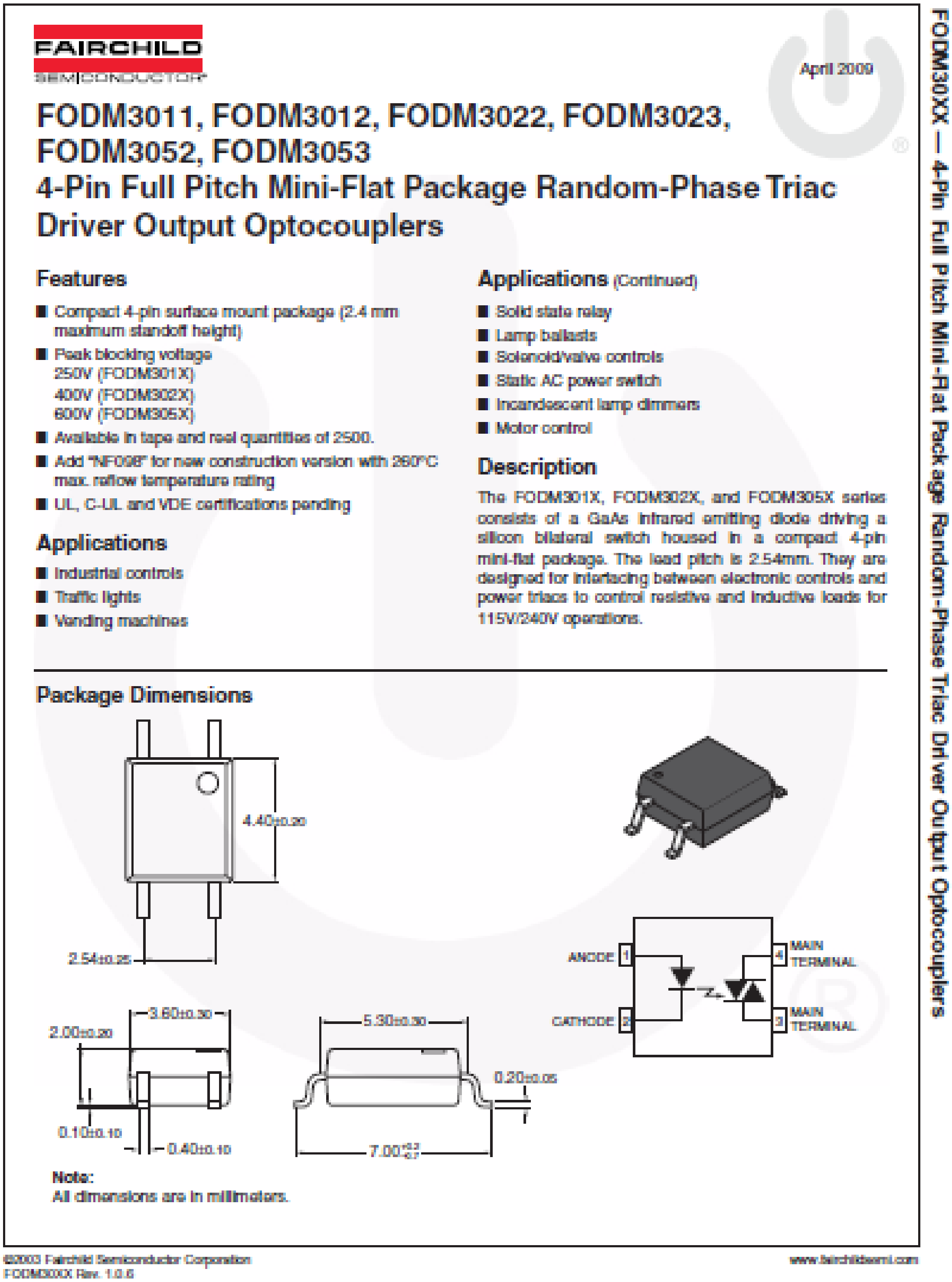


8. Solid State Loudspeaker Relay Specifications

Absolute Maximum Amplifier Supply: 150 V (V+ to V-) (using recommended Mosfets)

Typical ON Resistance at 25° C:	<15 milli Ω (using recommended Mosfets)
OFF Isolation at 1 kHz ref 250 W:	better than -85 dB
OFF Voltage Capability*:	c. 20% above and below amplifier supply rails.
Switch ON Activation:	<5 µs (drive signal rise/fall times of 100 ns)
Switch OFF Deactivation:	<25 µs – determined primarily by value of R7 in Fig. 1
Fault Interrupt Current:	up to 50 A
Switch Dissipation at 250 W 8 Ω load:	<0.5 W across both devices
Inductive Energy Dump Capability:	up to 588 mJ
Switching Lifetime at 250 W 250 mJ load:	Essentially infinite number of switching cycles provided thermal and electrical limits are not exceeded
Distortion:	See Figures 7 and 8;
	Better than 1 ppm at +-65 V pk-pk (-150 dB) at 20 kHz
Approximate cost:	$6-00 (component costs at one off quantities – relay only)

*This is the maximum amplifier voltage swing with the SSR OFF that will not cause the SSR to go into conduction due to the mosfet switch gate threshold being exceeded. This voltage capability is bounded by the Vds rating of the mosfets



FAIRCHILD SEMICONDUCTOR®

April 2009

FODM3011, FODM3012, FODM3022, FODM3023, FODM3052, FODM3053 4-Pin Full Pitch Mini-Flat Package Random-Phase Triac Driver Output Optocouplers

Features

- Compact 4-pin surface mount package (2.4 mm maximum standoff height)
- Peak blocking voltage
  250V (FODM301X)
  400V (FODM302X)
  600V (FODM305X)
- Available in tape and reel quantities of 2500.
- Add "NF098" for new construction version with 260°C max. reflow temperature rating
- UL, C-UL and VDE certifications pending

Applications

- Industrial controls
- Traffic lights
- Vending machines

Applications (Continued)

- Solid state relay
- Lamp ballasts
- Solenoid/valve controls
- Static AC power switch
- Incandescent lamp dimmers
- Motor control

Description

The FODM301X, FODM302X, and FODM305X series consists of a GaAs infrared emitting diode driving a silicon bilateral switch housed in a compact 4-pin mini-flat package. The lead pitch is 2.54mm. They are designed for interfacing between electronic controls and power triacs to control resistive and inductive loads for 115V/240V operations.

Package Dimensions

Note:
All dimensions are in millimeters.

FODM30XX — 4-Pin Full Pitch Mini-Flat Package Random-Phase Triac Driver Output Optocouplers

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Figure 12 - Fairchild Random-Phase Triac Trigger

Simple Solid State Loudspeaker Relay Document History

30th April 2012	Document updated and reformatted
5th July 2012	Added distortion graphs and tables; updated specifications; corrected usage of SI units
2nd Aug 2012	Added section 7 covering application ideas for SSLR, including latching