

# MOSFETs Make Sense for Tracking and Sequencing Power Supplies

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## Introduction:

### Charge MOSFETs with the Task of Supply Control

In electronic systems with multiple supplies, the need for tracking and/or sequencing is well established. On the one hand, core and I/O power might be required to ramp up and down together with less than a diode's voltage drop between them to avoid potentially destructive latch-up. Coincident tracking, as shown in Figure 1a, solves this problem. On the other hand, in a distributed supply chain, some supplies might need to be fully operational before others. Supply sequencing, as shown in Figure 1d, solves that problem. Other systems may require simultaneous completion of supply ramps (Figure 1b), voltage offsets or time delays (Figure 1c), or combinations of such profiles.

Linear's line of no-MOSFET tracking and sequencing control products, the LTC2923, LTC2925, and LTC2927, work outstandingly well with DC/DC converters and other supply generators that allow access to the feedback nodes that set their output voltage. In many applications, however, MOSFET control of power supply tracking and sequencing is necessary. Supply modules provide no access to their feedback node, and some linear regulators also resist the current-injection control method employed by the LTC2923 family.

MOSFET-controlled tracking and sequencing can improve power system segmenting and allow reuse, which reduces parts count and board area. A single-output supply generator can power different rails of the same voltage (e.g., analog power, digital power, and housekeeping power) because each rail's tracking profile can be set independently. Multiple-output modules can replace several single-input modules without the need for complex ON/OFF pin signaling to implement

sequencing or tracking. Furthermore, a series MOSFET can be shut off, which guarantees that the load is disconnected when so desired.

The LTC2926 MOSFET-controlled power supply tracker provides exceptionally flexible control of supply tracking and sequencing that can

realize all of the profiles in Figure 1, and combinations of them. Each of two "slave" supplies can be configured independently to track a "master" ramp signal using just an N-channel MOSFET and a few resistors per supply. A single capacitor sets the slope of a voltage ramp that may be employed

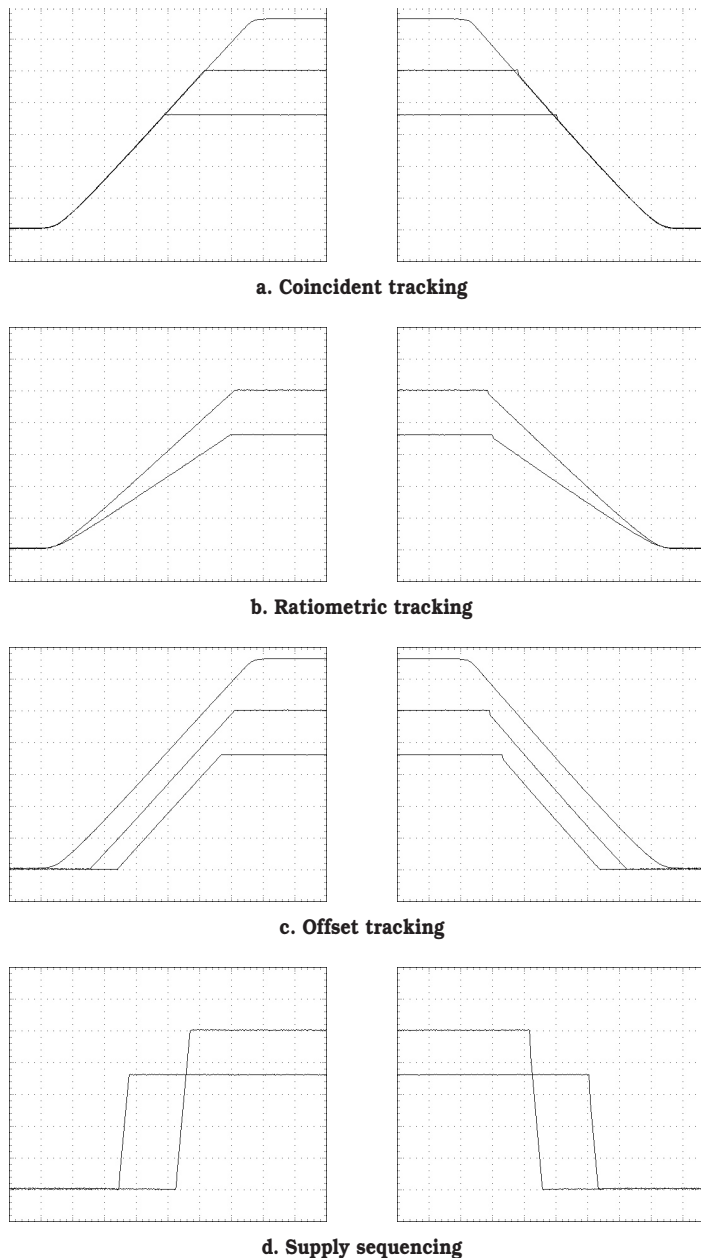
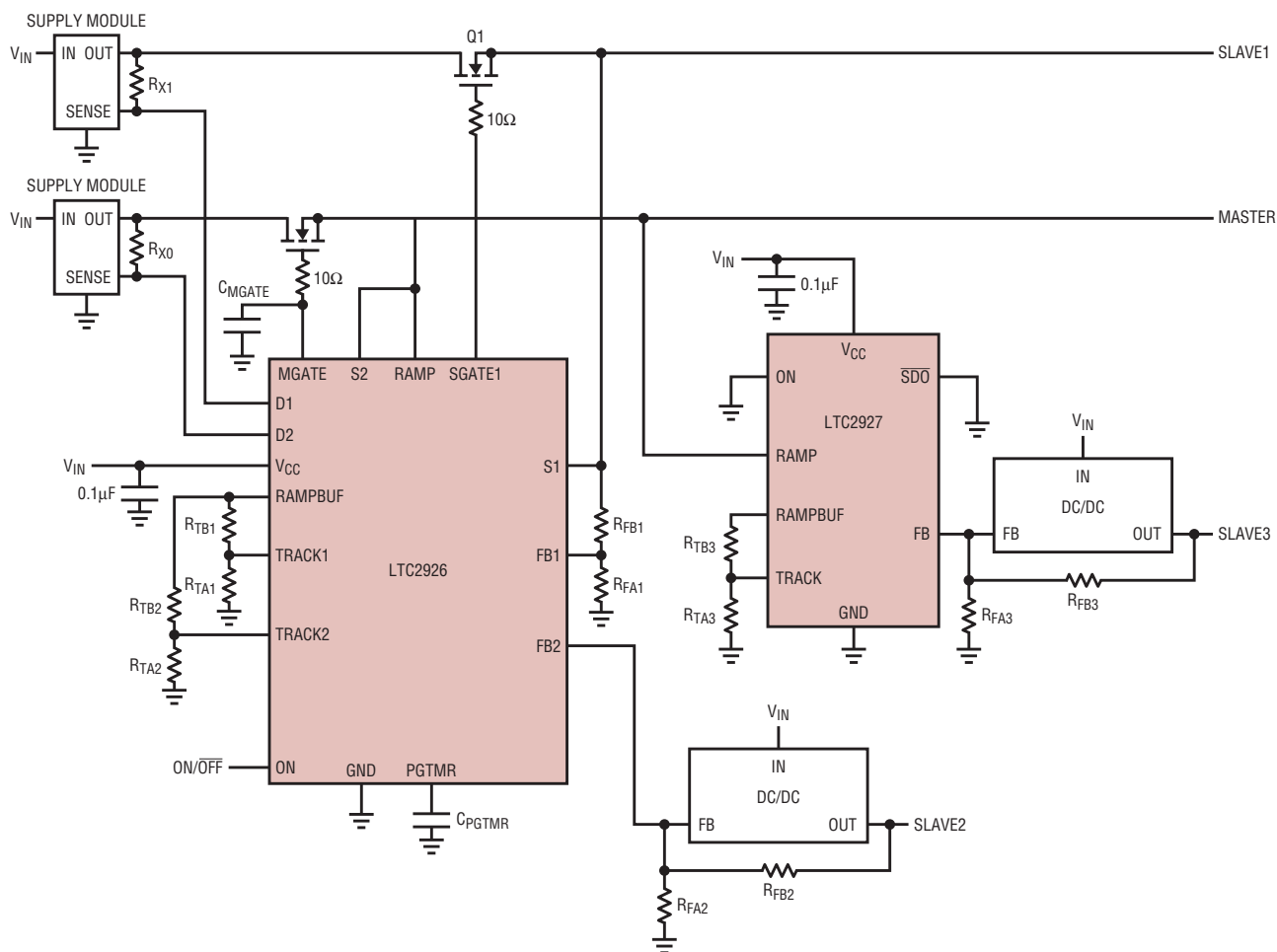


Figure 1. Power supply voltage tracking profiles





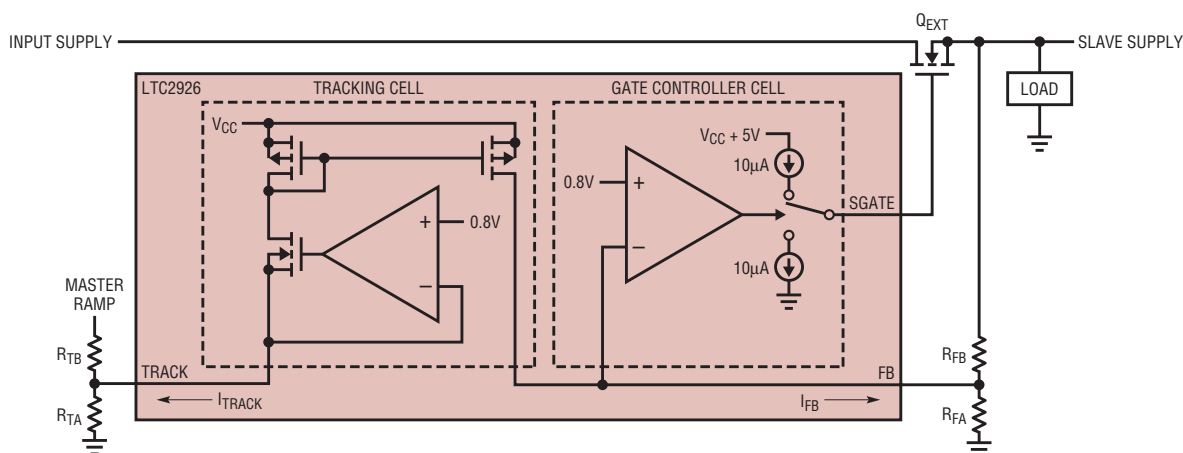
**Figure 4.** LTC2926 and LTC2927 4-rail application. The second slave channel of the LTC2926 requires no MOSFET in this example.

the feedback resistors multiplies the increasing reference voltage to create a rising slave supply voltage that is limited by the input supply voltage at the drain of the MOSFET. With proper selection of the feedback resistor ratio, the gate controller cell drives

the SGATE pin to  $V_{CC} + 5V$  when the slave supply reaches its maximum. The logic-level MOSFET becomes a simple closed switch, able to pass input supply voltages of from 0V to  $V_{CC}$ .

The relationship between the master ramp and the slave voltage is

called the tracking profile, and it is a function of the input supply voltage, the master ramp voltage, the track resistors ( $R_{TA}$ ,  $R_{TB}$ ), and the feedback resistors ( $R_{FA}$ ,  $R_{FB}$ ). All of the profiles in Figure 1 can be realized by properly selecting the track and feedback resis-



**Figure 5.** Simplified tracking cell and gate controller cell combination

tors. Combinations are also possible because each channel's profile is set independently.

### MOSFETs Make Remote Sense, Too: Whip a Problem with a Switch

Even with the selection of a low  $R_{DS(ON)}$  MOSFET as the tracking control device, the load current causes a voltage

difference between the supply generator and the load. Worst yet, dynamic load current produces a dynamic voltage error. Without modification, the standard solution, to let the supply generator remotely sense the load voltage and compensate for the drop, does not work. During tracking up or down, the load voltage is deliberately

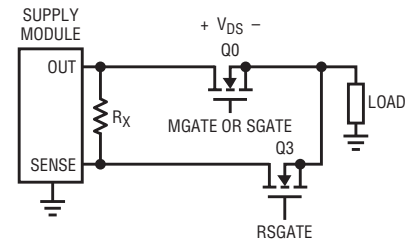


Figure 6. Functional schematic for remote sensing the load

## Tracking and Sequencing Supply Rails in Three Easy Steps

Any of the profiles shown in Figure 1 can be achieved by using the following simple design procedure. Figure 3 shows a basic 3-supply application circuit.

### 1. Set the ramp rate of the master signal.

Solve for the value of  $C_{MGATE}$  based on the desired ramp rate (volts per second) of the master ramp signal,  $S_M$ , and the MGATE pull-up current.

$$C_{MGATE} = \frac{I_{MGATE}}{S_M} \quad (1)$$

where  $I_{MGATE} \approx 10\mu A$

If the gate capacitance of the MOSFET is comparable to  $C_{MGATE}$ , reduce the value of  $C_{MGATE}$  to account for it. If the master ramp signal is not a master supply, tie the RAMP pin to the MGATE pin

### 2. Choose the feedback resistors based on the slave supply voltage and slave load.

It is important that the feedback resistors are significantly larger than the load resistance. Determine the effective slave load resistance,  $R_L$  (not shown), to satisfy the following equation:

$$\begin{aligned} R_{FB} &\geq 100 \cdot R_L \text{ (recommended),} \\ R_{FB} &\geq 23 \cdot R_L \text{ (required)} \end{aligned} \quad (2)$$

The LTC2926 must be able to fully enhance the slave control MOSFET at the end of ramping. Select  $R_{FA}$  based on the resistor tolerance,  $TOL_R$ , and the absolute maximum slave supply voltage,  $V_{SLAVE(max)}$ :

$$R_{FA} < R_{FB} \cdot \left( \frac{1 - TOL_R}{1 + TOL_R} \right) / \left( \frac{V_{SLAVE(max)}}{V_{FB(REF)(min)}} - 1 \right) \quad (3)$$

where  $V_{FB(REF)(min)} = 0.784V$

Note: Design with a value of  $V_{SLAVE(max)}$  that covers the maximum possible slave supply voltage by a good margin. If the slave generator exceeds that voltage during operation, an overvoltage shutdown can occur. The gate controller cell will turn off the MOSFET in an attempt to reduce the over-range supply voltage, which activates the STATUS/PGI pull-down, and thus a fault can occur if the power good timeout period has passed.

If no-MOSFET operation is desired and conditions for it are met, let the generator's design set  $R_{FA}$  and  $R_{FB}$ , substitute the generator's reference voltage for  $V_{FB(REF)}$  in step 3.

### 3. Solve for the tracking resistors that set the desired ramp rate and voltage offset or time delay of the slave supply.

Choose a ramp rate for the slave supply,  $S_S$ . If the slave supply tracks the master coincidentally or with only a fixed offset or delay, then the slave ramp rate equals the master ramp rate. Calculate the upper track resistor,  $R_{TB}$ , from:

$$R_{TB} = R_{FB} \cdot \left( \frac{S_M}{S_S} \right) \quad (4)$$

Choose a voltage difference based on the type of profile to be implemented:

$$\Delta V = \text{a voltage difference (offset tracking),} \quad (5a)$$

or

$$\Delta V = S_M \cdot t_{DLY} \text{ (supply sequencing),} \quad (5b)$$

where  $t_{DLY}$  is a delay time,

or

$$\Delta V = 0V \text{ (coincident or ratiometric tracking)} \quad (5c)$$

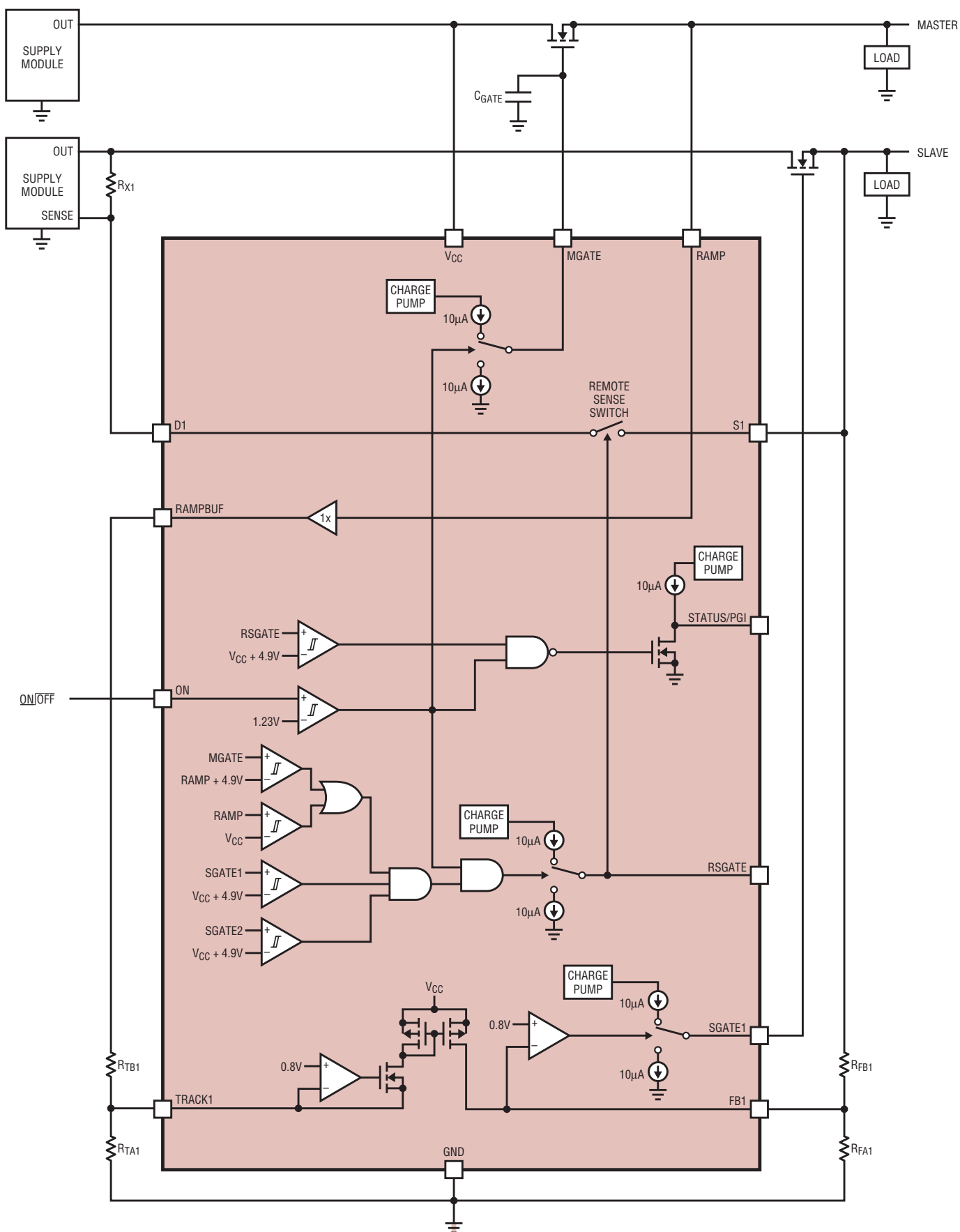
Be sure that the slave ramp rate and its offset or delay allow the slave voltage to finish ramping before the master ramp reaches its final value; otherwise, the slave supply voltage will be held below its intended level.

Finally, determine the lower track resistor,  $R_{TA}$ :

$$R_{TA} = \frac{V_{TRACK}}{\frac{V_{FB(REF)}}{R_{FB}} + \frac{V_{FB(REF)}}{R_{FA}} - \frac{V_{TRACK}}{R_{TB}} + \frac{\Delta V}{R_{TB}}} \quad (6)$$

where  $V_{TRACK} = V_{FB(REF)} = 0.8V$

Note that large ratios of slave ramp rate to master ramp rate,  $S_S/S_M$ , may result in negative values for  $R_{TA}$ . In such cases the offset or delay must be increased, or the slave ramp rate must be reduced.



**Figure 7. Simplified functional block diagram for the LTC2926**





input signal that initiates ramp up and ramp down, and two input/output signals,  $\overline{\text{FAULT}}$  and STATUS/PGI. Each of the two I/O signals reports an aspect of tracking status as its output, and each accepts a shut-down command as its input. Both the  $\overline{\text{FAULT}}$  and the STATUS/PGI pins include strong N-channel MOSFET pull-down transistors, and weak pull-up currents, which facilitates wired-OR signaling.

A high output at the STATUS/PGI pin indicates that tracking/sequencing and automatic remote sense switching have completed. It is typically connected to the  $\overline{\text{RST}}$  inputs of downstream devices such as an FPGA, a micro-controller, or a load voltage monitor (Figure 9). The weak pull-up hangs from a charge-pumped rail, which allows the STATUS/PGI output to control external MOSFET switches, as well as become a logic signal with the addition of a pull-up resistor.

The input function of the STATUS/PGI pin allows downstream devices and the LTC2926 itself to force open the remote sense switches and bring about supply disconnect if the pin voltage is low and the power good timeout period has expired. The MGATE, SGATE1, SGATE2, and RSGATE pins that control MOSFET gates are all pulled low to effect immediate supply disconnect and open the remote sense switches. In addition, an internal fault latch is set, which keeps the loads cut off until it is reset and re-armed via the ON pin. When connected as in Figure 8, the LTC2904 supply monitor forces supply disconnect if the programmed 10% load voltage tolerance is exceeded after the timeout period (set by  $C_{\text{TIMER}}$ ) expires.

The  $\overline{\text{FAULT}}$  pin's input aspect allows upstream devices to set the fault latch, open the remote sense switches, and cause supply disconnect without a timeout period when the pin is pulled low. In addition, the STATUS/PGI pull-down is activated, which informs downstream devices of the fault. Under normal conditions, a weak pull-up keeps the  $\overline{\text{FAULT}}$  pin voltage within a diode drop of  $V_{\text{CC}}$ —the internal Schottky diode allows the pin to be pulled above  $V_{\text{CC}}$  safely. Again,

the loads remain cut off until the fault latch is reset and re-armed by toggling the ON pin. The  $\overline{\text{FAULT}}$  pin might typically be connected to the  $\overline{\text{RST}}$  output of upstream supply devices such as voltage, current, or temperature monitors (Figure 8). Automatic fault retry is possible by tying the ON and  $\overline{\text{FAULT}}$  pins together.

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## **Direct Supply Generator Control: ¡No Más FETs, Mi Amigo!**

The LTC2926 can even set a tracking profile without MOSFETs just like the LTC2923, under certain conditions. As is the case for no-MOSFET tracking with the LTC2923 family, the supply generator must allow access to the feedback node that sets its output voltage, and its reference voltage must be ground-based. (MOSFET control is required for many three-terminal regulators, for example, because their references are relative to their output node.)


For tracking control when the slave generator's reference voltage is low enough,  $V_{\text{FB(SEN)}} \leq 0.75$ , simply connect the LTC2926's FB pin to the supply generator's FB pin (Figure 9a). Choose the track resistors based on the tracking profile and the generator's feedback resistors. When the master ramp signal is low, the tracking current is high, and it keeps the slave generator's output low. When the master ramp signal reaches its maximum, the LTC2926's FB pin current is zero, and it has no effect on the output

voltage accuracy, transient response, or stability of the generator.

A generator with  $V_{\text{FB(SEN)}} > 0.75\text{V}$  may be controlled without a MOSFET if the slave voltage is large enough; see Figure 10. The  $R_{\text{TA}}$  resistor must be split to create a new injection point for FB pin current, and the track resistor values must be scaled, as well (Figure 9b); consult the LTC2926 Data Sheet for details.

## **Conclusion: No Joke, It's a Great Product**

The LTC2926 solves a host of tracking and sequencing headaches and can simplify design by means of MOSFET control. MOSFET control separates supply generator start-up and shut-down details from specific tracking profile requirements, which allows for supply segmenting and generator consolidation. Because the LTC2926 creates its own regulator to ramp the rails, a multitude of supply generators can now be tracked and sequenced, including modules and 3-terminal linear regulators.

The LTC2926 is interoperable with Linear's no-MOSFET tracker/sequencers, and even provides that functionality itself, which can keep device count down and reduce parts assortment. Its integrated automatic remote sense switching eliminates a problem associated with series MOSFET control, and intelligent I/O lets this device broadcast status as well take shut-down commands from upstream and downstream devices. All of these features and fine control of start-up and shut-down of power supply rails in a single package make the LTC2926 powerful solution for tracking and sequencing. 

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