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Low-Level Analog Switching

Various support gadgets can distort your electric guitar sound. Here's how you can keep that sound clean.

By Dennis Hoffman

Using effects between an electric guitar and amp can be a superb and inspiring way to produce new sounds. However, the interconnections and bypass switching systems that control the effects can also blur and distort the original sound. In an attempt to minimize the destruction of tone, I have experimented with ways to retain as much of the guitar's fundamental character as possible. There are few things worse than bad tone.

You can accomplish switching low-level analog signals such as the voltage and current generated by an electric guitar pickup with an electronic relay if you consider specific details. By using self-latching low thermal emf relays, you can best preserve the analog components inside the electronic device. Control signals sent from the outside world must be optically coupled.

SELF-LATCHING RELAYS

As a first approximation, an electric guitar pickup generates a full-scale signal of 2V peak-to-peak, or 0.707V RMS. This is usually terminated into a 1Meg impedance at the guitar preamp, and the power is 500nW. Signals transmitted between effects devices in front of the guitar amp also run at this level.

A Panasonic Electric Works DS2E-S-DC12V 12V signal relay uses a holding current to pull in the contacts. Its coil resistance is 720Ω, and this is a power of 0.2W. Relay power is 400,000 times greater than the power in a guitar signal. The magnetic field is theoretically constant, but any power-supply ripple or noise components can electromagnetically couple into the analog signal. There is a very good chance that part of the control circuit power will be fed into the guitar signal. This is what led me to use self-latching relays that have zero holding current.

Self-latching relays have a small permanent magnet attached to the end of the coil's armature. A brief pulse will cause the coil to move to one of its two positions. There will be an iron post or another magnet that holds the armature in position. Reversing the polarity of the control pulse will send the armature to the other of its two positions.

Again, it will use the permanent magnet to latch itself in position after you remove the control pulse. The armature pushes against the contacts in one position and releases them in the other. These self-latching relays can also have two separate control coils that generate opposite magnetic control fields to pull the armature one way or the other. Be-

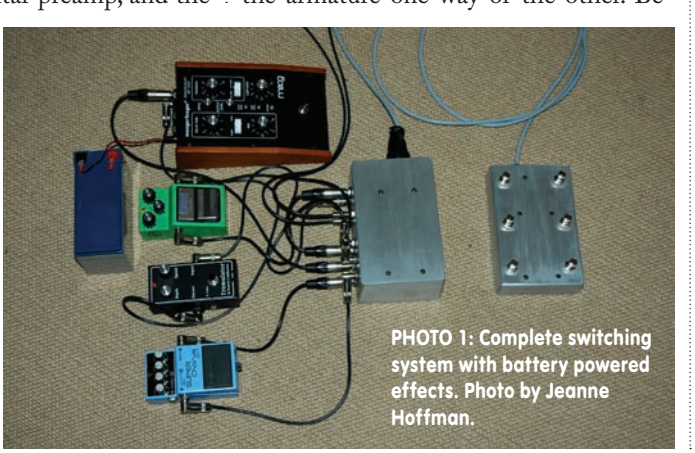

PHOTO 1: Complete switching system with battery powered effects. Photo by Jeanne Hoffman.

cause there is zero holding current, there is virtually no leakage.

To be specific, the solid-state circuit that drives the control coil will be in its cutoff condition, yet the transistor will have a small leakage current typically in the nanoamps. Also, by running the control circuit from a battery, you can further eliminate the usual electronic power-supply noise. At this point control current is infinitesimally small.

As an additional note, any effect powered by AC runs the risk of picking up pollution from the power line. Some devices may run on AC with a wall wart that outputs a low voltage DC to the effect, so you can substitute a rechargeable sealed lead acid battery with a high amp hour rating. I use a 12V/7AH battery with the Moog MF-104Z Analog Delay, and for me there is no question that the battery is the superior power source.

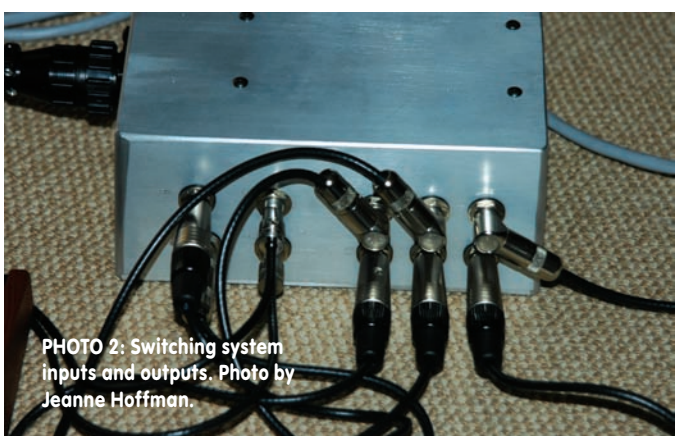

PHOTO 2: Switching system inputs and outputs. Photo by Jeanne Hoffman.

LOW THERMAL EMF CONTACTS

Any time current passes through two dissimilar metals, the connection generates a voltage. The voltage depends on the type of metal and the temperature of the junction. This is called the thermoelectric voltage, or thermal electromotive force. Either inside the relay or when the relay is connected to a wire (or printed circuit board), there will be a change from one metal composition to another. A relay designed to keep this voltage generation to a minimum will have a thermal emf of less than 10μV. A normal switch or relay can have a generated thermal emf several times greater.

While this thermal emf is mostly a DC offset error, it is dynamic because it will change with temperature and relay contact force. The error is a voltage artifact produced by the circuit, and this voltage is not a part of the information in the signal. The offset becomes one more flaw in the system.

Perhaps I am being overly analytical, and the imperfection is rather small in the larger scheme of things. Think about how many connections there are in a switching system and add all those errors together. You can minimize this problem by using a low thermal emf relay, such as the Panasonic Electric Works SX series. The only limitation is the signal must be less than 10V and 10mA.

A positive thermal emf offset will raise the signal above its normal 0V reference. You can reduce an A/D converter's input gain to keep it from being overdriven in the positive direction because of the offset. Due to the reduced gain, the negative excursion of the signal will never get to full-scale negative.

As a result, one or more least significant bits of accuracy are removed. You only get those low-order bits and your maximum signal-to-noise ratio if the signal can travel from 0V to full scale. A 20-bit digital converter will resolve a 674nV signal (.707V/2 exp 20), but that accuracy is now lost.

OPTICALLY COUPLED CONTROL SIGNALS

When you connect a copper wire control cable carrying electricity to a system, this can be an antenna for unwanted noise. A simple way to solve this problem is to use light to connect signals from one system to another. The use of optocouplers—an idea that has been around a long time—is a cheap and excellent solution. Current from the control circuit forward-biases a light emitting diode, and the photons from the LED turn on a photo transistor. Light does not pick up EMI.

And the optocouplers can hold off high voltages. The possibility of a ground loop also disappears. These details apply to the control systems of channel switching amplifiers as well as

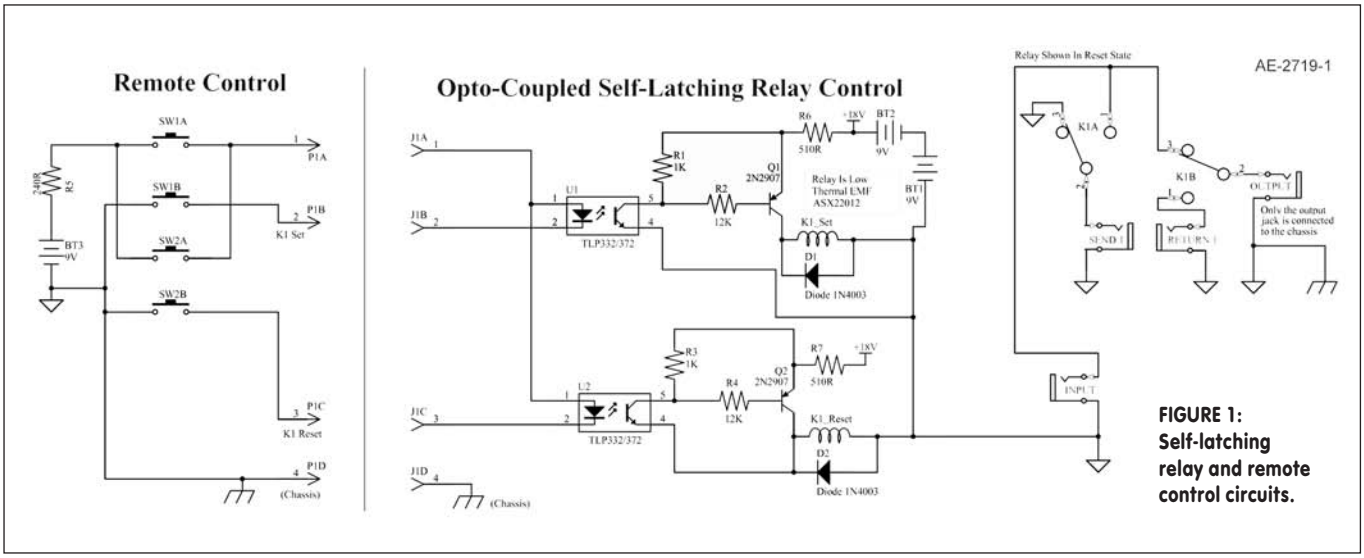

FIGURE 1: Self-latching relay and remote control circuits.

effects switching systems.

The remote control unit will have a battery to provide the pulses to temporarily turn on the optocouplers, which then turn on a transistor that momentarily energizes the self-latching relay's coil. Under normal operation there is no current flowing in either the remote control unit or the switching system. Only during switching pulses does current flow (**Fig. 1**).

The battery return and chassis of the remote control unit are connected together. This common point should be connected to the chassis of the switching unit, which may or may not have its signal ground connected to its own chassis at one single point, but this is a connection independent of the remote control unit. Do not connect the remote control unit ground directly to the switching unit's signal ground.

Inside the switching unit all of the control circuit relays and transistors are wired to the battery return. A single wire runs from the control circuit battery return to the signal ground, which helps to isolate control circuit leakage current from signal current. Finally, the typical ¼″ phone jack at the output is connected to the chassis, while the other jacks are isolated with shoulder washers.

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TABLE 1: LOW LEVEL ANALOG SWITCHING CIRCUIT PARTS LIST.

Part #	Part	Vendor	Vendor Number
BT1-3	9V battery	Digi-Key	N145-ND
SW1, 2	momentary switch (pushbutton)	Digi-Key	450-1094-ND
	switch cap	Digi-Key	450-1054-ND
P1	amp footswitch plug	Digi-Key	A1304-ND
	plug sockets	Digi-Key	A25137-ND
	plug cable clamp	Digi-Key	A1332-ND
J1	amp control signals receptacle	Digi-Key	A1305-ND
	receptacle pins	Digi-Key	A25136-ND
J2-5	¼″ phone jack long bushing	Mouser	502-L-12A
	⅜″ shoulder washer	Mouser	534-3069
K1	ASX22012 relay	Digi-Key	255-1589-5-ND
R1, R3	1k ¼W 5% resistor	Digi-Key	1.0KQBK-ND
R2, R4	12k ¼W 5% resistor	Digi-Key	12KQBK-ND
R6, R7	510R ¼W 5% resistor	Digi-Key	510QBK-ND
R5	240R ¼W 5% resistor	Digi-Key	240QBK-ND
D1, D2	1N4003 diode	Digi-Key	1N4003/4GICT-ND
U1, U2	TLP372 optoisolator	Digi-Key	TLP372-ND
Q1, Q2	2N2907/PN2907 PNP	Digi-Key	PN2907-ND
Optional			
SW1, SW2	Carling heavy duty stomp switch (expensive, long lead time)	Mouser	691-216-PM-OFF

Note that an effects device that radiates an electric disturbance into a guitar and amp system by itself will still emit this interference when connected to a switching system. Sometimes using the bypass on the device itself will help. For me, *The Analogman Tube Screamer* is a remarkable distortion pedal, yet the noise it radiates when not in use is rubbish. Consequently, you must switch this device using its own true bypass switch. In a live performance situation many of these things might not be a problem, but they can become evident when playing solo or recording.

SUBJECTIVE TONE

One last consideration is my subjective opinion of the effect on the sound. When playing an electric guitar, you should listen to the sound directly into the amp. Become comfortable with your direct tone. With switching units and effects connected, a distortion or blurring of the signal may sound like a damper has been placed on the string, which can't vibrate to its full excursion—it sounds flat and two-dimensional. The bass might sound muddy, or fat and bloated. Often the treble will be hard and brittle. The rhythmic flow of the boogie is just not there.

Ultimately, if you and I can keep playing and listen to the music, then all is well. But if the equipment is distracting and keeps calling attention to itself, we will know something needs tweaking.

All of the errors in a system obscure and distort the details of the music. While one error in itself may be small, the addition of many errors can present serious disturbances. 500nW of guitar signal is a very small quantity. *aX*