

Benefits of a Resistor-to-Digital Converter in Ultra-Low Power Supplies



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A resistor-to-digital (R2D) converter is circuitry inside an integrated circuit (IC) that determines the value of an external resistor in order to configure various settings within the IC. The R2D circuit provides several advantages for power supplies, such as the elimination of leakage current, smaller solution size, lower design cost, tighter output voltage accuracy and greater design flexibility.

In ultra-low-power industrial applications such as smart heat, gas, and water meters; asset tracking; and smart locks, the eliminated leakage current is of paramount importance in extending battery run time. In personal electronics applications such as wearables and fitness trackers, the eliminated leakage current and smaller size enable new levels of system performance. All applications benefit from tighter output voltage accuracy and design flexibility.

This white paper explains the R2D circuit, describing its primary benefits as well as its main limitations.

What is an R2D converter?

Inside a power-supply IC, an R2D converter is a calibrated current source and an analog-to-digital converter (ADC). Once enabled, the IC turns on the current source and ADC to measure the voltage generated across the external resistor, R_{SET} . Given the application of a known, calibrated current and an accurate voltage measurement with the ADC, it is possible to use Ohm's law to correctly determine the resistor value. The engineer chooses the desired external resistor value from the E96 list of standard resistor values in order to configure the IC based on a look-up table in the device data sheet. **Figure 1** shows a block diagram of the R2D circuit.

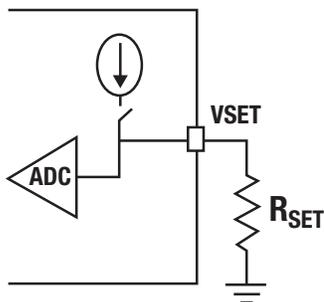


Figure 1. Block diagram of an R2D circuit, showing the current source and ADC.

Depending on the amount of R2D settings available, there may be one, two or more current source levels applied in order to read out the resistor value. Two different current source levels, for example, create two different voltages across the fixed external resistor value. The larger current source is applied first. Half of the possible resistor values create a voltage that exceeds the ADC's measurable input voltage range. These resistor values require a second R2D reading with the smaller current source level to create a voltage within the ADC's range. This multiread process allows accurate measurement of a wider range of resistor values with a fixed ADC input voltage range.

After reading the resistor value before soft start, the IC configures certain settings and stores them to memory. Then, the current source and ADC are disabled to eliminate their current consumption. The IC is now configured and begins normal operation as a power supply, beginning with soft start. The R2D circuit is not used again until the IC is disabled and re-enabled. **Figure 2** shows the R2D circuit measuring the resistor value with two current source levels.

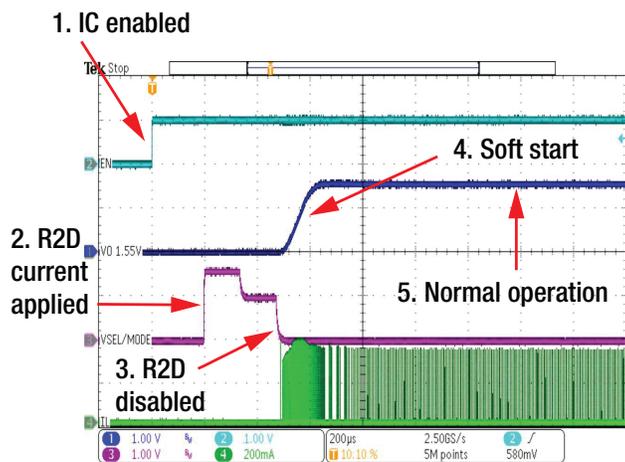


Figure 2. The power-supply IC is enabled, followed by R2D circuit operation with two current source levels, soft start and normal operation.

Primarily, R2D converters are used to set the output voltage. Some R2D converters adjust other settings, such as control-loop compensation. I'll describe both uses in this article.

R2D converter benefits

Although I listed the benefits of an R2D converter at the beginning of this paper, let's get into more detail.

Elimination of leakage current

The elimination of leakage current consumption in the feedback (FB) resistors is the primary reason to use an R2D converter in ultra-low-power applications, which use the lowest I_Q power supplies [1]. These applications, which have an average current consumption in the microamperes or even nanoamperes, cannot afford to waste even one microampere of current in the FB resistor network. Doing so would drastically reduce battery run time.

A traditional power supply uses two resistors – from the output voltage to the FB pin and from the FB pin to GND – to set the output voltage. This creates a leakage path from the output voltage to GND through the resistors. Since the FB net directly controls the output voltage, it is very noise-sensitive and must be immune to any noise sources in the system and application environment. Noise immunity is achieved by setting a large-enough current flowing through the FB resistors.

For example, the [TPS62125](#) low-power, 300-mA step-down converter's data sheet specifies at least 1 μA of current flow through the FB resistors. Higher-current supplies such as the 4-A [TPS62827](#) require higher FB currents due to the higher noise created by switching higher currents. This device's data sheet specifies that at least 6 μA of current flow in the FB resistors. **Figure 3** shows this FB current achieved with the 100-k Ω R2 value and the TPS62827's 0.6-V FB pin voltage.

This 1 μA or 6 μA of current is a loss term, since it does not flow to the load and must ultimately come from the input source or battery. For a 3.6- V_{IN} to 1.8- V_{OUT} application running at 80% efficiency, 6 μA of FB resistor current results in 3.75 μA of input current. Compared to the TPS62827's 4- μA I_Q , this 3.75 μA of additional input current is significant. But when using the 60-nA I_Q [TPS62840](#) instead, a 60 times increase in input current is quite unacceptable [2].

This FB current must be reduced for ultra-low power supplies. One way to achieve this is to bring the FB resistors inside the IC, directly on the silicon. Doing this greatly reduces the circuit area of the FB net. Reducing the area of a net vastly improves its noise immunity [3]. With the

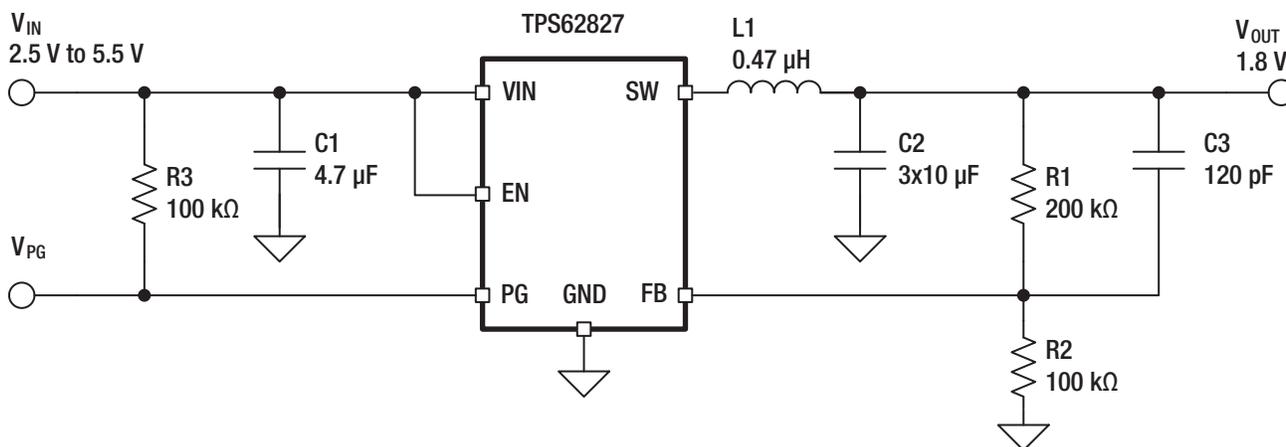


Figure 3. The TPS62827's FB resistors, R_1 and R_2 , consume 6 μA of current.

required noise immunity accomplished, the FB resistor values are increased and their current reduced. **Figure 4** shows the TPS62840's R2D converter on the VSET pin with resistor R_{SET} setting the internal FB resistor values, which set the output voltage.

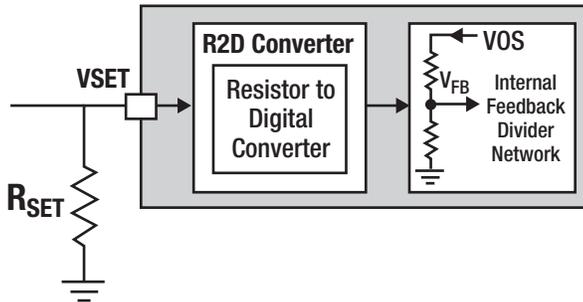


Figure 4. The TPS62840's FB resistors are internal and consume very little current.

Smaller size and lower cost

Comparing Figures 3 and 4, the R2D converter requires one less resistor to set the output voltage compared to the traditional FB circuit. While this saved printed circuit board (PCB) space is critical for wearable systems, the saved cost from having one fewer component can also be significant. In addition, many PCB assembly companies charge a fixed fee for each and every component picked and placed onto the PCB. Finally, one fewer component translates to a simpler PCB layout design. Especially with the fine lead pitches and small spacings in many PCBs, placing just one resistor correctly is easier and faster than placing two resistors correctly.

An R2D circuit also enables the IC to have fewer pins, compared to the implementation of internal FB resistors with voltage select (VSEL) pins. **Figure 5** shows the 8-pin [TPS62743](#), which uses three VSEL pins to select between eight output voltages. The 6-pin TPS62840, which uses a

single pin for an R2D converter, uses two fewer pins while having twice as many (16) output voltage settings.

Tighter output voltage accuracy

Having a tighter output voltage is critical for powering processors and radios to keep their supply voltage within a proper range. A more accurate output voltage also allows more margin for output voltage transients that might result from load changes, such as when a radio transmits or a processor performs certain computing tasks.

The R2D converter reads the external resistor in order to set the proper internal FB resistors, based on a digital look-up table. Since the IC's internal FB resistors are used, the R_{SET} resistor's tolerance does not affect the output voltage accuracy. The R_{SET} resistor does not function the same as a traditional power supply's resistor between the FB pin and GND. The output voltage accuracy with an R2D converter is determined only by the IC's accuracy, and no additional inaccuracy from the external resistor needs to be considered by the designer.

When using 1% accurate FB resistors with a traditional power supply, an R2D converter improves the output voltage accuracy by up to 2% [4]. Furthermore, internal FB resistors improve fault tolerance and failure mode analysis outcomes, since a fault on external FB resistors during operation is not possible with an R2D converter. The resistor is only read at startup and then not used during operation.

In order to ensure that the IC detects the desired value of R_{SET} , be sure and follow the data-sheet guidelines for selecting the R_{SET} resistor's parameters. Generally, a standard 1% resistor from the E96 series with a temperature coefficient of ± 200 ppm/ $^{\circ}\text{C}$ or better is required. Most 1% resistors satisfy these criteria. Place the R_{SET} resistor close to the IC and avoid parasitic capacitance and leakage paths on the VSET net.

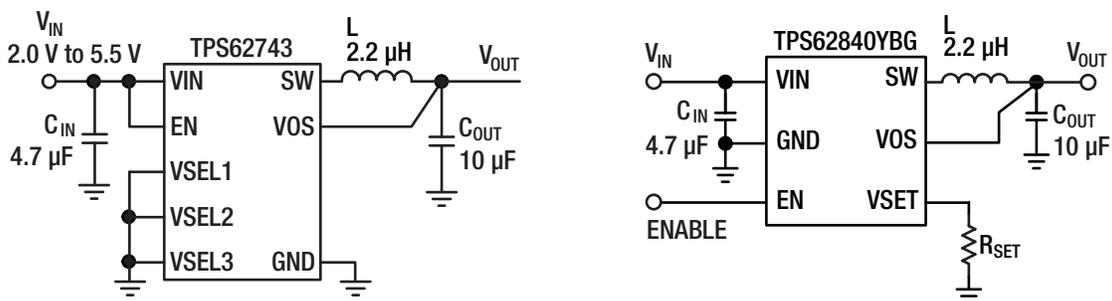


Figure 5. The TPS62743 uses three VSEL pins, instead of the TPS62840's single VSET pin, to set the output voltage.

Design flexibility

R2D converters make a single device and a single IC part number address the needs of more applications through the change of just a resistor. Instead of needing a different IC for each different output voltage or feature, a single device can be qualified, stocked and reused. The same IC can be used for 10 different systems, increasing the volume on that part number by a factor of 10. Higher volumes usually lead to lower cost.

As an example, **Table 1** shows that each IC in the **TPS62800** family provides 16 different output voltages. With just three IC part numbers, 48 output voltages are possible – it’s possible to use the same IC family for numerous, different systems.

So far in this white paper, the R2D converter has only set the output voltage. However, R2D converters can sometimes adjust other settings. For example, **Figure 6** shows the **TPS62810**’s R2D converter on its COMP/FSET pin. This R2D converter sets the internal loop compensation to be stable with different amounts of output capacitance. The COMP portion of the pin works the same as previously described for an R2D converter, while the FSET portion of the pin remains active during operation to control the switching frequency.

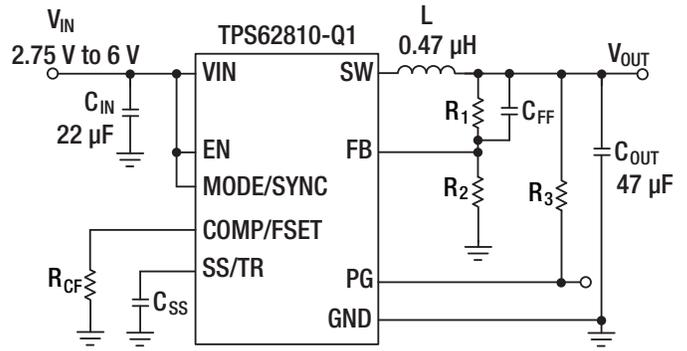


Figure 6. The TPS62810 family uses an R2D converter to set the control-loop compensation on the COMP/FSET pin.

R2D converter limitations

Now that I’ve reviewed the benefits, it’s time to understand the limitations.

An R_{SET} resistor is required

Compared to fixed-output-voltage devices, which require no resistors, an IC with an R2D converter usually requires one extra resistor. For example, the **TPS62230** family contains 20 different part numbers covering 18 different fixed output voltages. The TPS62800 family provides 48 different output voltages with just three part numbers. Some of the more

VSEL	Output voltage setting V_{OUT} [V]			R_{VSEL} Resistance [kΩ], E96 Resistor Series, 1% Accuracy, Temperature Coefficient better or equal than ± 200 ppm/°C
	TPS62800 TPS62806	TPS62801 TPS62807	TPS62802 TPS62808	
0	0.700	1.2	1.8	Connected to GND (no resistor needed)
1	0.400	0.8	1.8	10.0
2	0.425	0.85	1.9	12.1
3	0.450	0.9	2.0	15.4
4	0.475	0.95	2.1	18.7
5	0.500	1.0	2.2	23.7
6	0.525	1.05	2.3	28.7
7	0.550	1.1	2.4	36.5
8	0.575	1.15	2.5	44.2
9	0.600	1.2	2.6	56.2
10	0.625	1.25	2.7	68.1
11	0.650	1.3	2.8	86.6
12	0.675	1.35	2.9	105.0
13	0.700	1.4	3.0	133.0
14	0.725	1.45	3.1	162.0
15	0.750	1.5	3.2	205.0
16	0.775	1.55	3.3	249.0 or larger

Table 1. The TPS62800 family provides 48 different output voltage settings.

common output voltages – 0.7 V, 1.2 V and 1.8 V – do not require an R_{SET} resistor, as the VSET pin connects directly to GND. But a resistor is required for the other 45 output voltages. As noted earlier, using fewer IC part numbers simplifies stocking. For the most space-constrained applications, the R2D converter method is at a slight size disadvantage compared to a fixed-output-voltage IC.

The output voltage is fixed after startup

With an R2D converter, the output voltage is set and stored once at startup. Once the IC is operating, the system is unable to apply a signal into the internal FB pin to adjust the output voltage. For applications that require adjusting the output voltage during operation, you must use another method. The [TPS62866](#) shown in **Figure 7** provides two of these methods to adjust the output voltage: an I²C bus and a voltage identification definition (VID) pin [5].

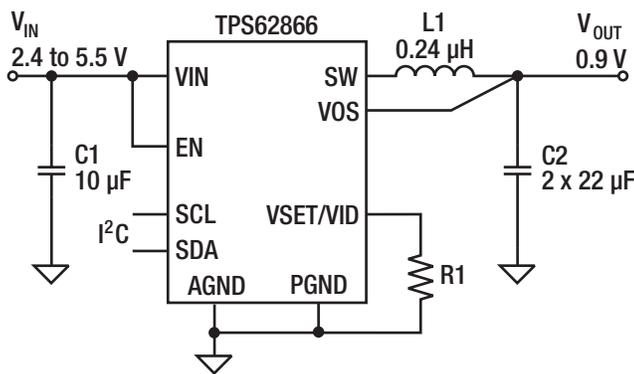


Figure 7. The TPS62866 contains both an I²C bus and a VID pin to adjust the output voltage after startup.

You need two pins for the output voltage

With an R2D converter, one pin (VSET) sets the output voltage and another pin (VOS) senses the output voltage for the FB circuit. A traditional IC such as the TPS62810 requires just an FB pin for both setting and sensing the output voltage.

This extra pin requirement is partially overcome on some devices by combining the VSET pin with another function. Since VSET is only used at startup, the same pin can perform a different function during normal operation. The TPS62866 combines VSET with a VID function to adjust the output voltage, while other TPS62866 versions combine VSET with a /PG function. The TPS62800 family combines VSET with a MODE function to be able to lower the output

noise at the expense of light load efficiency. With these devices, no pin is completely wasted and the device's functionality is maximized as much as possible.

Longer startup time

Compared to a traditional IC, an R2D converter IC takes longer to start up because R_{SET} has to be measured before the IC ramps up the output voltage. Figure 2 shows the R2D converter operating for about 280 µs; during this time, the output voltage is still at 0 V. The overall startup time is still very fast, however – well under 1 ms total.

Conclusion

R2D converters inside power-supply ICs eliminate the FB circuitry's leakage current, achieve smaller size and lower cost, provide tighter output voltage accuracy and offer additional design flexibility compared to a traditional IC's FB pin. Specific ICs have features and functions that overcome the R2D converter's main limitations: requiring one resistor to set the output voltage, adjusting the output voltage during operation, and needing an extra pin to set and control the output voltage. While the R2D converter's operation does lengthen the startup time, the total startup time remains short. Nearly all ultra-low-power applications benefit much more from the reduced current consumption than any of these four drawbacks hinders them.

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