R_{ON} -- A Key Figure of Merit for Selecting Analog Switches

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Like many “standard” off-the-shelf components, analog switches and multiplexers are in essence the “glue” that binds together the larger functional blocks of a complex system by controlling signal and power flow together with functions and interoperation. The larger, more complex, functional system blocks are often high-precision converters, processors and ASICs. The precision of these main blocks demands that the glue devices offer the highest performance and quality to ensure that the overall product performance is not degraded or impaired.

Engineers who use analog switches as glue components in their system designs are concerned about certain key switch parameters, or performance figures of merit, that impact the operation of the overall system. Such key parameters are any one or more of, but of course not limited to:

- ON resistance (R_{ON}), which correlates to how much signal attenuation will result as the signal passes through the switch
- R_{ON} flatness, relates to how the ON resistance will change as the signal voltage amplitude is varied across the switch and with changes in power supply voltage and temperature
- R_{ON} channel-to-channel matching, indicates amount of signal variance to expect from one switch channel to the next
- Leakage current, which correlates to how much voltage offset the switch will cause or how it will influence charge hold times in certain applications
- Charge injection, which tells the designer how much charge will be injected into the signal path as a result of each logic control command of the switch
- Turn ON and turn OFF times (t_{ON}, t_{OFF}), which tell the engineer how fast the switch will open and close in response to control commands, thus introducing propagation delays
- Many more…

Our investigation here focuses on the significance of just the first three listed parameters dealing with ON-resistance. Though not exclusive in concern to the engineer, R_{ON} is a very important parameter that can impact performance in nearly all analog-switch applications.

R_{ON}

ON resistance (R_{ON}) is the ohmic resistance that exists between the input and output pins of the switch when the switch is closed and is passing a signal. The switch is formed using two paralleled FETs, a p-channel and an n-Channel, to accommodate bi-directional signals. The combined drain-to-source channel conductivity of the paralleled FETs determines the ON resistance, sometimes referred to as $R_{ds(on)}$.

This resistance prevents the switch from being ideal, having no resistance at all, and forms a series voltage divider with the input impedance of the load, that which is connected to the switch's output terminal (see Fig. 1.)

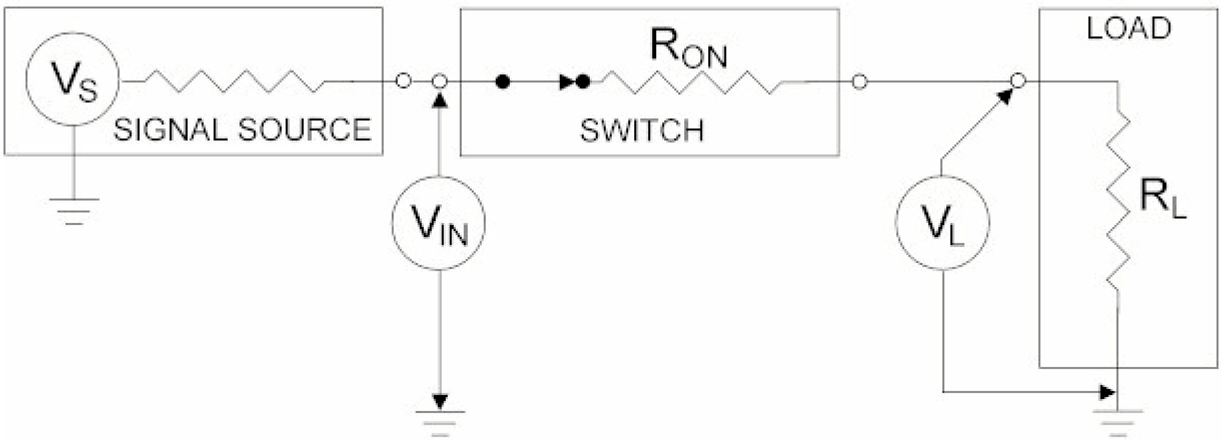

Fig. 1: R_{ON} Signal Attenuation

As a result, the switch itself drops a portion of the signal voltage across itself. In other words, the switch introduces some signal loss or attenuation. The amount of attenuation the switch introduces depends on the relationship between R_{ON} and the load impedance (R_L). Though beyond our discussion here, circuit capacitance will also have some attenuating affect that increases as signal frequency increases.

Signal Voltage to the Load = $V_L = V_{IN} [R_L/(R_{ON} + R_L)]$,

where, V_{IN} is the signal voltage at the switch input

If R_{ON} is very small compared to the load resistance, the amount of signal loss is small and the load voltage is approximately the same as the input voltage to the switch. So, for applications in which the load impedance is considered to be low, R_{ON} must be very low to minimize signal loss. For such applications, such as switching audio 8-Ω speaker or headphones, the engineer will usually select an analog switch that has the lowest possible R_{ON}.

However, there are tradeoffs that the engineer will consider when selecting a low-R_{ON} switch. Often, switches with very low R_{ON} require a larger chip area and may affect package size. Also, a lower R_{ON} usually means a greater input capacitance, which constricts bandwidth and increases switching currents and switching times. In addition, charge injection is higher because of higher gate capacitance currents. So, the designer must select circumspectly, giving consideration to these important tradeoffs.

R_{ON} Flatness

Unfortunately, the ON resistance of an analog switch is not constant, or flat, with changes in signal amplitude level, supply voltage and temperature. While the R_{ON} loss previously discussed can be tolerated in the design, R_{ON} deviation over a wide signal swing or temperature range is less acceptable. Naturally, the designer is concerned about this fact and is interested in minimizing its affects.

A graphical representation (Fig. 2) shows the influence of voltage and temperature on R_{ON}. Note the interesting, twin-peaked, characteristics of each curve, which is caused by the overlapping conduction of the two paralleled FETs that form the switch.

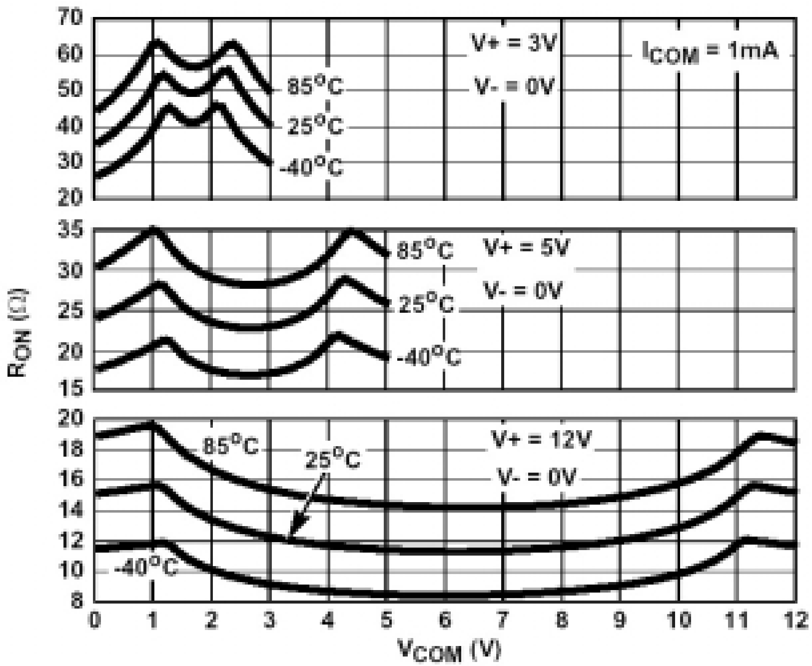

Fig. 2: ON Resistance Vs. Switch Voltage (Intersil ISL43143)

A careful examination of these graphs yields conclusions that must be considered by the designer:

1. R_{ON} changes indirectly with supply voltage. The higher the supply voltage, the lower is the ON resistance of the switch. Fig. 2 shows three sets of graphs that correspond to three different, yet typical, supply voltages that might be applied to power the switch: 3 V, 5 V, and 12 V, all referenced to ground. Note that the vertical R_{ON} scale for the 3-V graphs ranges from 20 to 70 Ω while the R_{ON} scale for the 12-V graphs ranges from only 8 to 20 Ω. The designer will concentrate on the set of graphs that correspond to the supply voltage that will be used to power the IC in the application. This change in R_{ON} with supply voltage is not usually considered to be a problem because the supply voltage is usually a constant value
2. R_{ON} changes directly with temperature. The higher the temperature, the higher R_{ON} becomes. Each set of graphs show how R_{ON} is related to the IC's temperature. Note that 25°C is standard, room temperature, while the other temperatures represent the industrial temperature

range extremes of -40 and +85°C. The designer must interpolate, or approximate, R_{ON} for the operating temperature range as found in the actual application, realizing that R_{ON} does not remain constant, or flat, when temperature changes. Change in IC temperature causes corresponding change in switch signal loss, or attenuation.

3. R_{ON} varies with input signal level. Signals biased at the mid-voltage point, i.e. 6 V for a 12-V supply, will cause relatively slight variations in R_{ON} for small signal excursions and larger variations for larger signal excursions. The designer must consider the amount of swing, or amplitude, in the input signal because extreme voltage excursions will cause greater changes in R_{ON} at the left and right ends of the graphs. Such non-linear variation in resistance will cause distortion in the signal that could become significant enough to be a concern. However, this distortion effect can be minimized if R_{ON} is significantly small compared to the input impedance of the load that the switch is serving. For example, an R_{ON} that varies between 14 and 16 Ω with signal swing will have little affect on signal quality if the load impedance is in kΩ.

R_{ON} Channel-to-Channel Matching

Many analog switch ICs contain more than one electronic switch to conserve space, costs or to provide a multiplexer/demultiplexer function. An example, Intersil's MightyMUX ISL43640 IC is a high-performance 4:1 bi-directional multiplexer that may also serve as a demultiplexer. Such a device delivers four separate signals to a single line, one at a time, or can redirect signals from one line to four separate lines. Routed signals might be audio, video or even dc levels.

For certain applications the designer does not want the switches contained in the IC to perform differently from each other. You might assume that if the switches are manufactured on the same silicon die at the same time using the same process under the same conditions, that they are identical. As it turns out, they are not. There is some deviation in parameters from switch-to-switch, or channel-to-channel. Fortunately, the R_{ON} variance from channel-to-channel is usually very small. Still, this is an important consideration for the engineer who does not want noticeable channel biasing to occur. Channel-to-channel matching should be as close as possible. Intersil's ISL43640 offers matching of 1%. That means there is less than half an Ohm variance in R_{ON} from switch-to-switch where R_{ON} is typically 45 Ω at 25°C with a 12-V supply. A modest variance such as this introduces very little channel bias to multiplexed signals.

As you can see, R_{ON} encompasses extremely significant parameters and figures-of-merit for selecting analog switches. The designer must consider how R_{ON} characteristics will affect the performance of the overall system. In so doing the engineer selects carefully among analog switches to ensure peak performance approaching as closely as possible to ideal switch characteristics. The affects of R_{ON} on system performance must be minimized by both careful selection and design. Intersil has worked closely with designers to meet their analog switch needs, offering a wide selection of MightyMUX analog switches and multiplexers that provide key parameter strengths.

About The Author

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