AC LED Lighting & Communications Developer's Kit Hardware Reference Guide
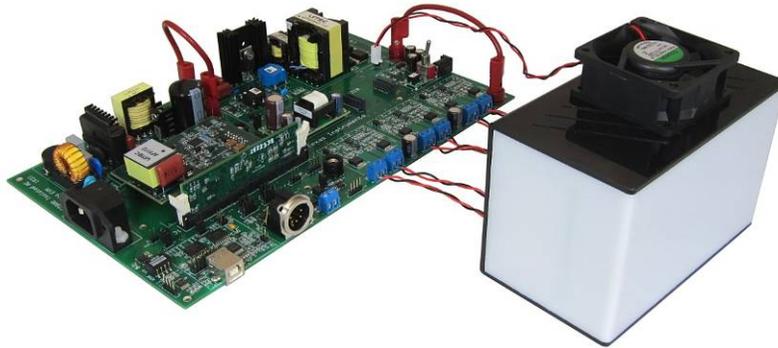
Fig 1: TMDSIACLEDCOMKIT

1 Introduction

The AC LED Lighting & Communications Developer's Kit provides a great way to learn and experiment with using a single MCU to accurately control a series of LED strings and efficiently control the power stages needed to make the LEDs work. This document goes over kit contents, the kit hardware details and explains the functions and locations of jumpers and connectors present on the board. This document supersedes all the documents available for the hardware of this kit.

NOTE: this kit is designed to be a kit to explore the functionality of the C2000 microcontroller. It is not intended to be a full refererence design. Full compliance to safety, EMI/EMC and other regulations are left to the designer of the final customer's system.

WARNING

⚠️ **This EVM is meant to be operated in a lab environment only and is not considered by TI to be a finished end-product fit for general consumer use.**

This EVM must be used only by qualified engineers and technicians familiar with risks associated with handling high voltage electrical and mechanical components, systems and subsystems.

This equipment operates at voltages and currents that can result in electrical shock, fire hazard and/or personal injury if not properly handled or applied. Equipment must be used with necessary caution and appropriate safeguards employed to avoid personal injury or property damage.

It is the user's responsibility to confirm that the voltages and isolation requirements are identified and understood, prior to energizing the board and or simulation. When energized, the EVM or components connected to the EVM should not be touched.

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2 Getting Familiar with the Kit

2.1 Assumed Operating Conditions

This kit is assumed to run at standard room conditions. The EVM should run at approximately Standard Ambient Temperature and Pressure (SATP) with moderate-to-low humidity.

2.2 Kit Contents

The kit consists of:

- AC LED Lighting & Communications motherboard
- Piccolo F28027 controlCARD
- LED panel which contain OSRAM Golden Dragon or Golden Dragon Plus white LEDs
- AC power cable
- 2 Red Banana Plug Cables
- 12V DC/DC power supply
- USB Cable
- USB drive with GUI executable inside and CCS Installer

A F28027 control card is shipped with the kit, however the board can also accept any other C2000 series controlCARD. Some software changes may be necessary to have the board work with a different controlCARD.

2.3 Kit Features: The kit has the following features

- **F28027 Microcontroller** is located on the secondary side of the board and controls the LLC Resonant, six LED strings and the communication interface which will control the LEDs.

- **Single Phase PFC Boost Power Stage** is used to increase the power factor to meet regulations, such as IEC 61000-3-2, which limit the strength of current harmonics that may be injected into the supply line.
  - o 85-250V AC input into [Main]-P1
  - o Regulated output of 380-395Vdc from [Main]-BS1
  - o Controlled by the low-cost UCC28810 Transitional Mode power controller
  - o Overvoltage Protection, open-feedback protection and enable circuits

- **LLC Resonant Stage** is used to step down the 400Vdc bus to the LED bus voltage. LLC converters are known for their low cost, high-efficiency and isolation capabilities.
  - o 375-395V DC input into [Main]-BS3
  - o 29V-36V DC output from [Main]-BS4
  - o 114kHz resonant tank frequency
  - o 63.2kHz-150kHz operating frequency (nearly all operation occurs when the operating frequency is less than the resonant frequency)

- **LED Dimming Stages** PWM dim each individual LED string to meet a desired average current.
  - o 28 – 36V DC input into [Main]-BS6 ***
  - o 1A max current per LED string
  - o 31.25Khz switching frequency for each LED dimming stage

- **Onboard Isolated JTAG emulation** with XDS100v1 emulator

- **Isolated UART** through the SCI peripheral and the FTDI device.

- **DMX512 Communications** through the C2000's SCI peripheral and interfacing circuitry. Receive capabilities have been tested thoroughly, but transmit capabilities have not although they are also implemented. Communications go through [Main]-J8.
  See TMDSIACLEDCOMKIT-DMX512Guide.pdf.

- **DALI Communications** via the C2000's eCAP peripheral and interfacing circuitry. Communicates through [Main]-TB7. See TMDSIACLEDCOMKIT-DALIGuide.pdf.

- **KNX Communications** header has been implemented and connects to the C2000's SCI peripheral. Header for communication is [Main]-J13.

- **PLC Communications** through an add-on board which can be connected at [Main]-J9. Uses the SPI/McBSP peripheral, ADC, and CPU horsepower of the C2000 device. This module plus a PLC-V3 kit are needed to show PLC and are sold as kits:

  o TMDSPLCMODA-P3X – Adapter board which supports Cenelec-A band PLC communication with the F28035 MCU.

  o TMDSPLCKIT-V3 – Standard PLC evaluation kit. Comes with two PLC docking station boards. One of these boards is used as the master in PLC communications with the TMDSIACLEDCOMKIT board slave.

  See TMDSIACLEDCOMKIT-PLCQSG.pdf for more information.

- **RF Communications** connector at [Main]-J10 that could interface with a CC1101EMK or CC2520EMK module. No claims are made as to RF compliance or operation. If done, the user proceeds at their own risk.

- **I^2C interface** header that could communicate with the onboard EEPROM or any other capatible I^2C device (such as a temperature sensor)

- **Hardware Developer's Package** that includes schematics and bill of materials, is available through controlSUITE.

***The DC input for the LEDBus should match with the specifications for the attached LED string. On the panel that comes with the board, each LED conducts with a forward voltage between 2.8-3.4 volts. Therefore, for the LED panel that ships with the kit using ~34V DC input is recommended.

Note that the board is shipped with a 250V, 3 Amp fuse in the PFC power stage's fuse holder [M1]-F1, this fuse may need to be replaced with an appropriate rating fuse.

3 Hardware Overview

Fig 2, illustrates a LED lighting system running from AC power. The TMDSIACLEDCOMKIT board assumes an mains AC input, steps down the DC voltage to a common LED bus voltage, and then controls each LED string (Fig 2 and 4).
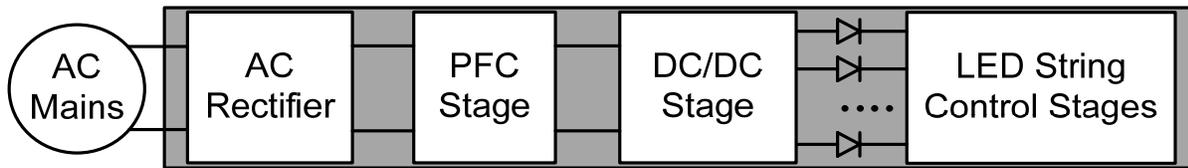

Fig2: Block Diagram for a typical LED lighting application

There are multiple ways of controlling LEDs. On this board, we use the C2000 to generate a common DC supply for all the LED strings. Dimming is then accomplished on the C2000 by varying the time at which an LED is on. In this way, we alter the average current passed through an LED string and this current is monitored and controlled. Since average current is roughly proportional to lumen output, each LED strings' brightness is controlled.

3.1 Macro Blocks

The LED Lighting board is separated into functional groups that together create a complete LED system. In our documentation, these groups are referred to as macro blocks. Following is a list of the macro blocks present on the board and their functions:

- [Main] – consists of controlCARD socket, all communications hardware, many major jumpers, and the routing of signals between the controlCARD and the macro blocks. This section is all of the area outside of the macro blocks.
- [M1] – A single-phase PFC boost stage.
- [M2] – A LLC resonant DC/DC conversion stage, used to decrease the input voltage to the voltage used by the LED strings.
- [M3]-[M5] – stages used to individually dim an LED string. Each macro consists of the components needed to control two strings.
- [M6] – Converts 400V DC input into 18V DC for the primary side and 12V DC for the secondary side.
- [M7] – Generates the 12V, 5V, and 3.3V DC rails from an external 12V supply that is not included with the kit.
- [M8] – Provides on-board isolated JTAG connection through USB to the host. Is also used to provide isolated SCI (UART) communcation for connection with a GUI.

Fig 3, illustrates the position of these macro blocks on the board. The use of a macro block approach, for different power stages enables easy debug and testing of one stage at a time. Banana jack connectors can be used to interconnect the power line of these power stages / blocks to construct a complete system. All the PWM and ADC signals, which are the actuation and sense signals, have designated test points on the board. This makes it easy for an application developer to try out new algorithms and strategies.

Nomenclature: A component on the board is referred to with a macro number in the brackets followed by a dash and the reference number. For example, [M7]-J1 refers to the jumper J1 located in the macro M7 and [Main]-J1 refers to the J1 located on the board outside of the defined macro blocks.
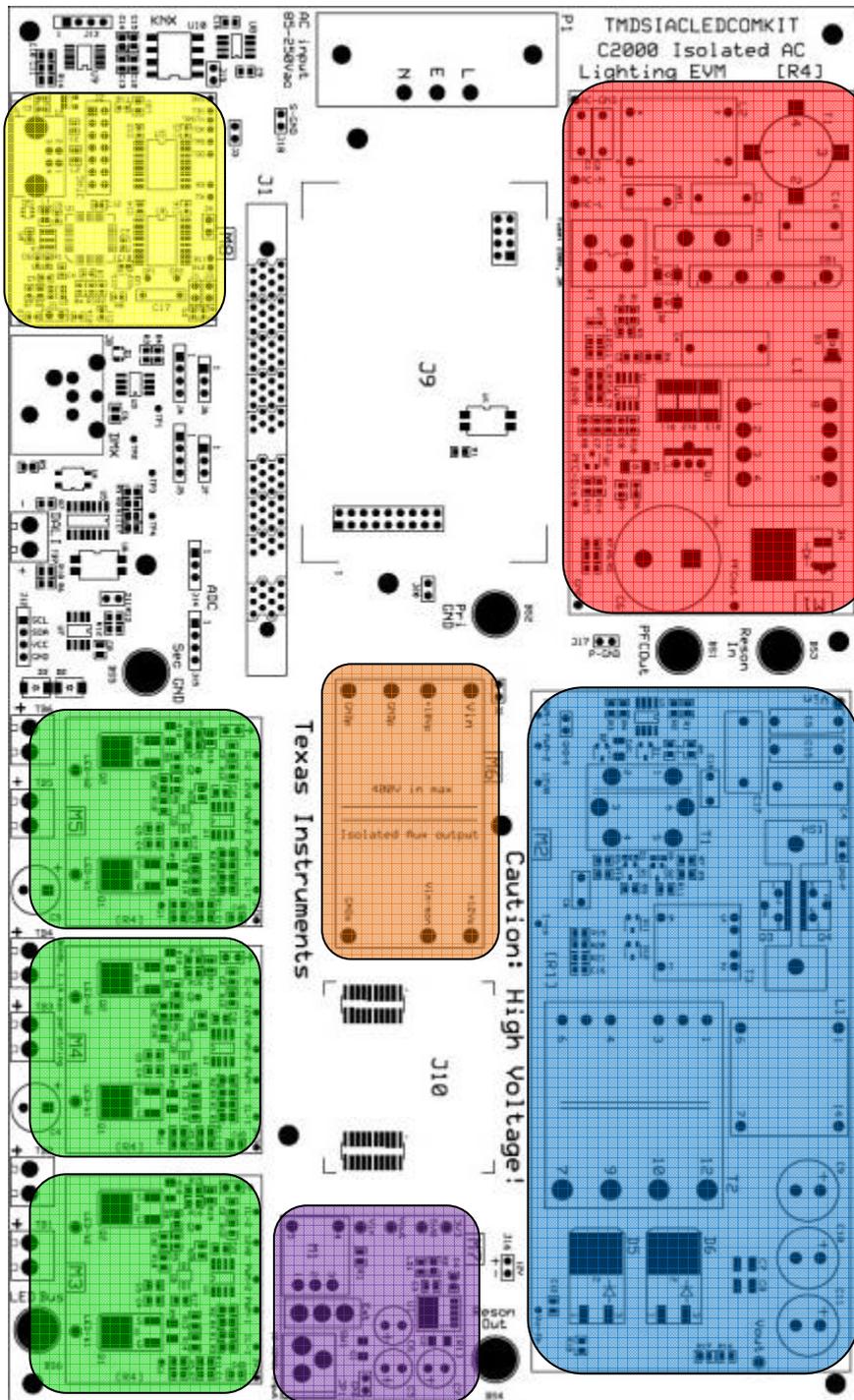
| [Main] - controlCARD connection, jumper configurations, communications |
| [M1] – PFC Stage |
| [M2] – LLC Resonant Converter Stage |
| [M3-M5] – LED Dimming Stages |
| [M6] – Isolated DC/DC converter module |
| [M7] – DC power entry |
| [M8] – Isolated USB Emulation |

3.2 Powering the Board:

Using the AC LED Lighting & Communications board may be used such that all stages are hooked together in series or each stage may be tested independently. The question of which mode of operation should be used will depend on if the board is being used for evaluation or for experimentation.

⚠️ **WARNING:** **Always use caution when using the board's electronics due to presence of high voltages.**

1) **Evaluation Mode –** used to quickly show how the boards functions with the GUI that is included with the software. In this mode all power used by the board is provided from the AC mains.
    * Jumpers:
        i.   [Main]-J2, [Main]-J20 should be populated
        ii. [Main]-J3 should be unpopulated
        iii. [Main]-J4 and [Main]-J5 should both be populated across positions 2 and 3.
        iv. [Main]-J6 and [Main]-J7 should both be populated across positions 1 and 2 (or if using DMX512 software in the 2, 3 position)
    * [Main]-BS1 and [Main]-BS3 should be connected by a red banana cable.
    * [Main]-BS4 and [Main]-BS6 should be connected by a red banana cable
    * The LED which comes with the kit should be attached to [Main]-TB1-TB6.
    * [M7]-SW1 should be switched away from "Ext".
    * 12V does NOT need to be connected to [M7]-JP1.
    * AC input cable should be put into [Main]-P1 (once this is done the board should be considered live)

2) **PFC Experimentation Mode** – uses two different supplies to minimize the risk of damage caused while experimenting. One will be supplied to the AC line (ideally by a current limited AC source) and the other will supply 18V to power the controller.
    * Jumpers [Main]-J2 and [Main]-J20 should be unpopulated
    * Connect, but do not turn on, a +18V dc supply across the left pin of [Main]-J20 (+) and [Main]-J17 (-)
    * Some load can be attached between [Main]-BS1 (+) and [Main]-BS2 (-)
    * AC input cable should be put into [Main]-P1 (once this is done the board should be considered live)
    * Turn on PFC controller and then AC source.

3) **LLC/LED Experimentation Mode** – uses two different supplies to minimize the risk of damage caused while experimenting. One supply will be used to power the high voltage line that will feed the LLC or LED bus and the other will power the auxilliary supply that will power the MCU. This mode also allows for more experimentation with how the LLC or LED stages work.
    * Jumpers:
        i.   [Main]-J3 should be populated
        ii. [Main]-J4 and [Main]-J5 should both be populated across positions 2 and 3.
        iii. [Main]-J6 and [Main]-J7 should both be populated across positions 1 and 2.
    * 12V should be connected to [M7]-JP1.
    * [M7]-SW1 should be switched toward "Ext".
    * Use CCS to experiment with the board (see TMDSIACLEDCOMKIT_CCS.pdf)

    For LLC testing:
    ➢ 390V DC should be applied between [Main]-BS3 (+) and [Main]-BS2 (-).
    ➢ A 10-250W load should be connected across [Main]-BS4 (+) and [Main]-BS5 (-).

For LED testing
- ➢ 0-40V DC should be applied between [Main]-BS6 (+) and [Main]-BS5 (-). The voltage input to this stage is limited to 43V. If the LED panel provided is used the input should be 36V DC maximum.
- ➢ An LED panel, such as the one that comes with this kit ***, should be attached to [Main]-TB1-TB6.

***If the LEDs used are different from the ones shipped with the board or the user has decided to change the amount of LEDs to better fit their application, the DC bus voltage would need to be altered to compensate.

3.3 Boot Modes

Software written around the kit assumes the controlCARD will boot from FLASH. Table 1, describes the jumper and switch settings that are needed for booting from FLASH for the controlCARD.

	Boot from FLASH
F2802x	SW1 on controlCARD- Position 1 = 1 Position 2 = 1 Remove the jumper [Main]-J3
F2803x	SW2 on controlCARD- Position 1 = 1 Position 2 = 1 Remove the jumper [Main]-J3
F2806x	SW1 on controlCARD- Position 1 = 1 Position 2 = 1 Remove the jumper [Main]-J3

Table 1: Boot Options

To instead run a system with Code Composer Studio active and debug a project, [Main]-J3 should be populated.

3.4 GUI Connection

The FTDI chip present on the board can be used as an isolated SCI for communicating with a HOST i.e. PC. The following jumper settings must be done to enable this connection

1. Populate the jumper [M8]-J4
2. Remove the jumper [Main]-J3 if booting from FLASH.
3. For F28035, put SW3 on the F28035 Control Card to OFF position
   For F28027, unpopulate the resistor R10 on the F28027 control card.
4. Connect a USB cable from [M8]-JP1 to host PC.

3.5 Ground Levels and Safety

- The user must not touch any part of the board or components connected to the board while energized.

- The power stages on the board are individually rated. It is the user's responsibility to make sure that these ratings (i.e. the voltage, current and power levels) are well understood and complied with, prior to connecting these power blocks together and energizing the board and / or simulation.

4 Hardware Resource Mapping

4.1 Resource Allocation

The Fig 4 shows the various stages of the board in a block diagram format and illustrates the major connections and feedback values that are being mapped to the C2000 MCU. Table 2, below lists these resources.

Macro Name		Signal Name	PWM Channel/ ADC Channel No Mapping for F28035	Function
Resonant LLC Stage		PWM	PWM-4A	LLC converter PWM1
		PWM	PWM-4B	LLC converter PWM2
		Vout-Fb	ADC-A2	LLC output voltage feedback
		Iout-Fb	ADC-A4	LLC current sense
LED-Dimmming-Dual Stages	M3	PWM-1	PWM-1A	String 1 PWM
		PWM-2	PWM-1B	String 2 PWM
		IL-1	ADC-B1	String 1 current sense
		IL-2	ADC-B2	String 2 current sense
	M4	PWM-1	PWM-2A	String 3 PWM
		PWM-2	PWM-2B	String 4 PWM
		IL-1	ADC-B3	String 3 current sense
		IL-2	ADC-B4	String 4 current sense
	M5	PWM-1	PWM-3A	String 5 PWM
		PWM-2	PWM-3B	String 6 PWM
		IL-1	ADC-B6	String 5 current sense
		IL-2	ADC-A3	String 6 current sense
Auxiliary Power Module (M6)		Vpfcout-meas	ADC-A1	PFC output voltage monitor
PLC Systems Module (J9)		PLC-ADCRx	ADC-A0	Conditioned PLC receive signal
Main		ADC-A5	ADC-A5	Spare
Main		ADC-A6	ADC-A6	Spare
Main		ADC-B5	ADC-B5	Spare

Table 2: PWM and ADC resource allocation
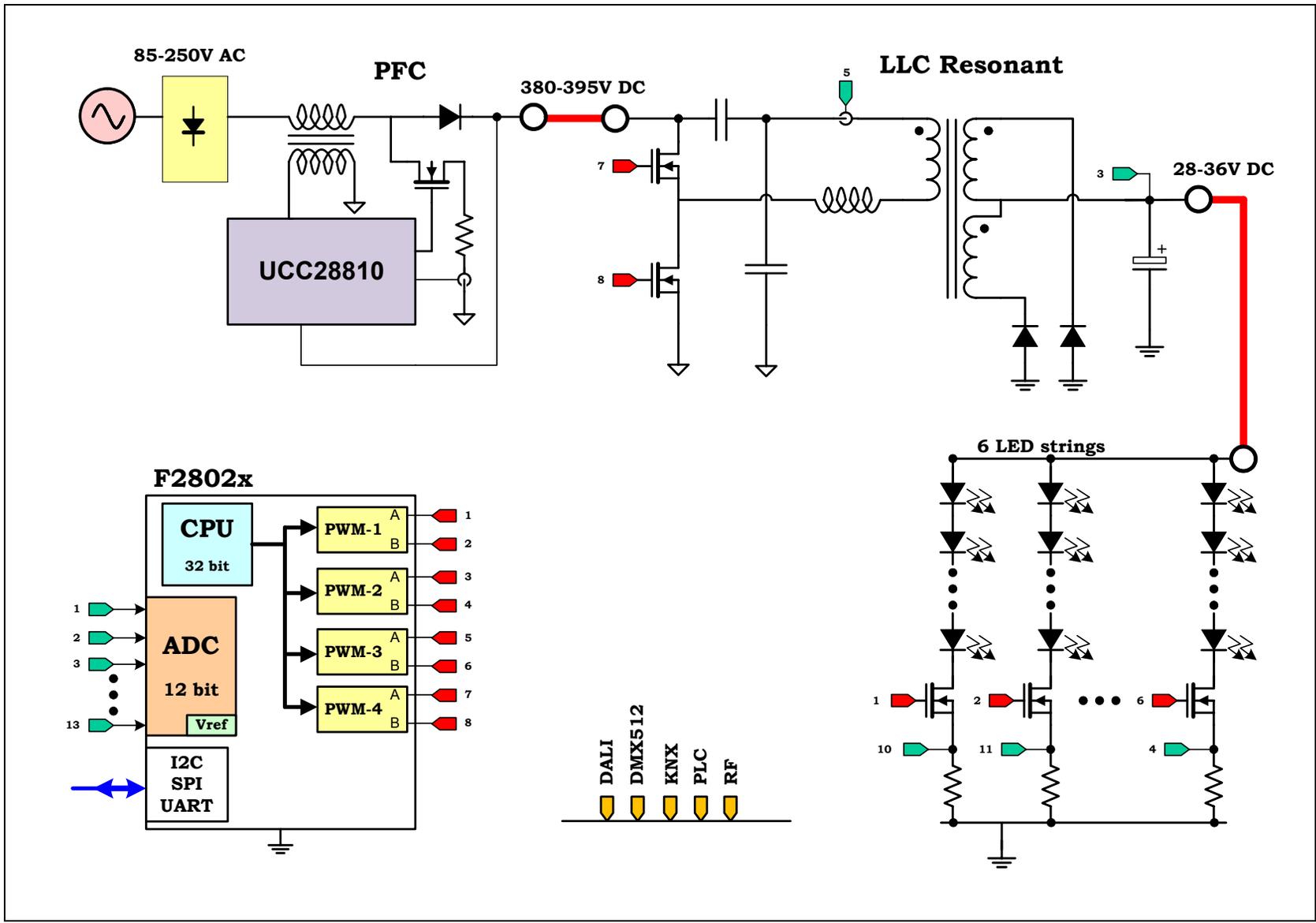
Fig4: AC LED Lighting & Communication board block diagram with F28027

[Main] BS6 – Banana Jack for LED Bus input

[Main] TB1-TB6 – LED string connectors for LED panel

[Main] J12 – I2C connector

[Main] TB7 – DALI communications header

[Main] J8 – DMX512 communications connector

[Main] J4-J7 – Communications selection jumpers

[M8] J5 – On-board emulation disable jumper

[M8] JP1 – USB Connection for onboard emulation

[M7] JP1 – 12-15V external power connector

[Main] J13 – KNX communications header

[M8] J2 – External JTAG emulator interface

[M7] SW1 – Low Voltage Power Switch

[Main] J3 – JTAG TRSTn Jumper

[Main] BS4 Banana Jack for Resonant output

[M8] J4 – FTDI UART Jumper

[Main] P1 – Universal AC Connector (85-250Vac)

[Main] J16 +12V DC header for fan

[Main] J1 – 100-pin DIMM controlCARD connector

[Main] BS5 Banana Jack for secondary side GND

[Main] J2 – 400V-to-12V enable jumper

[Main] J20 – 400V-to-18V enable jumper

[Main] BS2 – Banana Jack for primary side GND

[Main] BS3 – Banana Jack for Resonant Input

[Main] BS1 – Banana Jack for PFC output

[Main] J9.1 & [Main] J9.2 – PLC module connectors (shown here with the PLC module that comes in the TMDSPLCMODA-P3X kit)

Fig5. AC LED Lighting and Communications Board Jumpers and Connectors Diagram

4.2 Jumpers and Connectors

Table 3 below shows the various connections available on the board, and is split up by the macro each connection is included in. Fig 5, above, illustrates the location of these connections on the board with help of a board image:

[Main]-BS1	Banana Jack for PFC Output (385-400VDC when active)
[Main]-BS2	Banana Jack for Primary Side Ground
[Main]-BS3	Banana Jack for LLC Resonant Input (385-400VDC input)
[Main]-BS4	Banana Jack for LLC Resonant Output (28-38VDC output if LLC is active)
[Main]-BS5	Banana Jack for Secondary Side Ground
[Main]-BS6	Banana Jack for LED Bus Input (28-36VDC input)
[Main]-J1	100-pin DIMM controlCARD connector
[Main]-J2	400V-to-12V enable jumper. If populated, [M6] will create 12V for the secondary side of the board. Also enables 18V DC to be generated for the primary side if J20 is also populated.
[Main]-J3	JTAG TRSTn disconnect jumper, populating the jumper enables JTAG connection to the microcontroller. The jumper needs to be unpopulated when booting from FLASH, SCI, or another medium.
[Main]-J4	DALI-RF selection jumper. The default position and the way the software is used has a jumper placed between position 1 & 2. GPIO-24 does not exist on the F28027 controlCARD. ➤ Position 1&2: Jumper here means that DALI-RX will come out of GPIO-24. ➤ Position 2&3: Jumper here means that DALI-RX will come out of GPIO-19. ➤ Position 3&4:Jumper here means that RF-SPIEn will come out of GPIO-19
[Main]-J5	DALI-RF selection jumper. The default position and the way the software is used has a jumper placed between position 1 & 2. GPIO-25 does not exist on the F28027 controlCARD. ➤ Position 1&2: Jumper here means that DALI-TX will come out of GPIO-25. ➤ Position 2&3: Jumper here means that DALI-TX will come out of GPIO-18. ➤ Position 3&4:Jumper here means that RF-SPICLK will come out of GPIO-18
[Main]-J6	UART-DMX512 selection jumper. The default position (1&2) is placed such that the board will work with the designed GUI. ➤ Position 1&2: Jumper here means that UART-RX will go to GPIO-28 ➤ Postion 2&3: Jumper here means that DMX512-RX will go to GPIO-28
[Main]-J7	UART-DMX512 selection jumper. The default position (1&2) is placed such that the board will work with the designed GUI. ➤ Position 1&2: Jumper here means that UART-TX will go to GPIO-29 ➤ Postion 2&3: Jumper here means that DMX512-TX will go to GPIO-29
[Main]-J8	DMX512 communications connector (XLR-5). ➤ Cable - one compatible part number is Newark part number: 18J1683 ➤ Master – one compatible DMX512 master is Enttec's Open DMX USB or Enttec's DMX USB Pro

[Main]-J9	Connector to PLC AFE Systems Module (see Texas Instruments addon kit TMDSPLCMODA-P3X). Documentation for how this board works with the addon kit can be found in the TMDSIACLEDCOMKIT-PLCQSG guide included in this kit's documentation.
[Main]-J10	Connector to interface with a Texas Instruments RF module. This connector could interface with a CC1101EMK or CC2520EMK module. **WARNING:** No claims are made as to RF compliance or operation on this board. If done, the user proceeds at their own risk.
[Main]-J11	I^{2}C EEPROM enable jumper. If populated user may use the on-board EEPROM.
[Main]-J12	I^{2}C output header.
[Main]-J13	KNX output header. Pin 1 is TX, pin 2 is 3V3, pin 3 is GND, and pin 4 is RX.
[Main]-J14, J15	Spare connectors for ADC inputs. See schematic for more details.
[Main]-J16	12-Volt power connector. Its main purpose is to power an external fan used to cool the LED panel. Fan should be used if output power used is greater than 35W.
[Main]-J17	Primary Ground connector
[Main]-J18	Secondary Ground connector
[Main]-J19	KNX enable jumper
[Main]-J20	400V-to-18V enable jumper. If populated, [M6] will create 18V for the primary side of the board as long as [Main]-J2 is also populated.
[Main]-P1	Universal AC input connector port. 85-250V AC
[Main]-TB1-TB6	LED string output connectors. Each connector is setup to output 36V DC, 1.1A maximum per terminal (per string).
[Main]-TB7	DALI communications connector. Can be connected up to a DALI busmaster such as the Tridonic DALI-BM RS-232.
[M1]-F1	Fuse holder. Fuse used is a 250V, 3A fuse
[M7]-JP1	12-15V DC input connector (mates with a 2.1mm inner diameter, 5.5mm outer diameter plug). A potential part number is Digikey part number: T1096-P5P-ND

[M7]-SW1	Low Voltage Power Switch. This switch determines whether the MCU, and all components whose supplies are 12V or less, will be supplied externally or internally.
	   ➢ Ext – The 12V used to supply much of the board will be taken from the adapter found at [M6]-JP1
	   ➢ Int (not marked) – The 12V used to supply much of the board will be taken from [M6] if [Main]-J2 is populated. [M6] takes it's power from the AC line.

[M8]-JP1	USB connection for on-board emulation and UART communication
[M8]-J1&J3	Boot Option Jumpers, not used for F2802x, F2803x or F2806x devices. Leave these unpopulated.
[M8]-J2	External JTAG interface: this connector gives access to the JTAG emulation pins. If external emulation is desired, place a jumper across [M8]-J5 and connect the emulator to the board. A USB connector will still need to be connected to [M8]-JP1 to power the emulation and isolation logic.
[M8]-J4	Populate when using FTDI chip as a UART i.e. when using the provided GUI to interact with the MCU.
[M8]-J5	On-board emulation disable jumper: Place a jumper here to disable the on-board emulator and UART. This jumper should not be necessary but could remove contention if using an external emulator.

Table 3: Key features explanation

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