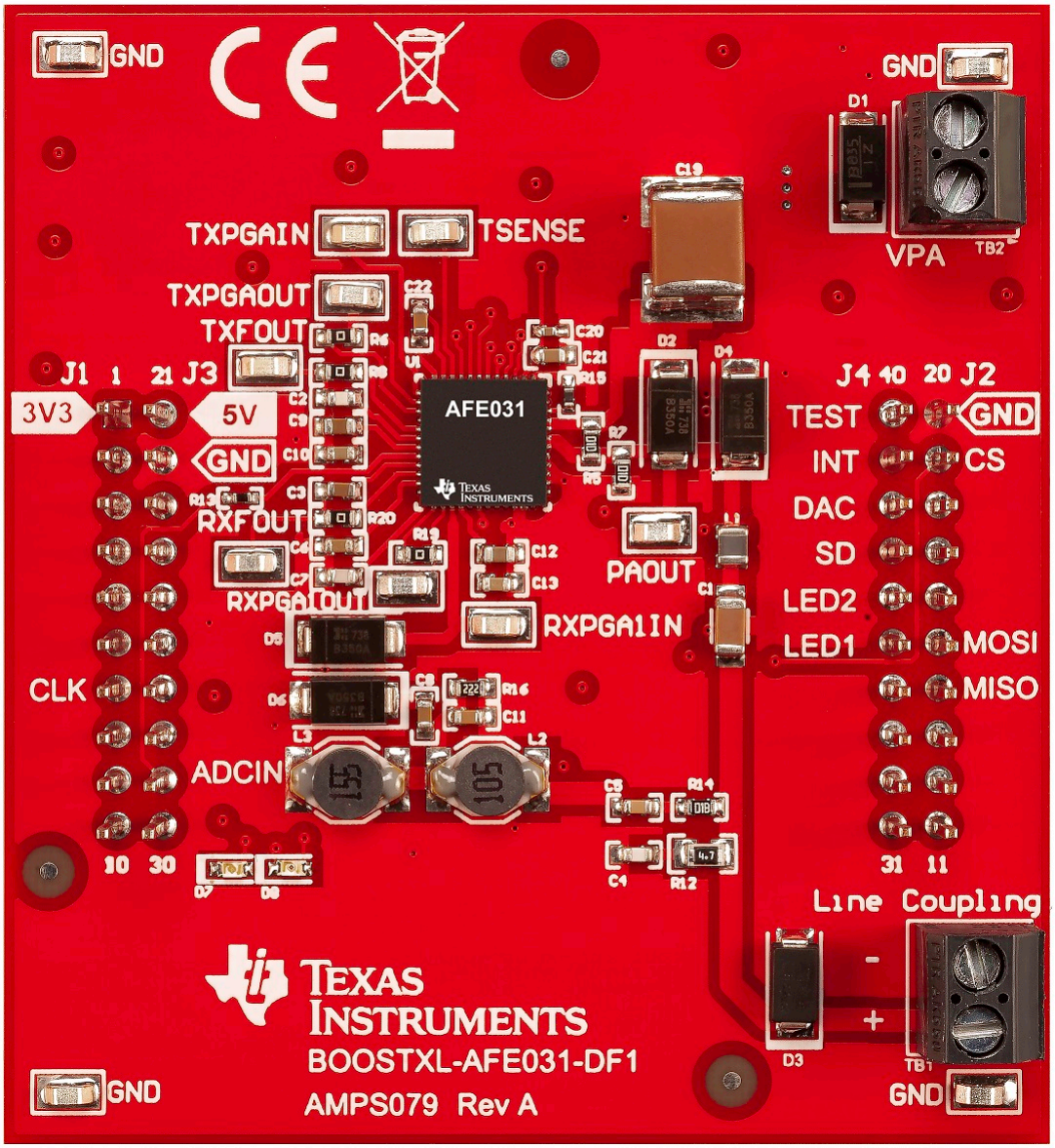
BOOSTXL-AFE031-DF1



The BOOSTXL-AFE031-DF1 evaluation module features the AFE031, TI's integrated power-line communication analog front-end device. When paired with a supported C2000™ microcontroller unit (MCU) LaunchPad™ development kit, the BoosterPack™ plug-in module offers a robust evaluation platform for PLC applications, specifically SunSpec Rapid Shutdown. The BOOSTXL-AFE031-DF1 hardware, software, and operation are presented in this user's guide.

Contents

List of Figures

List of Tables

Trademarks

1 Overview

1.1 AFE031 Power-Line Driver

The AFE031 is an integrated analog front end (AFE) device that enables communication over high-voltage ac and dc power lines. The receiver detects power-line communication (PLC) signals down to 20 μV_{RMS}, and the integrated power amplifier (PA) drives low-impedance lines that require up to 1.5 A into reactive loads.

As illustrated in the functional block diagram presented in Figure 1, the AFE031 transmit (Tx) signal path comprises a digital-to-analog converter (DAC), programmable gain amplifier (PGA), low-pass filter (LPF), and PA. The receive (Rx) signal path includes another LPF and two PGAs that, together, amplify the incoming PLC signal up to 128 times.

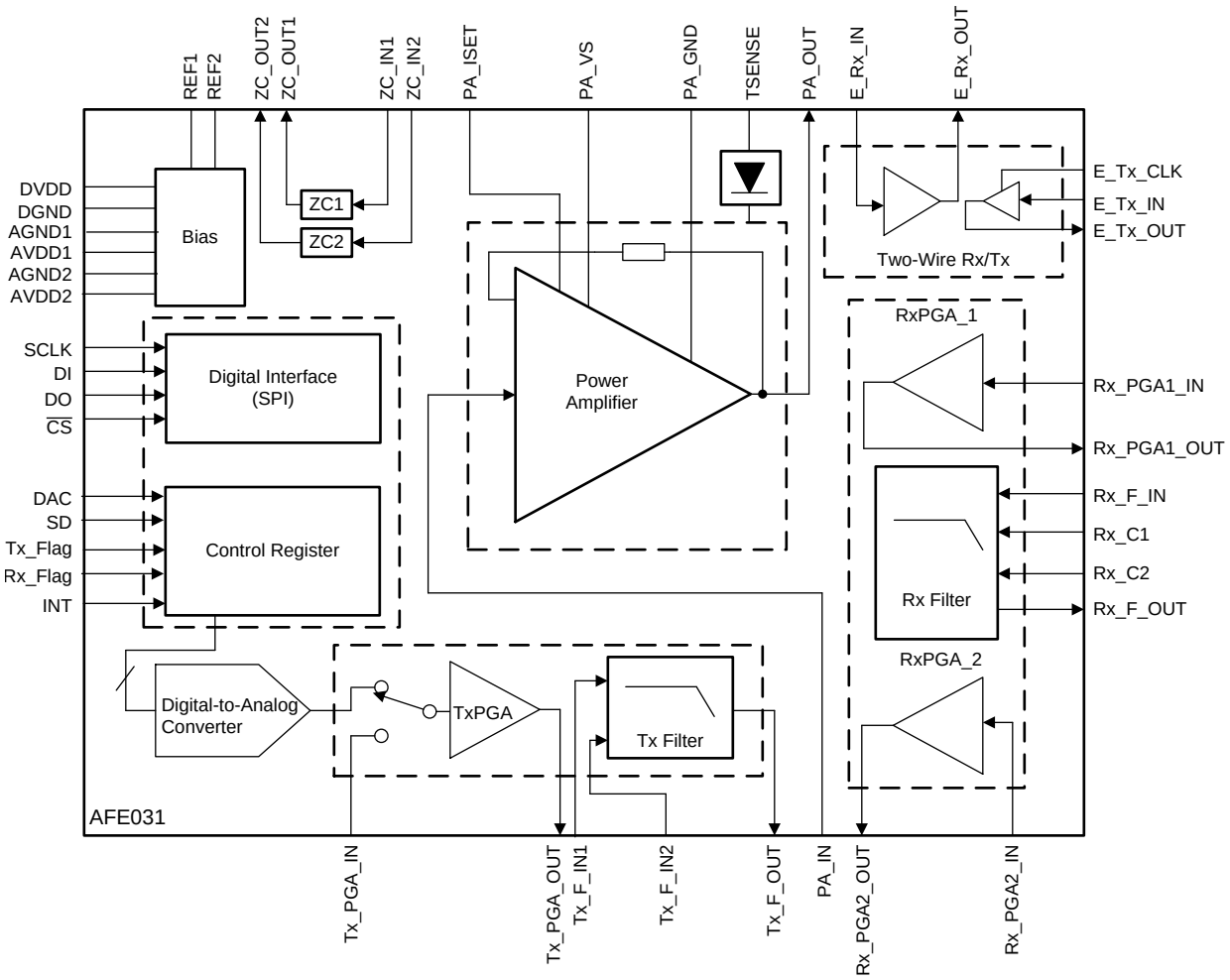


Figure 1. AFE031 Functional Block Diagram

With internal protection against PA overcurrent and thermal shutdown conditions, the monolithic integrated circuit offers high reliability in demanding PLC applications, including eMetering, building automation, electric vehicle charging, and solar power.

1.2 SunSpec Rapid Shutdown

The solar power industry has established a safety mandate to protect first responders and service technicians against harmful shock hazards while interacting with photovoltaic (PV) modules. An open standard for the rapid shutdown (RSD) of PV modules, along with specifications for interoperability testing, has been developed by the SunSpec Alliance. The SunSpec *Communication Signal for Rapid Shutdown Specification*, also referred to as the *RSD communication specification* in this user's guide, applies to the rapid shutdown requirements of PV systems governed by NEC 2017. Effectively, the requirements are:

- A transmitter must broadcast a SunSpec-compliant *permission to operate* signal every second.
- A receiver must detect the absence of a SunSpec-compliant *permission-to-operate* signal and disconnect its companion PV module output from the high voltage dc line input to the host inverter.

The BOOSTXL-AFE031-DF1 demonstrates a SunSpec-compatible application of the AFE031 as a front-end PLC transceiver that can be integrated with a solar power inverter (transmitter), PV module (receiver), or both, to implement the mandated RSD requirement.

1.2.1 RSD Communication Specification

Binary frequency shift keying (BFSK) is a modulation scheme that uses discrete frequency changes of a carrier signal to communicate digital information. Essentially, a pair of carrier frequencies is designated for binary 0 (space) and binary 1 (mark), f_S and f_M, respectively. Table 1 provides critical BFSK parameters defined by the SunSpec RSD communication specification and implemented by the BOOSTXL-AFE031-DF1.

Table 1. SunSpec BFSK Parameters

Parameter	MIN	TYP	MAX	Unit
Mark frequency (f_M)	131.236875	131.25	131.263125	kHz
Space frequency (f_S)	143.735625	143.75	143.764375	kHz
Bit period	5.119488	5.12	5.120512	ms
Logic word 0 (W0): +1 = mark, –1 = space	{ +1, +1, +1, –1, –1, –1, +1, –1, –1, +1, –1 }			—
Logic word 1 (W1): +1 = mark, –1 = space	{ –1, –1, –1, +1, +1, +1, –1, +1, +1, –1, +1 }			—
Permission To Operate packet	[{ W1 }, { W1 }, { W1 }]			—
Accelerated Shutdown packet	[{ W0 }, { W0 }, { W0 }]			—
Tx period (19 words)	1069.972992	1070.08	1070.187008	ms
Tx duration (3 words)	168.943104	168.96	168.976896	ms
Idle duration (16 words)	901.029888	901.12	901.210112	ms

1.3 Related Documentation

Table 2 lists TI literature related to the use of the BOOSTXL-AFE031-DF1.

Table 2. Related TI Literature

Document	Literature Number
AFE031 data sheet	SBOS531
LAUNCHXL-F280049C user's guide	SPRUII7
LAUNCHXL-F28379D user's guide	SPRUI77
Interfacing the C2000™ With an AFE030/1: FSK Example application report	SPRAC94

2 Hardware

2.1 PLC System

Figure 2 shows how the BOOSTXL-AFE031-DF1 serves as the centerpiece of an integrated PLC system that also requires the following:

- C2000 MCU LaunchPad development kit
- C2000Ware firmware
- Line-coupling board (optional)

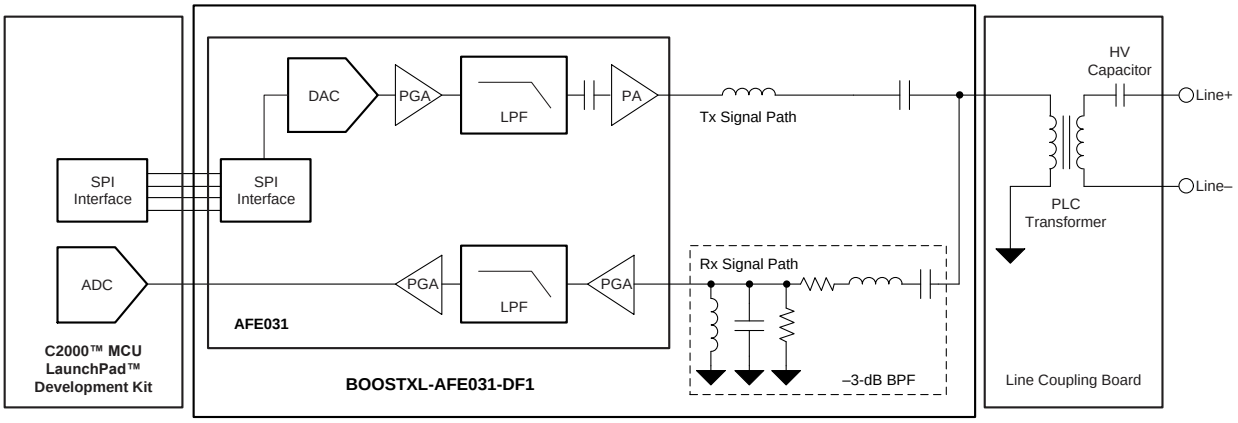


Figure 2. PLC System Diagram

Along with the AFE031 integrated LPF, a -3-dB bandpass filter (BPF) is included in the BOOSTXL-AFE031-DF1 Rx signal path to attenuate the voltage gain of the external line coupling transformer and improve out-of-band noise rejection. The filtered Rx signal is sampled by an analog-to-digital-converter (ADC) and demodulated by the C2000 MCU to decipher the PLC data.

2.2 C2000 MCU LaunchPad Development Kit

The BOOSTXL-AFE031-DF1 must be used with a supported C2000 MCU LaunchPad development kit. There are two LaunchPad development kits available for use: LAUNCHXL-F28379D and LAUNCHXL-F280049C. Figure 3 provides top view images of the two supported LaunchPad targets.

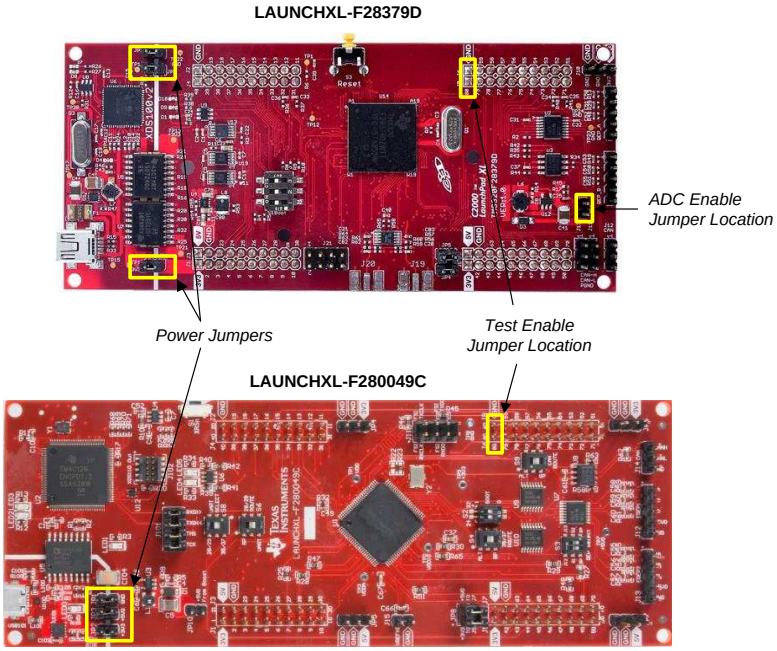


Figure 3. LaunchPad Configuration

2.2.1 Power Jumpers

The BOOSTXL-AFE031-DF1 supplies power to the host LaunchPad; therefore, remove the power jumpers highlighted in Figure 3 before plugging the BoosterPack into the LaunchPad and supplying power to the BoosterPack.

2.2.2 ADC Enable Jumper (LAUNCHXL-F28379D only)

The location of the ADC enable jumper on the LAUNCHXL-F28379D is highlighted in Figure 3. Install the ADC enable jumper when the LAUNCHXL-F28379D is hosting the C2000Ware receiver example; see Section 3.1.1 for more information.

2.2.3 Test Enable Jumper

The test enable jumper location is also highlighted in Figure 3. Combined with the BOOSTXL-AFE031-DF1 test select jumper highlighted in Figure 4, a subset of transmitter test modes can be manually configured.

Table 3 lists the jumper settings for the hardware-selectable transmitter test modes. By default, with no jumpers installed, the transmitter outputs *permission to operate* packets per the RSD communication specification. Additional software-selectable transmitter test modes can be invoked using the serial terminal interface described in Section 4.5.

Table 3. Hardware-Selectable Test Modes

Test Enable Jumper Installed	Test Select Jumper Installed	Transmitter Test Mode
No	No	*Permission to operate* packets
No	Yes	*Accelerated shutdown* packets
Yes	No	Continuous mark tone
Yes	Yes	Continuous space tone

2.3 BOOSTXL-AFE031-DF1 BoosterPack

Figure 4 shows the SunSpec-compatible BOOSTXL-AFE031-DF1 BoosterPack evaluation module (EVM). The BoosterPack must be used with a supported LaunchPad, as described in Section 2.2.

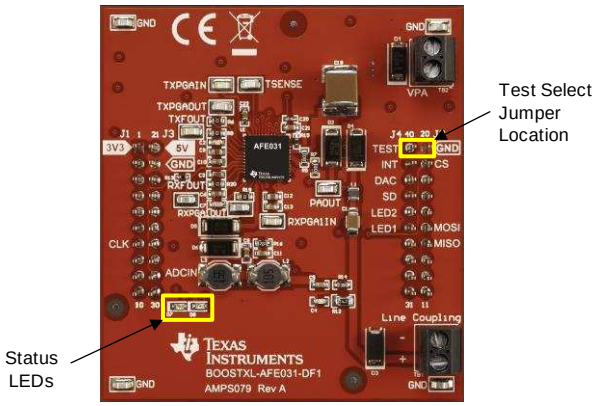


Figure 4. BoosterPack Test Select Jumper

2.3.1 Test Select Jumper

The BOOSTXL-AFE031-DF1 test select jumper location is highlighted in Figure 4. See Table 3 for the hardware-selectable test modes.

2.3.2 Status LEDs

Also highlighted in Figure 4 are two light-emitting diodes (LEDs) that are controlled by the host MCU, and used to indicate the Tx/Rx status. See Section 3 for C2000Ware transmitter and receiver LED operation.

2.3.3 BoosterPack Features

A complete list of BOOSTXL-AFE031-DF1 evaluation features is provided in Table 4. See Section 5 for the BOOSTXL-AFE031-DF1 schematic and bill of materials (BOM).

Table 4. BoosterPack Evaluation Features

Designator	Type	Description
TB1	Terminal Block	Line Coupling Interface
TB2	Terminal Block	PA Supply Input
D7	LED	Blue Status LED
D8	LED	Red Status LED
PAOUT	Test Point	AFE031 PA Output (TP3)
TXPGAIN	Test Point	AFE031 Tx PGA Input for DAC Bypass (TP1)
TXPGAOUT	Test Point	AFE031 Tx PGA Output (TP2)
TXFOUT	Test Point	AFE031 Tx LPF Output (TP11)
RXFOUT	Test Point	AFE031 Rx LPF Output (TP12)
RXPGA1IN	Test Point	AFE031 Rx PGA1 Input (TP4)
RXPGA1OUT	Test Point	AFE031 Rx PGA1 Output (TP10)
GND	Test Point	Probe Grounds (TP6,TP7,TP8,TP9)
TEST	Header Pin	Hardware Test Select Input
INT	Header Pin	AFE031 Overcurrent/Overtemperature Output
DAC	Header Pin	AFE031 DAC Mode Select Input
SD	Header Pin	AFE031 PA Shutdown Input
LED2	Header Pin	TMS320F28x Red Status LED Output
LED1	Header Pin	TMS320F28x Blue Status LED Output
CS	Header Pin	AFE031 SPI Chip-Select Input
MOSI	Header Pin	AFE031 SPI Data Input
MISO	Header Pin	AFE031 SPI Data Output
CLK	Header Pin	AFE031 SPI Clock Input

2.3.4 Installation

To install the BoosterPack onto the LaunchPad, align the 3V3, 5V, and GND labels and carefully plug the BoosterPack into LaunchPad headers J1-J4. Next, while observing voltage polarity, connect a 10-VDC, 1-A bench supply to terminal block 2 (TB2). Although the AFE031 PA supports a wide supply voltage range (7 VDC ≤ VPA ≤ 24 VDC), 10 VDC is adequate for the featured SunSpec-compatible application.

NOTE: The BOOSTXL-AFE031-DF1 employs a TPS62177 buck converter to step the PA supply voltage (V_{PA}) down to 3.3 V for the AFE031 low voltage blocks and host LaunchPad. As instructed in Section 2.2, remove the LaunchPad power jumpers before applying power to TB2.

2.4 Line Coupling Board

The AFE031 is capable of both capacitor-coupled and transformer-coupled connections to the target power line. The transformer-coupled solution presented in Figure 2 is designed for optimal power transfer to the load, and protects the line driver from harmful power-line transients. The high-voltage (HV) capacitor on the secondary side of the transformer is responsible for ac coupling the PLC signal to the dc power line. Table 5 lists the recommended components for the line coupling board.

Table 5. Line Coupling Components

Component	Properties	Manufacturer	Part Number
PLC transformer	Turns ratio = 1.3:1 (primary:secondary)	Wurth Electronik	750510476
	L_{MAG} = 870 µH		
	L_{LEAK} = 507 nH		
HV capacitor	Capacitance = 1.5 µF	KEMET	C4AQSBU4150A1XJ
	Max voltage = 1.5 kV		

NOTE: The prescribed line coupling solution addresses SunSpec PLC applications with dc line voltages ≤ 1 kV and transmitter loads ≥ 1 Ω. Line-coupling components (that is, transformer and HV capacitor), Tx/Rx filters, and the AFE031 configuration must all be carefully matched for dc lines > 1 kV, transmitter loads < 1 Ω, or both.

3 Software

3.1 C2000Ware

C2000Ware is a robust library of open-source firmware and accompanying documentation that minimize the embedded systems development effort. With device-specific drivers, and examples that demonstrate how to use the plethora of C2000 peripherals, C2000Ware offers a robust foundation for evaluating the BOOSTXL-AFE031-DF1. Specifically, C2000Ware includes separate example projects that demonstrate SunSpec-compatible AFE031 transmitter and receiver applications on the two supported LaunchPad targets: LAUNCHXL-F28379D and LAUNCHXL-F280049C.

Table 6 lists the file paths of the C2000Ware example projects that support the BOOSTXL-AFE031-DF1 relative to the root C2000Ware installation directory.

Table 6. C2000Ware Example Projects

LaunchPad	Example	Relative Project Path
LAUNCHXL-F280049C	Receiver	.\device_support\f28004x\examples\boostxl_afe031_f28004x_rx
LAUNCHXL-F280049C	Transmitter	.\device_support\f28004x\examples\boostxl_afe031_f28004x_dacmode
LAUNCHXL-F28379D	Receiver	.\device_support\f2837xd\examples\cpu1\boostxl_afe031_f28379d_rx
LAUNCHXL-F28379D	Transmitter	.\device_support\f2837xd\examples\cpu1\boostxl_afe031_f28379d_dacmode

See Section 4.3 for guidance on downloading, installing, and using C2000Ware and the Code Composer Studio™ (CCS) integrated development environment (IDE) for C2000 MCUs to evaluate the BOOSTXL-AFE031-DF1 example projects.

3.1.1 Receiver Example

NOTE: When the LAUNCHXL-F28379D is configured to host the C2000Ware receiver example, the ADC enable jumper must be installed. Figure 3 shows the ADC enable jumper location for the LAUNCHXL-F28379D.

The C2000Ware receiver example uses two enhanced pulse width modulation (ePWM) channels available on the host TMS320F28x to pace real-time demodulation of the SunSpec RSD signals. One ePWM interrupt service routine (ISR) samples the ADC at least two times the highest carrier frequency (300 kHz, for example) and feeds the acquired values to a correlation-based detection algorithm. Another ePWM ISR runs at three times the SunSpec bit frame rate (586 Hz, for example) to detect the received data bits based on the results of the real-time correlation algorithm.

The main loop simply waits until a full packet is received, and updates the BoosterPack status LEDs based on the packet decode. Table 7 defines the status LED operation for each detected packet.

Table 7. Receiver Status LEDs

Detected Packet	Blue LED	Red LED
None or Unknown	Off	Off
Permission to operate	Toggle	Off
Accelerated shutdown	Off	Toggle
Continuous mark tone	On	Off
Continuous space tone	Off	On

3.1.2 Transmitter Example

Like the receiver example in Section 3.1.1, the C2000Ware transmitter example uses two ePWM channels available on the host TMS320F28x to pace real-time modulation of SunSpec RSD signals. One ePWM channel is programmed to generate an interrupt every 5.12 ms to precisely time bit transitions during packet transmission and to de-energize the line while idle. As illustrated in Figure 5, a *permission to operate* packet is transmitted approximately once per second (209 data bit frames) with a duration of 169 ms (33 data bit frames).

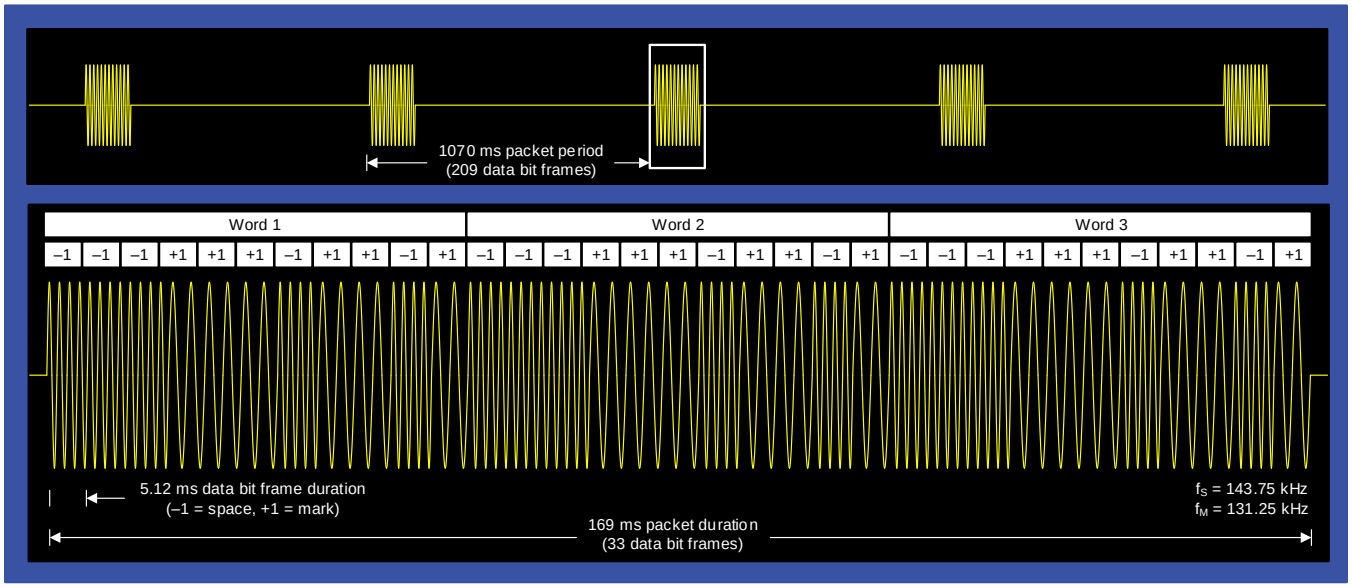


Figure 5. SunSpec *Permission to Operate* Packet

The other ePWM channel is programmed to generate an interrupt every microsecond to update the AFE031 output. Whenever the 1-µs ePWM timer expires, a serial peripheral interface (SPI) transaction is initiated that writes a value from a direct memory access (DMA) data buffer to the AFE031 DAC register, entirely under hardware control. Effectively, the DMA data buffer feeds a decimated, 4096-point sine table to the AFE031 DAC in real time at a 1-MHz rate to modulate the SunSpec space and mark tones for each bit of the *permission to operate* packet.

Meanwhile, approximately 20 times per second, the main loop does the following:

- Sets the DMA data buffer based on the user-selected test mode.
- Manages a serial communication interface (SCI) that enables dynamic calibration of the transmitter.
- Monitors AFE031 overcurrent and thermal shutdown faults.
- Updates the BoosterPack status LEDs to indicate the transmitter state.

Table 8 defines status LED operation for each transmitter state.

Table 8. Transmitter Status LEDs

Transmitter State	Blue LED	Red LED
Idle with no faults detected	Off	Off
Transmitting with no faults detected	On	Off
Multiple overcurrent faults detected	On while transmitting	Toggle
Multiple overtemperature faults detected	On while transmitting	On
Software-selected shutdown test mode	Off	On

4 Operation

4.1 Load Resistor

The C2000Ware transmitter example described in Section 3.1.2 is calibrated to produce a 1-V_{RMS} (1.414-V_{PK}) signal across a typical (10-Ω) load resistor installed on the Line+ and Line– terminals of the line coupling board shown in Figure 2. However, quick bench testing is facilitated by simply installing a load resistor on TB1. Use Equation 1 to determine the required power rating (P) of the load resistor.

$$P = \frac{V^2}{R} \quad (1)$$

where

- V is the voltage applied to the load resistor.
- R is the resistance of the load resistor.

In this case, the voltage (V) applied to the load resistor is the same as the voltage produced on the primary side of the PLC transformer, if the transformer is installed. Therefore, the line-coupling circuit must be included in the power analysis. Effectively, the impedance of the transformer secondary leakage inductance (Z_L), HV capacitor (Z_C), and load resistor (Z_R) form a voltage divider driven by the AFE031 PA. Equation 2 is used to determine Z_L at the SunSpec mark frequency (f_M) of 131.25 kHz.

$$Z_L = 2 \times \pi \times f_M \times L \quad (2)$$

where

- L is the leakage inductance of the transformer secondary winding, 507 nH.

Therefore, Z_L = 0.42 Ω.

Equation 3 is used to determine Z_C at the SunSpec mark frequency (f_M) of 131.25 kHz.

$$Z_C = \frac{1}{2 \times \pi \times f_M \times C} \quad (3)$$

where

- C is the capacitance of the HV capacitor, 1.5 µF.

Therefore, Z_C = 0.81 Ω.

Next, use Equation 4 to determine the transformer secondary voltage (V_S).

$$V_S = V_R \times \frac{Z_R + Z_{LC}}{Z_R} \quad (4)$$

where

- V_R is the voltage across the load resistor, 1 V_{RMS}.
- Z_R is the impedance of the load resistor, 10 Ω.
- Z_{LC} is the series impedance of the HV capacitor and transformer leakage inductance.

Therefore, V_S = 1.12 V_{RMS}, or 1.6 V_{PK}.

Then, use Equation 5 to determine the peak voltage at the primary side of the transformer (V_P) with a 1.3:1 primary-to-secondary turns ratio.

$$V_P = V_S \times 1.3 \quad (5)$$

where

- V_S is the transformer peak secondary voltage.

Therefore, V_P = 2.1 V_{PK}.

Finally, substituting V_P back into Equation 1, a 10-Ω load resistor with 10% or better manufacturing tolerance requires a power rating ≥ 0.5 W. Although this analysis methodology yields a good approximation of the peak voltage produced at the line coupling terminal (TB1), perform a bench measurement to determine the actual peak voltage applied to the load resistor.

4.2 Power Supply

The operating region of the AFE031 PA is determined largely by the line-coupling circuit components and their ac impedances at the SunSpec mark and space carrier frequencies. Using the transformer coupling recommended in Figure 2, the AFE031 PA drives the series impedance comprising the leakage inductance of the transformer secondary winding, high voltage (HV) capacitor, and load resistor.

The analysis presented in Section 4.1, which is used to determine the power rating of the load resistor, also yields the theoretical peak voltage on the primary side of the transformer. Effectively, the single-supply AFE031 PA outputs the dc-coupled version of the PLC signal centered at midsupply. Use Equation 6 to determine the minimum AFE031 PA supply voltage (V_{PA}).

$$V_{PA} = 2 \times \left(V_P + 2V_{SWING} \right) \quad (6)$$

where

- V_P is the transformer's peak primary voltage.
- 2 V_{SWING} is the maximum swing from rail specification for the AFE031 PA.

Therefore, V_{PA} = 8.2 V.

Although the computed value is a good starting point for the design, simulation is recommended for analyzing the behavior of circuits that comprise complex reactive and resistive loads. The best practice is to probe the AFE031 PA output to minimize the supply voltage while making sure the signal is not distorted.

CAUTION

Do not set the supply voltage higher than the minimum required level to avoid excessive power consumption and overheating, and thus premature device failure.

4.3 Firmware Programming

C2000Ware includes SunSpec-compatible transmitter and receiver examples that can be used to evaluate the BOOSTXL-AFE031-DF1 with one of the supported LaunchPad platforms: LAUNCHXL-F28379D or LAUNCHXL-F280049C. The following instructions provide quick-start programming guidance:

1. Download and install Code Composer Studio (CCS) Integrated Development Environment (IDE) for C2000 Microcontrollers.
2. Download and install C2000Ware.
3. Connect the universal serial bus (USB) cable included with the host LaunchPad.
4. Refer to the CCS application help menu for guidance on importing, compiling, and loading C2000Ware example projects. Table 6 provides relative file paths to the AFE031 example projects for the supported LaunchPad platforms.

4.4 Transmitter Calibration

The BOOSTXL-AFE031-DF1 offers SunSpec-compatible transmitter operation over a wide range of loads ≥ 1 Ω. Although the preset firmware modulation parameters enable quick-start demonstration, each SunSpec RSD transmitter implementation may require calibration to provide SunSpec-compatible operation. Use the following steps to calibrate the transmitter:

1. Configure the transmitter hardware with the application-specific line coupling circuit, including the equivalent load impedance of the receiver network.
2. Use the *test enable* jumper on LaunchPad and *test select* jumper on BoosterPack to output continuous mark and space tones.
3. Optimize the *GAIN_MARK_x1024* and *GAIN_SPACE_x1024* global variables in the main source file of the C2000Ware transmitter project (for example, *boostxl_afe031_f28004x_dacmode_main.c* for the LAUNCHXL-F280049C), such that the ac voltage across load resistor measures 1 V_{RMS} for both tones. Section 4.3 provides programming guidance for the BOOSTXL-AFE031-DF1 firmware examples.

4.5 Serial Terminal Interface

To facilitate AFE031 calibration, the C2000Ware transmitter example implements a simple serial terminal interface. Along with version information and help, commands are included to invoke user test modes and adjust the mark and space firmware gain values, as well as DAC offset code. With the USB programming cable connected, use the Windows™ Device Manager to discover which COM port is assigned to the LaunchPad. Then, use a serial terminal program to configure the serial port, connect to the LaunchPad, and send commands to the transmitter in real time. When enhanced with commands to read and write nonvolatile memory, the serial terminal functionality enables production calibration of individual transmitters.

LaunchPad serial communication parameter values are listed inTable 9.

Table 9. Serial Communication Parameters

Parameter	Value
Baud rate	230400
Parity	None
Data bits	8
Stop bits	1

All serial commands are in 8-bit ASCII text format, and are terminated with a single carriage return (CR) character. Similarly, all responses are in 8-bit ASCII text format and are terminated with a carriage return-line feed (CRLF) character combination and command prompt (>>).

A description of the serial commands implemented by the C2000Ware transmitter example is provided in Table 10. Hardware-selected test modes defined in Table 3 can be overridden by software-selected test modes (that is, using the serial terminal interface) and vice versa.

Table 10. Transmitter Serial Commands

Command	Description	
h	Get command help.	
v	Get version Information.	
m	Get mark firmware gain.	
m=*ddd*	Set mark firmware gain (*ddd* is decimal value in the range 0 to 999).	
s	Get space firmware gain.	
s=*ddd*	Set space firmware gain (*ddd* is decimal value in the range 0 to 999).	
o	Get DAC offset code.	
o=*dd*	Set DAC offset code (*dd* is decimal value in the range 0 to 99).	
c	Get PA overcurrent count.	
c=*d*	Set PA overcurrent count (*d* is typically set to 0 to reset counter).	
t	Get PA overtemperature count.	
t=*d*	Set PA overcurrent count (*d* is typically set to 0 to reset counter).	
u	Get user test mode.	
u=*d*	Set user test mode (*d* is decimal value in the range 0 to 7).	
	Test Mode Value	**Test Mode Description**
	0	Transmit *Permission to operate* packets.
	1	Transmit *Accelerated shutdown* packets.
	2	Transmit continuous mark tone.
	3	Transmit continuous space tone.
	4	Transmit continuous logic word 0 (W0).
	5	Transmit continuous logic word 1 (W1).
	6	Transmit PA shutdown.
	7	Transmit PA enable.

NOTE: A simple PLC network can be demonstrated using two BoosterPack and LaunchPad pairs: one pair configured as the transmitter, and the other pair as the receiver. With the load resistor described in Section 4.1 installed on the transmitter BoosterPack, carefully wire the positive (+) and negative (–) terminals of the transmitter and receiver line-coupling terminal blocks (TB1) together. Then, apply power to both BoosterPacks and observe the receiver status LEDs while changing the transmitter test mode.

5 Schematic and Bill of Materials

5.1 Schematic

Figure 6 shows the schematic for BOOSTXL-AFE031-DF1.

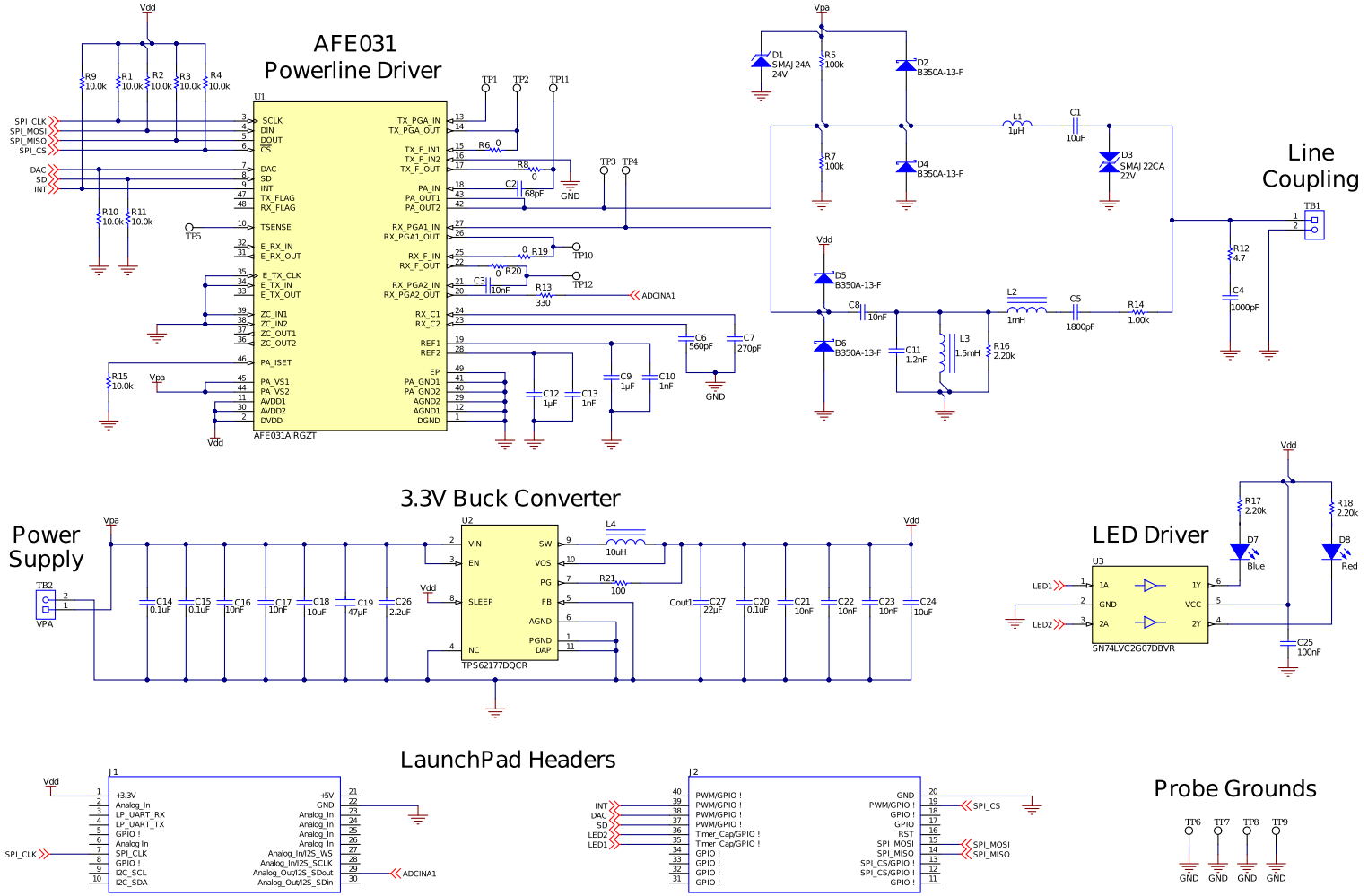


Figure 6. BOOSTXL-AFE031-DF1 Schematic

5.2 Bill of Materials

Table 11 provides the parts list for the BOOSTXL-AFE031-DF1.

Table 11. BOOSTXL-AFE031-DF1 Bill of Materials

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer
!PCB	1		Printed Circuit Board		AMPS079	Any
C1	1	10uF	CAP, CERM, 10 uF, 50 V, +/- 10%, X5R, 1206	1206	C3216X5R1H106K160AB	TDK
C2	1	68pF	CAP, CERM, 68 pF, 50 V, +/- 5%, C0G/NP0, 0603	0603	06035A680JAT2A	AVX
C3, C8, C16, C17, C21, C22, C23	7	0.01uF	CAP, CERM, 0.01 µF, 50 V,+/- 10%, X7R, 0603	0603	885012206089	Wurth Elektronik
C4	1	1000pF	CAP, CERM, 1000 pF, 50 V, +/- 10%, C0G/NP0, 0603	0603	06035A102KAT2A	AVX
C5	1	1800pF	CAP, CERM, 1800 pF, 50 V, +/- 10%, X7R, 0603	0603	GRM188R71H182KA01D	MuRata
C6	1	560pF	CAP, CERM, 560 pF, 50 V, +/- 5%, C0G/NP0, 0603	0603	06035A561JAT2A	AVX
C7	1	270pF	CAP, CERM, 270 pF, 50 V, +/- 5%, C0G/NP0, 0603	0603	06035A271JAT2A	AVX
C9, C12	2	1uF	CAP, CERM, 1 uF, 50 V, +/- 10%, X7R, 0603	0603	UMK107AB7105KA-T	Taiyo Yuden
C10, C13	2	1000pF	CAP, CERM, 1000 pF, 16 V, +/- 10%, X7R, 0603	0603	885012206034	Wurth Elektronik
C11	1	1200pF	CAP, CERM, 1200 pF, 100 V, +/- 5%, X7R, 0603	0603	06031C122JAT2A	AVX
C14, C15, C20	3	0.1uF	CAP, CERM, 0.1 uF, 35 V, +/- 10%, X5R, 0402	0402	GMK105BJ104KV-F	Taiyo Yuden
C18, C24	2	10uF	CAP, CERM, 10 uF, 35 V, +/- 20%, X5R, 0603	0603	GRM188R6YA106MA73	Nichicon
C19	1		47µF ±20% 35V Ceramic Capacitor X7R Stacked SMD, 2 J-Lead	Stacked SMD/2220	KRM55WR7YA476MH01K	Murata
C25	1	0.1uF	CAP, CERM, 0.1 uF, 16 V, +/- 5%, X7R, 0603	0603	0603YC104JAT2A	AVX
C26	1	2.2uF	CAP, CERM, 2.2 uF, 50 V, +/- 10%, X5R, 0603	0603	GRM188R61H225KE11D	MuRata
C27	1	22uF	CAP, CERM, 22 µF, 25 V,+/- 20%, X5R, AEC-Q200 Grade 3, 0805	0805	GRT21BR61E226ME13L	MuRata
D1	1	24V	Diode, TVS, Uni, 24 V, 38.9 Vc, 400 W, 10.3 A, SMA	SMA	SMAJ24A	Littelfuse
D2, D4, D5, D6	4	50V	Diode, Schottky, 50 V, 3 A, SMA	SMA	B350A-13-F	Diodes Inc.
D3	1	22V	Diode, TVS, Bi, 22 V, 35.5 Vc, 400 W, 11.3 A, SMA (non-polarized)	SMA (non-polarized)	SMAJ22CA	Littelfuse
D7	1	Blue	LED, Blue, SMD	LED_0603	150060BS75000	Wurth Elektronik
D8	1	Red	LED, Red, SMD	LED_0603	150060RS75000	Wurth Elektronik
J1, J2	2		Receptacle, 2.54mm, 10x2, Tin, TH	10x2 Receptacle	SSQ-110-03-T-D	Samtec
L1	1		FIXED IND 1UH 1.65A 119 MOHM SMD	0806	LQM2MPN1R0MEHL	Murata
L2	1	1mH	Inductor, Drum Core, Ferrite, 1 mH, 0.1 A, 19 ohm, SMD	6.6x2.49x4.45mm	DO1607B-105MLB	Coilcraft

Table 11. BOOSTXL-AFE031-DF1 Bill of Materials (continued)

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer
L3	1	1.5mH	Inductor, Drum Core, Ferrite, 1.5 mH, 0.08 A, 21 ohm, SMD	6.6x2.49x4.45mm	DO1607B-155MLB	Coilcraft
L4	1	10uH	Inductor, Shielded Drum Core, Ferrite, 10 uH, 1.25 A, 0.18 ohm, SMD	LPS4018	LPS4018-103MRB	Coilcraft
R1, R2, R3, R4, R9, R10, R11, R15	8	10.0k	RES, 10.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040210K0FKED	Vishay-Dale
R5, R7	2	100k	RES, 100 k, 1%, 0.1 W, 0603	0603	RC0603FR-07100KL	Yageo
R6, R8, R19, R20	4	0	RES, 0, 5%, 0.1 W, 0603	0603	RC0603JR-070RL	Yageo
R12	1	4.7	RES, 4.7, 5%, 0.125 W, AEC-Q200 Grade 0, 0805	0805	ERJ-6GEYJ4R7V	Panasonic
R13	1	330	RES, 330, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW0402330RJNED	Vishay-Dale
R14	1	1.00k	RES, 1.00 k, 1%, 0.1 W, 0603	0603	RC0603FR-071KL	Yageo
R16, R17, R18	3	2.20k	RES, 2.20 k, 1%, 0.1 W, 0603	0603	RC0603FR-072K2L	Yageo
R21	1	100	RES, 100, 1%, 0.1 W, 0402	0402	ERJ-2RKF1000X	Panasonic
TB1, TB2	2		Terminal Block, 3.5mm Pitch, 2x1, TH	7.0x8.2x6.5mm	ED555/2DS	On-Shore Technology
TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12	12		Test Point, Miniature, SMT	Testpoint_Keystone_Miniature	5015	Keystone
U1	1		Powerline Communications Analog Front End, 7 to 26 V, -40 to 125 degC, 48-pin QFN (RGZ48), Green (RoHS & no Sb/Br)	RGZ0048B	AFE031AIRGZT	Texas Instruments
U2	1		28V, 0.5A Step-Down Converter with SNOOZE Mode, DQC0010A (WSON-10)	DQC0010A	TPS62177DQCR	Texas Instruments
U3	1		Dual Buffer/Driver with Open-Drain Output, DBV0006A, LARGE T&R	DBV0006A	SN74LVC2G07DBVR	Texas Instruments

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1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an “EVM” or “EVMs”) to the User (“User”) in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.

   1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM (“Software”) shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software

   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

   2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

User shall operate the Evaluation Kit within TI’s recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI’s recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI’s instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *Regulatory Notices:*

3.1 *United States*

3.1.1 *Notice applicable to EVMs not FCC-Approved:*

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

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6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY EPIDEMIC FAILURE WARRANTY OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

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9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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