

Cypress Powerline Communication Board Design Analysis

Associated Part Family: **CY8CPLC10, CY8CPLC20**

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This application note describes the on-board circuitry of Cypress's high voltage 110 V to 240 V AC Powerline Communication (PLC) boards (CY3274). It describes the filter, coupling circuit, and power supply design. It also explains the selection of critical components necessary to meet performance and compliance requirements.

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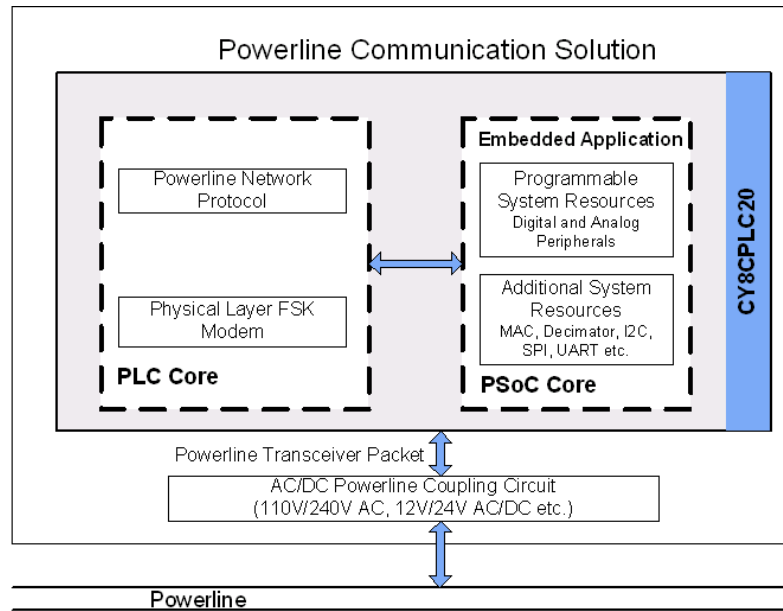
1 Introduction

Powerlines are widely available communication media for PLC technology all over the world. The pervasiveness of powerline also makes it difficult to predict the characteristics and operation of PLC products. Because of the variable quality of powerlines around the world, implementing robust communication over powerline has been an engineering challenge for years. The Cypress PLC solution enables secure and reliable communication over powerline. The features of Cypress PLC include:

- Integrated Powerline PHY modem with optimized filters and amplifiers to work with lossy high voltage and low voltage powerlines.
- Powerline optimized network protocol that supports bidirectional communication with acknowledgement based signaling. In case of data packet loss due to louder noise on the powerline, the transmitter has the capability to retransmit the data.
- The powerline network protocol supports 8-bit CRC for error detection and data packet retransmission.
- A Carrier Sense Multiple Access (CSMA) scheme is built into the network protocol; it minimizes collision between packet transmissions on the powerline, supports multiple masters, and enables reliable communication on a bigger network.

A block diagram of the PLC solution with the CY8CPLC20 programmable PLC chip is shown in [Figure 1](#). To interface the device to the powerline, a coupling circuit is required.

Figure 1. Cypress PLC Solution Block Diagram



Cypress provides the CY3274 High Voltage Programmable PLC Development Kit (DVK) for evaluating the Cypress PLC solution.

The CY3274 is designed with the filtering and power supply circuitry to operate on 110-240 V AC powerlines. They are compliant to the following CENELEC and FCC standards:

- Powerline Signaling (EN50065-1:2001, FCC Part 15)
- Powerline Immunity (EN50065-2-1:2003,
- EN61000-3-2/3)
- Safety (EN60950)

The CY3274 kits are used to develop a powerline controller and embedded host application on the CY8CPLC20 Programmable PLC device. They contain many user interface options such as I2C, RS232, GPIO, analog voltage, LCD display, and LED to develop a full application.

The following sections describe the design of the filter circuits and power supplies, including the selection of critical components for meeting performance and compliance requirements.

2 High Voltage Board Design

This section describes the design of the high voltage (110 V AC to 240 V AC) PLC board CY3274.

The design includes all circuitry to meet the requirements for signaling on high voltage lines according to the EN50065-1:2001 standard. The high voltage boards include an isolated offline switch mode power supply accepting input voltages in the range of 110-240 V AC, and 50-60 Hz line frequency, operating off the same powerlines that carry the communication signaling.

The design contains transmit signal filtering and amplification to meet the conducted emissions requirements of the CENELEC and FCC standards. It also has receive signal filtering and signal isolation external to the Cypress PLC device. This provides a compact and low cost implementation that is adaptable to a wide variety of PLC applications.

The schematic in [Figure 2](#) shows the Cypress high voltage board's transmit filter and amplification, receive filter, and coupling circuit to the high voltage powerline. The Bill of Materials (BOM) of these components is listed in [Table 1](#).

Figure 2. Cypress High Voltage PLC Board Signal Filtering, Amplification, and Coupling Circuit

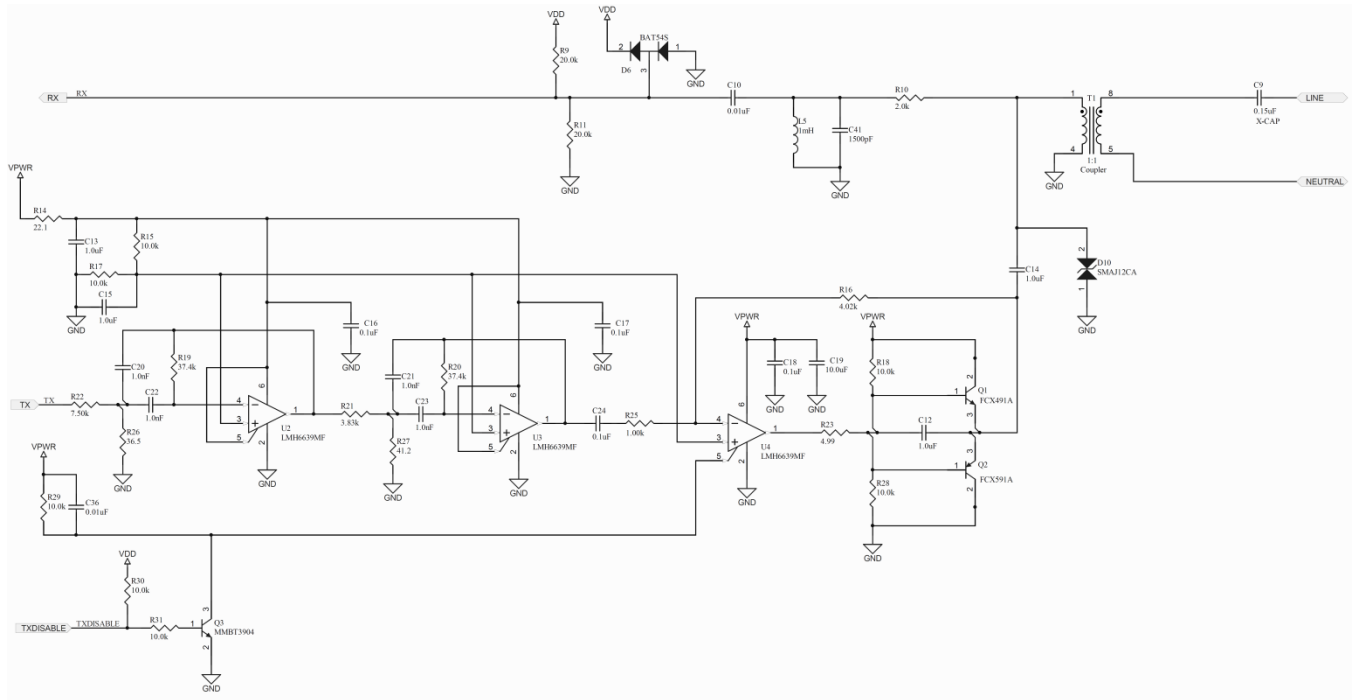


Table 1. Cypress High Voltage PLC Board Signal Filtering, Amplification, and Coupling BOM

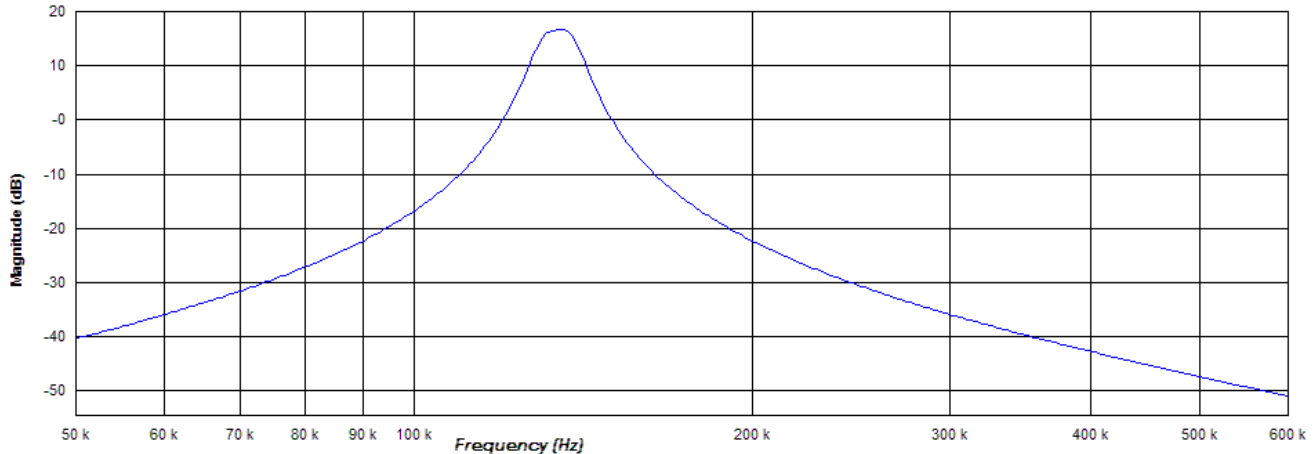
Description	Designator	Qty.	Value	Manufacturer	Manufacturer Part#	Vendor	VPN
High Voltage Coupling Circuit							
Capacitor Metal Poly Film 0.15uF 300VAC X1	C9	1	0.15 μ F	Panasonic	ECQ-U3A154MG	Digikey	P11117-ND
Isolation Transformer	T1	1		Precision Components, Inc.	0505-0821G	http://www.pcitransformers.com	
Transient Voltage Suppressor 400W 12V BIDIRECT SMA	D10	1		Micro Commercial Co	SMAJ12CA-TP	Digikey	SMAJ12CA-TPMSCT-ND
Transmitter Circuit							
Transmit Amplification							
Capacitor Ceramic 1.0uF 16V X7R 0603	C12, C13, C14, C15	4	1.0 μ F	Taiyo Yuden	EMK107B7105KA-T	Digikey	587-1241-1-ND
Capacitor Ceramic 0.10uF 10% 16V X7R 0603	C18, C24	2	0.1 μ F	Panasonic	ECJ-1VB1C104K	Digikey	PCC1762CT-ND
Capacitor Ceramic 10.0uF 10% 25V X5R 1206	C19	1	10.0 μ F	Taiyo Yuden	TMK316BJ106KL-T	Digikey	587-1337-1-ND
Capacitor Ceramic 0.01uF 25V X7R 0603	C36	1	0.01 μ F	AVX	06033C103JAT2A	Digikey	06033C103JAT2A-ND
Transistor NPN HV 40V 1A SOT-89	Q1	1		Zetex	FCX491ATA	Digikey	FCX491ACT-ND
Transistor PNP HV 40V 1A SOT-89	Q2	1		Zetex	FCX591ATA	Digikey	FCX591ACT-ND
Transistor NPN SOT-23	Q3	1		Fairchild	MMBT3904LT1	Digikey	MMBT3904LT1INCT-ND
Resistor 22.1 1% 1/10W 0603	R14	1	22.1	Yageo	RC0603FR-0722R1L	Digikey	311-22.1HRCT-ND
Resistor 10.0k 1% 1/10W 0603	R15, R17, R18, R28, R29, R30, R31	7	10.0 k	Yageo	RC0603FR-0710KL	Digikey	311-10.0KHRTR-ND
Resistor 4.02k 1% 1/10W 0603	R16	1	4.02 k	Yageo	RC0603FR-074K02L	Digikey	311-4.02KHRCT-ND
Resistor 4.99 1% 1/10W 0603	R23	1	4.99	Yageo	RC0603FR-074R99L	Digikey	311-4.99HRCT-ND
Resistor 1.00k 1% 1/10W 0603	R25	1	1.00 k	Yageo	RC0603FR-071KL	Digikey	311-1.00KHRTR-ND
Op-Amp 190MHz	U4	1		National Semiconductor	LMH6639MF/NOPB	Digikey	LMH6639MFCT-ND
Transmit Filtering for FCC/CENELEC							
Capacitor Ceramic 0.10uF 10% 16V X7R 0603	C16, C17	2	0.1 μ F	Panasonic	ECJ-1VB1C104K	Digikey	PCC1762CT-ND
Capacitor Ceramic 1000PF 1% 5V NP0 0603	C20, C21, C22, C23	4	1.0 nF, 1%	AVX	06033A102FAT2A	Digikey	06033A102FAT2A-ND
Resistor 37.4k 1% 1/10W 0603	R19, R20	2	37.4 k	Yageo	RC0603FR-073K4L	Digikey	311-37.4KHRCT-ND
Resistor 3.83k 1% 1/10W 0603	R21	1	3.83 k	Yageo	RC0603FR-073K83L	Digikey	311-3.83KHRCT-ND
Resistor 7.50k 1% 1/10W 0603	R22	1	7.50 k	Yageo	RC0603FR-077K5L	Digikey	311-7.50KHRTR-ND
Resistor 36.5 1% 1/10W 0603	R26	1	36.5	Yageo	RC0603FR-0736R5L	Digikey	311-36.5HRCT-ND
Resistor 41.2 1% 1/10W 0603	R27	1	41.2	Yageo	RC0603FR-0741R2L	Digikey	311-41.2HRCT-ND
Op-Amp 190MHz	U2, U3	2		National Semiconductor	LMH6639MF/NOPB	Digikey	LMH6639MFCT-ND
Receiver Circuit							
Capacitor Ceramic 0.01uF 25V X7R 0603	C10	2	0.01 μ F	AVX	06033C103JAT2A	Digikey	06033C103JAT2A-ND
Capacitor Ceramic 1500pF 10% 50V X7R 0603	C41	1	1500 pF	Yageo	CC0603KRX7R9BB152	Digikey	311-1184-2-ND
Dual Schottky Diode	D6	1		ST Micro	BAT54SFILM	Digikey	497-2522-1-ND
Inductor 1mH 10% 1007	L5	1	1 mH	Taiyo Yuden	CB2518T102K	Digikey	587-2195-1-ND
Resistor 2.0k 1% 1/10W 0603	R10	1	2.0 k	Yageo	RC0603FR-072KL	Digikey	311-2.00KHRCT-ND
Resistor 20.0k 1% 1/10W 0603	R9, R11	2	20.0 k	Yageo	RC0603FR-0720KL	Digikey	311-20.0KHRCT-ND

2.1 Transmit Signal Path

2.1.1 Transmit Filter

The FSK transmit signal TX is generated on the FSK_OUT pin of the Cypress PLC device as a low amplitude (~125 mVp-p), unfiltered signal. This signal is applied to the input of an external transmit filter block consisting of opamps U2 and U3, and their related passive components. The transmit filter is a fourth order Chebyshev response band pass filter, designed for 1.5 dB maximum pass band ripple. It provides 16.5 dB of gain at the center frequency of 133 kHz, suppression of -20 dBc at the 150 kHz band limit, and -50 dBc and -60 dBc at the second and third carrier harmonics, respectively. The transmit filter response is shown graphically in [Figure 3](#).

Figure 3. Cypress High Voltage PLC Board Transmit Filter Response



The power supply for the transmit filter opamps is a filtered version of the VPWR supply. This prevents the relatively large currents produced by the power amplifier from feeding back into the high-Q filter circuit through the power supply and causing oscillations. Hence, it is advisable to avoid routing the high current transmit signal near the filter circuit.

2.1.2 Transmit Amplification

The filtered transmit data signal is applied to the power amplifier, which consists of opamp U4, transistors Q1 and Q2, and associated passive components. The power amplifier provides an additional 12 dB voltage gain, and is capable of driving low impedance loads presented by the powerline.

2.1.3 High Voltage Coupling

The transmit signal from the power amplifier is driven on to the powerlines via the isolation transformer T1. Capacitor C14 provides DC isolation for the transmitter on the device side, and C9 provides line frequency isolation on the line side.

When the device is not actively transmitting, the signal TX_DISABLE is asserted from the PLC device. This disables the external power amplification circuitry to save power and make the transmit amplification circuit have a high impedance so that the receive signal is not attenuated. Note that the transmit filter stage amplifiers U2 and U3 are always enabled, so that there is no spurious noise output on the line due to filter ringing at startup.

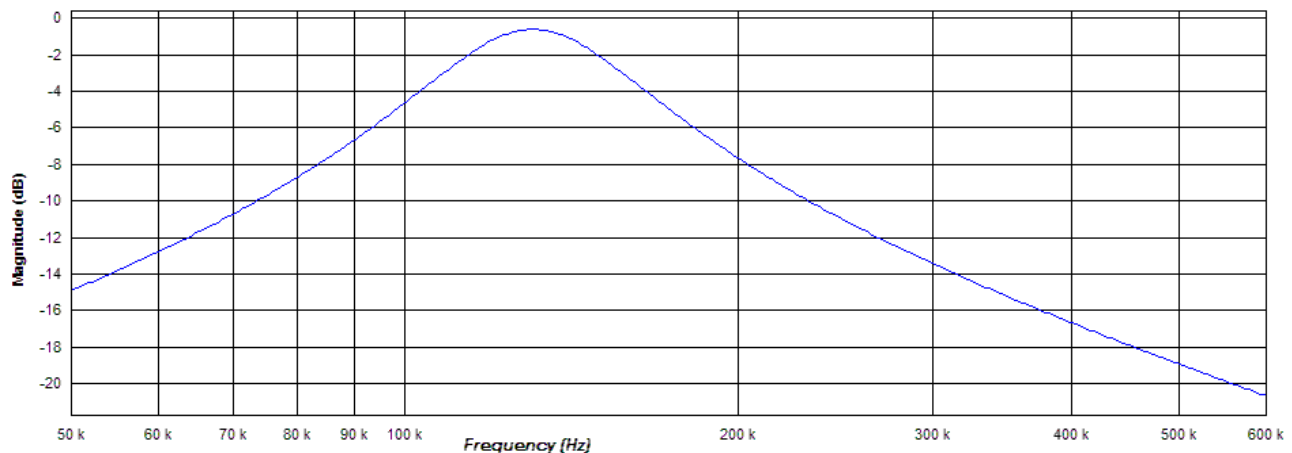
2.2 Receive Signal Path

The receive signal is coupled from the line into the kit via the same isolation transformer, T1, as is used by the transmitter.

2.2.1 Receive Filter

Capacitor C10 provides DC isolation. Resistor R10 provides a signal input impedance for the receiver. This resistor, in combination with D6, provides signal limiting to protect the receiver circuitry from high amplitude transmitter signals and any large signals coupled in from the line. The receive filter comprised of L5 and C41, in combination with R10, provides some rejection of out-of-band interference, such as AM broadcast signals. This interference may be coupled from the line and would otherwise swamp the PLC device's internal receiver circuitry. The response of the receive filter is shown in Figure 4. Resistors R9 and R11 set the $V_{CC}/2$ bias voltage required on the receive pin of the PLC device.

Figure 4. Cypress High Voltage PLC Board Receive Filter Response



2.3 Signal Path Component Requirements

The values of the transmit filter passive components are relatively critical; 1% tolerance parts should be used to ensure an accurate response. The opamps used in the transmit filter implementation must meet the following requirements:

- Gain Bandwidth (GBW) > 50 MHz
- Voltage feedback
- $V_{DD} - V_{SS} \geq 12$ V
- Power Supply Rejection Ration (PSRR) > 70 dB
- Total Harmonic Distortion (THD) < -60 dB

The coupling transformer T1 must provide a low DC resistance (<0.5 Ω), low leakage inductance (<12 μ H) to minimize signal loss and isolation, consistent with safety requirements per EN60950 specification. The signal coupling transformer, T1, used in the CY3272 provides 3750 V isolation, a DC resistance of <0.35 Ω and a leakage inductance less than 1 μ H.

Capacitor C9 must be X1 or X2 rated to accommodate the turn-on surge, which occurs when power is applied to the device, as well as surge immunity according to EN 61000-4-5 and EN 50065-2-1 standards. The capacitor C9, used in the high voltage board design is a 300 V AC Panasonic ECQUG series metalized polyethylene film device, which is rated for direct across-line application, accommodating the surge requirements of the previously mentioned specifications.

2.4 Power Supply

This section describes the power supply design for the high voltage boards. The schematic of the power supply is shown in Figure 5. The BOM of the power supply is listed in Table 2.

The offline switch mode power supply on the high voltage boards is a standard isolated flyback converter. Bridge rectifier D7 produces a rectified input from the AC line, which is used to drive the primary side of the converter. Capacitors C30 and C31 provide charge storage to guarantee a sufficiently high input voltage to operate the converter throughout the entire AC line cycle. C30 and C31, in combination with T3, minimize the conduction of power supply switching transients onto the AC line. R41 provides in-rush current limiting.

Inductor L3 and capacitor C29 provide isolation to prevent the 133 kHz transmitter signal from riding the AC line voltage into the rectifier, creating harmonic energy on the AC lines. The inductor also presents a high impedance to the powerline so that the power supply does not load the PLC signal. These components provide an additional measure of protection for both conducted immunity and conducted radiation.

An iWatt iW1690 power controller manages the power conversion. Startup current for the device is provided on its Vin pin via resistors R32 and R34. When it starts operating, power and regulation voltage sensing is provided to the controller by the auxiliary secondary winding of T2.

Figure 5. Cypress High Voltage PLC Board Power Supply Circuit

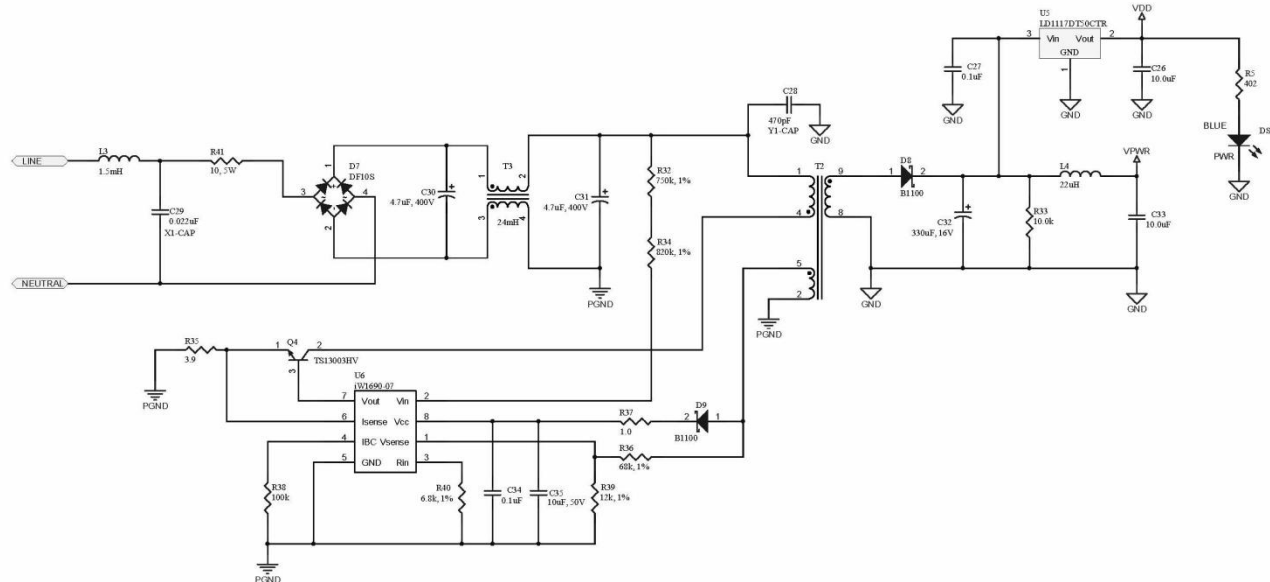


Table 2. Cypress High Voltage PLC Board Power Supply BOM

Description	Designator	Quantity	Value	Manufacturer	Manufacturer Part#	Vendor	VPN
Capacitor Ceramic 10.0uF 10% 25V X5R 1206	C26, C33	2	10.0 μF	Taiyo Yuden	TMK316BJ106KL-T	Digikey	587-1337-1-ND
Capacitor Ceramic 0.10uF 10% 16V X7R 0603	C27, C34	2	0.1 μF	Panasonic	ECJ-1VB1C104K	Digikey	PCC1762CT-ND
Capacitor Ceramic 470PF 250VAC X1Y1 RAD	C28	1	470 pF	TDK	CD95-B2GA471KYNS	Digikey	445-2407-ND
Capacitor Metal Poly Film 0.022uF 300VAC X1	C29	1	0.022 μF	Panasonic	ECQ-U3A223MG	Digikey	P11112-ND
Capacitor Electrolytic 4.7uF, 400V	C30, C31	2	4.7 μF, 400 V	Nichicon	UVR2G4R7MPD	Digikey	493-1229-ND
	C30, C31 (2nd source, 105C)		4.7 μF, 400 V	United Chemi-Con	EKMG401ELL4R7MJ16S	Digikey	565-1411-ND
Capacitor Electrolytic 330uF 16V 20%	C32	1	330 μF, 16 V	Nichicon	UPW1C331MPD	Digikey	493-1784-ND
Capacitor Electrolytic 10uF 50V 20%	C35	1	10 μF, 50 V	Nichicon	UPW1H100MDD	Digikey	493-1890-ND
Full Wave Diode Bridge	D7	1		Fairchild	DF10S	Digikey	DF10SCT-ND
Schottky Diode 100V 1A SMA	D8, D9	2		Diodes Inc	B1100-13-F	Digikey	B1100-FDICT-ND
Inductor 1500uH 0.2A 5% Radial	L3	1	1.5 mH	Taiyo Yuden	LHL08TB152J	Digikey	LHL08TB152J-ND
Inductor 22uH 20% 1210	L4	1	22 uH	Taiyo Yuden	CBC3225T220MR	Digikey	587-1626-1-ND
NPN Silicon Planar Medium Power High-Gain Transistor	Q4	1		TSC	TS13003HVCT	mouser.com	821-TS13003HVCT
	Q4 (2nd Source)			ST Micro	STX616-AP	Digikey	497-7625-1-ND
Resistor 750k 1% 1206	R32	1	750 k, 1%	Yageo	RC1206FR-07750KL	Digikey	311-750KFRCT-ND
Resistor 10.0k 1% 1/10W 0603	R33	1	10.0 k	Yageo	RC0603FR-0710KL	Digikey	311-10.0KHRTR-ND
Resistor 820k 1% 1206	R34	1	820 k, 1%	Yageo	RC1206FR-07820KL	Digikey	311-820KFRCT-ND
Resistor 3.9 Ohm 1% 0805	R35	1	3.9	Yageo	RC0805FR-073R9L	Digikey	311-3.90CRCT-ND
Resistor 68.0k Ohm 1/8W 1% 0805	R36	1	68k, 1%	Yageo	RC0805FR-0768KL	Digikey	311-68.0KCRTR-ND
Resistor 1.00 Ohm 1/10W 1% 0603	R37	1	1.0	Yageo	RC0603FR-071RL	Digikey	311-1.00HRCT-ND
Resistor 100k 1/10W 1% 0603	R38	1	100 k	Yageo	RC0603FR-07100KL	Digikey	311-100KHRTR-ND
Resistor 12.0K 1/10W 1% 0603	R39	1	12 k, 1%	Yageo	RC0603FR-0712KL	Digikey	311-12.0KHRCT-ND
Resistor 6.8k, 1% 0603	R40	1	6.8 k, 1%	Yageo	RC0603FR-076K8L	Digikey	311-6.80KHRTR-ND
RESISTOR 10.0 OHM 5W 5% WIREWND	R41	1	10, 5 W	Vishay	AC0500001009JAC00	Digikey	PPC5W10.0CT-ND
Power Transformer EE-16	T2	1	3.2 mH	Shenzen Goldenway	EE-16 (5+5) (rev-A)	e-mail:sales@greensmps.com	
	T2 (2nd Source)			Renco Electronics	RLCY-1014	e-mail:sales@rencousa.com	
24mH Common Mode Choke	T3	1	24 mH	Shenzen Goldenway	EE8.3(2+2)-hori, (rev-A)	e-mail:sales@greensmps.com	
	T3 (2nd Source)			Renco Electronics	RLCY-1013	e-mail:sales@rencousa.com	
Voltage Regulator 5 Volt Off-Line Switcher	U5	1		ST Micro	LD1117S50CTR	Digikey	497-1243-1-ND
	U6	1		iWatt	iW1690-07	e-mail:sales@iwatt.com	

Switching transistor Q4 is operated directly by the iW1690. Switch current is sensed across resistor R35. The switching frequency of the iW1690 is approximately 75 kHz. The basic cycle-by-cycle operation of the power converter is described briefly in the following paragraph.

With Q4 switched ON, current is pulled from the line through the primary winding of T2. Diodes D8 and D9 ensure that the secondary windings of T2 do not conduct current during the switch ON time and energy is stored in the magnetic field of T2. With Q4 switched OFF, the voltage polarity across the primary and secondary windings of T2 is reversed, causing D8 and D9 to be forward biased. Current now flows in the secondary windings, delivering energy to the loads. Bulk filter capacitance is provided on the main secondary output by C32. The auxiliary secondary output is filtered at C35 to power the controller. The auxiliary secondary voltage is monitored by the converter at its Vsense pin. This voltage is used to implement output secondary voltage regulation by setting the switch duty cycle.

The voltage on each of the rectified secondary outputs is determined by the primary voltage, the turns ratio of the transformer, and the switch duty cycle, as follows:

$$V_{out} = \frac{D * N * V_{in}}{(1 - D)} \quad \text{Equation 1}$$

Where, N is the secondary or primary turns ratio and D is the switch duty cycle. The nominal turns ratio for both secondaries of T2 is 0.13. As the input voltage varies over the course of an AC line cycle, the power controller varies D to maintain a constant voltage on the secondary supplies. Because the voltages of the secondary outputs are related by the turns ratios, it is possible to regulate multiple, isolated outputs by monitoring just one of the secondaries. In this case, the controller regulates the main output by monitoring its own supply winding. The voltage produced at C32 is approximately 10 V. This voltage is filtered via L4/C33 to further reduce switching noise and produce the VPWR supply, which drives the transmitter circuitry. The 10 V supply is also applied to the input of linear regulator U5, which produces a 5 V V_{DD} power supply for the Cypress PLC device and optionally, an external controlling device.

2.5 Power Path Component Requirements

The power converter is designed for worldwide operation and is expected to operate from line voltages ranging from 90-240 V AC. This results in peak voltages approaching 350 V DC, and hence, filter capacitors C30 and C31 must be rated to accommodate these peak voltages.

In the flyback (Q4 OFF) state, the peak voltage generated on the primary winding of T2 (the collector of Q4), strictly as a result of the circuit operation, is higher than V_{in} . This voltage is given as follows:

$$V_{pk} = \frac{V_{in}}{(1 - D)} \quad \text{Equation 2}$$

In addition, transformer leakage inductance results in an additional increase, above V_{pk} , at Q4 turn off. This results in peak voltages approaching 500 V being possible at the collector of Q4.

Resistor R41 should be a high power rated (≥ 3 W), wire wound resistor that can support the surge requirements of the system.

Capacitor C29 must be X1 or X2 rated to accommodate the turn on surge, which occurs when power is applied to the device, as well as surge immunity according to EN 61000-4-5 and EN 50065-2-1. The capacitor used in the high voltage board design is a 300 V AC Panasonic ECQUG series metalized polyethylene film device, which is rated for direct across-line application. It accommodates the surge requirements of the specifications mentioned earlier.

L3 should be rated for ≥ 0.2 A of current.

Capacitor C28 must be a Y1-rated safety capacitor. The capacitor used in the high voltage board design is a 4000 V AC TDK CD series mid-high voltage ceramic device. This device is rated for direct line-ground applications and accommodates the surge requirements of the previously mentioned specifications.

It is important to note that a bleeder resistor may need to be used, depending on the discharge path for the PLC coupling capacitor C9. When power is disconnected, this capacitor will still be charged unless it can discharge through the power supply. In the Cypress high voltage boards, it was tested that the voltage discharges quickly enough to meet the safety requirements of CENELEC EN60950. However, other power supplies may not discharge the voltage quickly enough and in that case, a bleeder resistor (> 1 M Ω 0.25 W, working voltage >360 V DC) should be used.

2.5.1 Protection Circuit

Basic protection against line transients is provided by transient suppressor D1. The high voltage boards employ a Panasonic ZNR type device with a peak surge current capability in excess of 1000 A and a voltage rating of 275 V AC. This type of device has the advantage of low shunt capacitance, 120 pF in this case, which ensures that it does not degrade the PLC signal. Protection against catastrophic circuit failure is provided by fuse F1, which is a 2 A, 250 V AC Slow-Blow device. This protection circuit is shown in [Figure 6](#) and the BOM is listed in [Table 3](#).

Figure 6. Cypress High Voltage PLC Board AC Line Input Protection Circuit

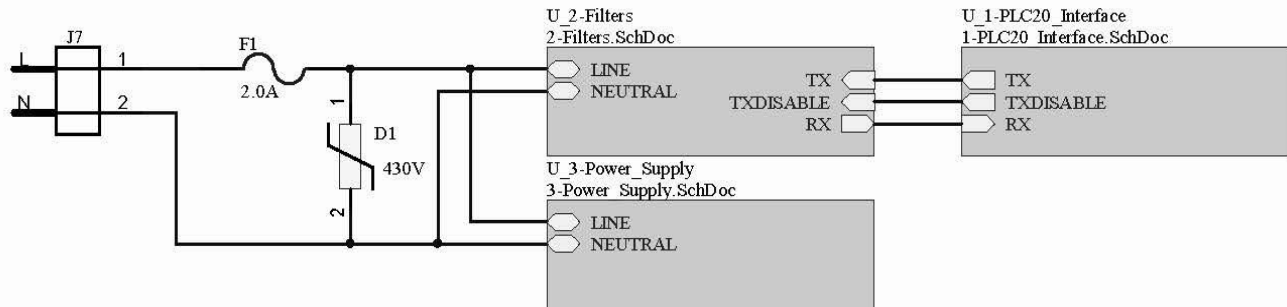


Table 3. Cypress High Voltage PLC Board AC Line Input Protection BOM

Description	Designator	Qty.	Value	Manufacturer	Manufacturer Part#	Vendor	VPN
Transorb Voltage Suppressor 430V 1250A ZNR	D1	1	430 V	Panasonic	ERZ-V07D431	Digikey	P7251-ND
Fuse 2A Slow Blow 250VAC	F1	1	2.0 A	Bel Fuse	RST 2	Digikey	507-1179-ND

2.6 PLC Device Interface

This section describes the circuitry that is directly connected to the Cypress PLC device (U1) and not part of the transmitter and receiver circuitry described above. In the schematic shown in Figure 7, there are many components shown that are not required for the final system, but are useful for status indication and debugging. The BOM for this circuit is shown in Table 4. It separates the required components from the optional components.

The 32.768 kHz crystal (Y2) is required for PLC communication because it is used for the precise timing of the network protocol and if selected, is also used for the timing of the FSK modulator and demodulator. On the other hand, the 24.00 MHz oscillator (Y1) is not required in most designs. It is provided as an optional clock source for timing the FSK modulator and demodulator because it generates a tighter frequency spectrum, which may help with designs that are marginal to meeting the FCC or CENELEC conducted emissions requirements. The selection between the FSK modem source is made by setting the CLKSEL pin ('1' = 32.768 kHz crystal, '0' = 24.00 MHz oscillator, internal pull-up).

Resistor R2 and capacitor C3 form a low pass filter that is used to filter the received 2400 bps demodulated signal, which is output on pin RXCOMP+. The filtered signal is then connected to the pin RXCOMP-, where it is further filtered and then deserialized.

Capacitors C1 and C2 are used for decoupling noise from the power supply. Similarly, C5 provides a cleaner signal from the crystal to the device, and C6 provides a cleaner internal analog ground reference for the modem.

The I2C interface requires pull-up resistors on the bus. If the external host does not have pull-up resistors, then R6 and R7 should be used. The recommended value for these resistors is 2.4-7.5 k.

The LEDs are optional for PLC status indication (DS2 = receiving, DS3 = transmitting, DS4 = band-in-use detection) and power indication (DS5). The resistors (R1, R3, R4, R5) associated with these LEDs are for current limiting.

The DIP switch bank S1 is optional for setting the device's PLC address and I2C address, as well as selecting the modem's clock source.

Push-button S2 with current-limiting resistor R8 is optional and is used to easily reset the device to the default state, instead of disconnecting and reconnecting power.

Figure 7. Cypress PLC Device Interface Circuit (on the High Voltage Board)

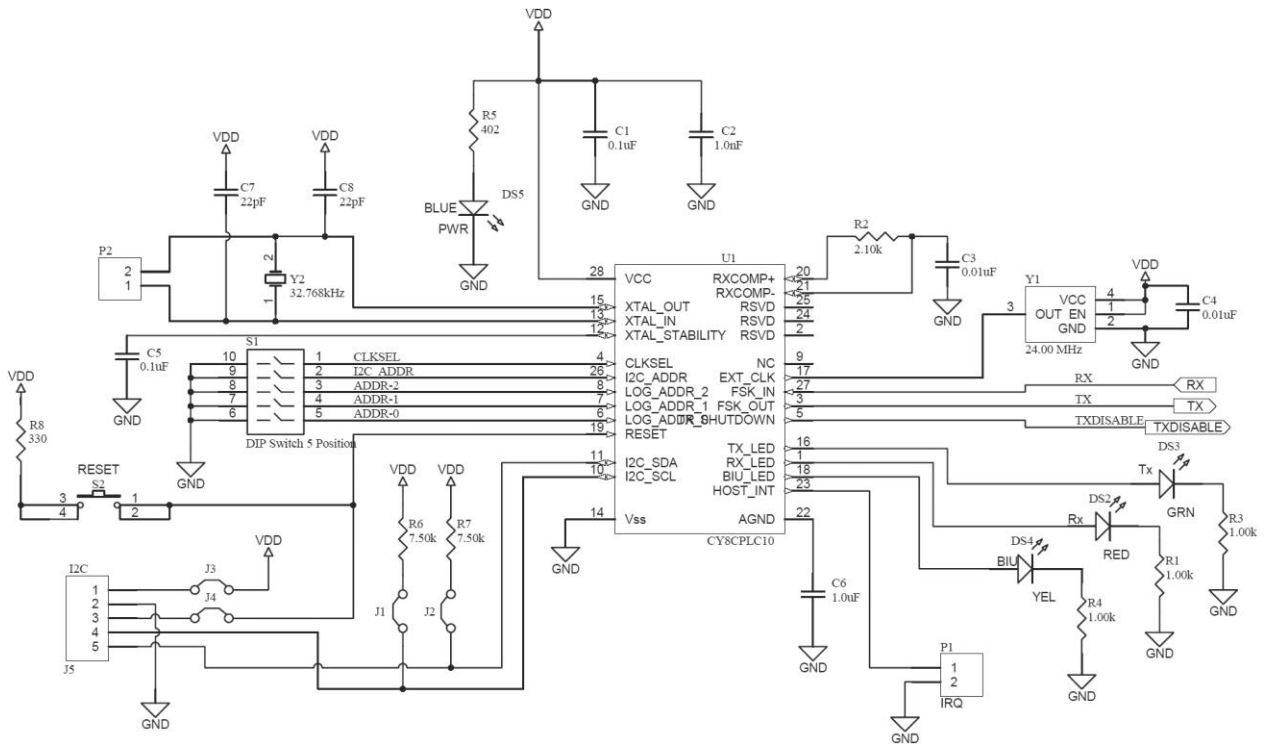


Table 4. Cypress PLC Device Interface BOM (on the High Voltage Board)

Description	Designator	Qty.	Value	Manufacturer	Manufacturer Part#	Vendor	VPN
Discretes and Crystal							
Capacitor Ceramic 0.10uF 10% 16V X7R 0603	C1, C5	2	0.1 μ F	Panasonic	ECJ-1VB1C104K	Digikey	PCC1762CT-ND
Capacitor Ceramic 1.0nF X7R 10% 25V C0603	C2	1	1.0 nF	Murata	GRM033R71E102KA01D	Digikey	490-3184-1-ND
Capacitor Ceramic 0.01uF 25V X7R 0603	C3, C4	2	0.01 μ F	AVX	06033C103JAT2A	Digikey	06033C103JAT2A-ND
Capacitor Ceramic 1.0uF 16V X7R 0603	C6	1	1.0 μ F	Taiyo Yuden	EMK107B7105KA-T	Digikey	587-1241-1-ND
Capacitor Ceramic 22pF 100V C0G 0603	C7, C8	2	22 pF	Murata	GRM1885C2A220JA01D	Digikey	490-1335-1-ND
Resistor 2.1k 1% 1/10W 0603	R2	1	2.10 k	Yageo	RC0603FR-072K1L	Digikey	311-2.10KHRTR-ND
Crystal 32.768kHz 12.5pF	Y2	1	32.768 kHz	ECS Inc.	ECS-3X8X	Digikey	X1123-ND
I2C, Jumpers, and LEDs (Optional)							
LED Red Clear 0805	DS2	1		Lite-On	LTST-C170KRKT	Digikey	160-1415-1-ND
LED Green Clear 0805	DS3	1		Lite-On	LTST-C170KGKKT	Digikey	160-1414-1-ND
LED Yellow Clear 0805	DS4	1		Lite-On	LTST-C170KSST	Digikey	160-1416-1-ND
Header 2-Pin 0.1 Centers	J1, J2, J3, J4, P1, P2	6		Sullins	PEC02SAAN	Digikey	S1012E-02-ND
Header 5-Pin Locking 0.1Centers	J6	1		Amp/Tyco	640456-5	Digikey	A19471-ND
Resistor 1.00k 1% 1/10W 0603	R1, R3, R4	3	1.00 k	Yageo	RC0603FR-071KL	Digikey	311-1.00KHRTR-ND
Resistor 2.70k 1% 1/10W 0603	R6, R7	2	2.70 k	Yageo	RC0603FR-072K7L	Digikey	311-2.70KHRTR-ND
Resistor 330 1% 1/10W 0603	R8	1	330	Yageo	RC0603FR-07330RL	Digikey	311-330HRCT-ND
Resistor 402 1% 1/10W 0603	R5	1	402	Yageo	RC0603FR-07402RL	Digikey	311-402HRTR-ND
DIP Switch 5 Position DIP-5	S1	1		E-Switch	KAJ05LAGT	Digikey	EG4429-ND
Pushbutton N.O.	S2	1		E-Switch	TL3301AF160QG	Digikey	EG2526CT-ND
Oscillator	Y1	1	24.00 MHz	Crystek	C3290-24.000	Digikey	C3290-24.000-ND
	Y1 (2nd Source)		24.00 MHz	Citizen	CSX750FCC24.000M-UT	Digikey	300-7214-2-ND

Table 5. Low Voltage PLC Board Signal Filter, Amplification, and Coupling Circuit BOM

Description	Designator	Qty.	Value	Manufacturer	MFGPN	Vendor	VPN
Low Voltage Coupling Circuit							
Capacitor Ceramic 10uF 35V X5R 10% 1206	C30	1	10 μ F	Murata	GRM31CR6YA106KA12L	Digikey	490-5524-1-ND
Ferrite Chip 100 Ohm 4A 0805	L2	1		TDK	MPZ2012S101A	Digikey	445-1567-1-ND
Inductor Power Unshielded 470uH SMD	L3	1	470 uH	Pulse	P0752.474NLT	Digikey	553-1071-1-ND
Transmitter Circuit							
Capacitor Ceramic 0.1uF 25V X7R 0603	C1	1	0.1 μ F	AVX	06033C104JAT2A	Digikey	478-3713-1-ND
Capacitor Ceramic 0.1uF 25V X7R 0603	C9	1	0.1 μ F	AVX	06033C104JAT2A	Digikey	478-3713-1-ND
Capacitor Ceramic 10uF 16V X5R 1206	C10	1	10 μ F	TDK	C3216X5R1C106K	Digikey	445-4052-1-ND
Capacitor Ceramic 1uF 50V Y5V 0805	C31	1	1.0 μ F	Murata	GRM21BF51H105ZA12L	Digikey	490-3903-1-ND
Diode Ultrafast 100V 1A	D2, D3	2	ES1B	Diodes Inc.	ES1B	Digikey	ES1B-FDICT-ND
Transistor NPN SOT-23	Q1	1	MMBT3904	Fairchild	MMBT3904LT1	Digikey	MMBT3904LT1INCT-ND
Transistor NPN 45V 3A	Q2	1	ZXT690B	Zetex	ZXT690BKTC	Digikey	ZXT690BKCT-ND
Transistor PNP 40V 3A	Q3	1	ZXT790A	Zetex	ZXT790AKTC	Digikey	ZXT790AKCT-ND
Resistor 620 OHM 1/10W 1% 0603 SMD	R3, R4	2	620	Rohm	MCR03EZPFX6200	Digikey	RHM620HCT-ND
Resistor 4.99 1% 1/10W 0603	R5	1	4.99	Yageo	RC0603FR-074R99L	Digikey	311-4.99HRCT-ND
Resistor 10.0k 1% 1/10W 0603	R13, R23, R37, R39, R48	5	10.0 k	Rohm	MCR03EZPFX1002	Digikey	RHM10.0KHCT-ND
Resistor 4.70K OHM 1/10W 1% 0603 SMD	R25	1	4.7 k	Yageo	RC0603FR-074K7L	Digikey	311-4.70KHRCT-ND
Resistor 0.5 1% 1/4W 0805	R27, R28	2	0.5 1/4 W	Susumu	RL1220S-R50-F	Digikey	RL12S.50FCT-ND
Op-Amp 190MHz	U1	1	LMH6639MF	National Semiconductor	LMH6639MF/NOPB	Digikey	LMH6639MFCT-ND
Receiver Circuit							
Capacitor Ceramic 1500pF 10% 50V X7R 0603	C4	1	1500 pF	Yageo	CC0603KRX7R9BB152	Digikey	311-1184-2-ND
Capacitor Ceramic 0.01uF 25V X7R 0603	C5	1	0.01 μ F	AVX	06033C103JAT2A	Digikey	06033C103JAT2A-ND
Diode Schottky 40V 0.3A SOT-23	D1	1	BAT54S	ST Micro	BAT54SFILM	Digikey	497-2522-1-ND
Inductor 1mH 10% 1007	L5	1	1 mH	Taiyo Yuden	CB2518T102K	Digikey	587-2195-1-ND
Resistor 10.0k 1% 1/10W 0603	R33, R43	2	10.0 k	Rohm	MCR03EZPFX1002	Digikey	RHM10.0KHCT-ND
Resistor 2.0k 1% 1/10W 0603	R52	1	2.0 k	Yageo	RC0603FR-072KL	Digikey	311-2.00KHRCT-ND

3.1 Transmit Signal Path

3.1.1 Transmit Amplification

The FSK transmit signal TX is generated on the FSK_OUT pin of the Cypress PLC device as a higher amplitude (approximately 1.55 Vp-p), unfiltered signal. The low voltage boards do not have any transmit filtering, which reduces the BOM cost. There is one output amplification stage, implemented using op-amp U1 and transistors Q2 and Q3, to drive the low impedance load presented by the powerline. Resistors R3 and R4 set a gain of 1x.

When the device is not actively transmitting, it asserts the signal TX_DISABLE. This disables the external power amplification circuitry to save power. This also makes the transmit amplification circuit have a high impedance so that the receive signal is not attenuated.

3.1.2 Low Voltage Coupling

The transmit signal from the power amplifier is driven on to the powerlines via chip bead L2. Capacitor C6 provides DC isolation for the transmitter on the device side. Capacitor C30 provides line frequency isolation on the line side. With inductor L3, capacitor C30 provides a filter to remove out-of-band noise from entering the receiver.

3.2 Receive Signal Path

The receive signal is coupled from the line into the low voltage boards via the same chip bead L2, as is used by the transmitter.

3.2.1 Receive Filter

Capacitor C5 provides DC isolation. Resistor R52 provides a signal input impedance for the receiver. This, in combination with D6, provides signal limiting to protect the receiver circuitry from the relatively high amplitude transmitter signals, including any large signals coupled in from the line. The receive filter comprised of R52, L5, and C4, provides some rejection of out-of-band interference such as AM broadcast signals. This interference may be coupled from the line, and may otherwise swamp the PLC device's internal receiver circuitry. Resistors R33 and R43 set the VCC/2 bias voltage required on the receive pin of the PLC device.

3.3 Signal Path Component Requirements

The chip bead L2 is designed specifically for powerline applications and provides a low DC resistance (0.02Ω) and high current handling capability (3 A). Its impedance curve is similar to that of a $0.4 \mu\text{H}$ inductor. The transmit capacitors C10 and C30 should be sized so that they match the impedance of the inductor as closely as possible. This reduces the transmit impedance, which increases the driving distance of the system. In this case, C10 and C30 are each $10 \mu\text{F}$, which yields an equivalent capacitance of $5 \mu\text{F}$. At 132 kHz, the impedance of this equivalent capacitor matches the inductor to within 0.1Ω . Capacitor C30 must also be rated to be above the maximum voltage on the powerline.

The opamp U1 used in the transit amplifier section must provide both high speed to minimize crossover distortion, and relatively high output currents to drive the output transistors.

3.4 Power Supply

This section describes the power supply design for low voltage boards. The schematic of the power supply is shown in Figure 9 and the BOM for the power supply is listed in Table 6.

Inductor L4 provides high impedance to the powerline so that the power supply does not load the PLC signal. It should be rated to $\geq 200 \text{ mA}$.

Resistor R2 limits in-rush current. It should be rated to $\geq 1 \text{ W}$.

D9 protects the circuit from voltage transients and D10 rectifies the voltage when AC power is present.

Regulator U7 provides a 5 V output, which is used for the PLC device and the transmit amplifier.

The $100 \mu\text{F}$ electrolytic capacitor C24, along with a $10 \mu\text{F}$ tantalum capacitor and two $0.1 \mu\text{F}$ ceramic capacitors provide the necessary decoupling for the PLC device, considering the 5 V supply is shared with the transmit amplifier.

Figure 9. Power Supply Circuit while designing Low Voltage PLC Board

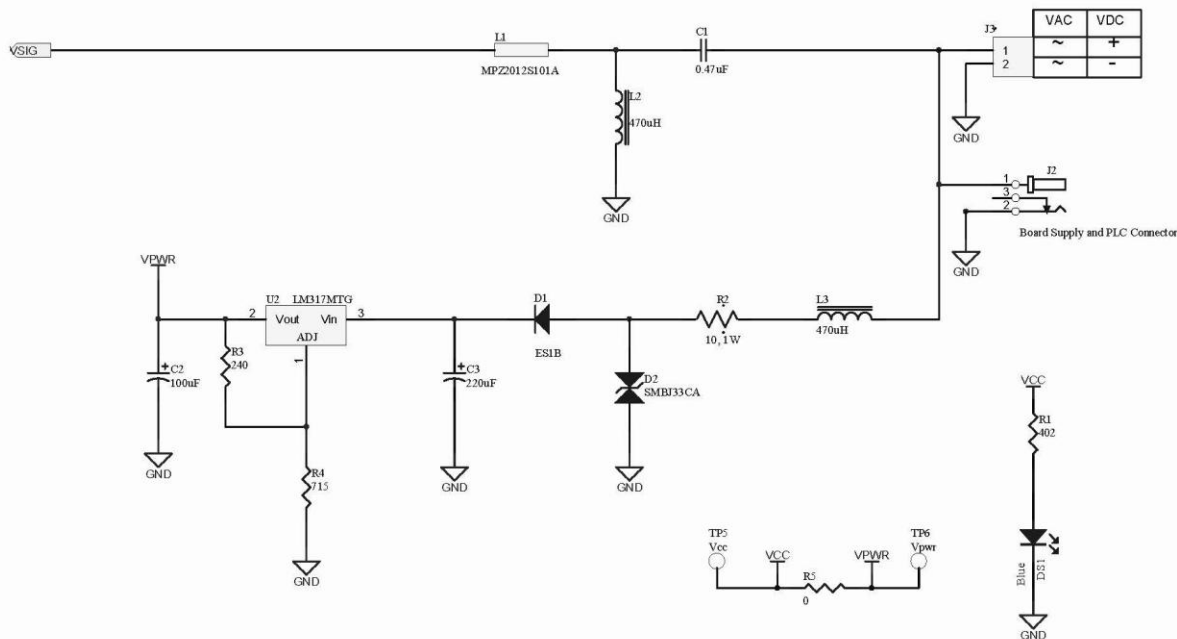


Table 6. Power Supply BOM for Low Voltage PLC Board

Description	Designator	Qty.	Value	Manufacturer	MFGPN	Vendor	VPN
Capacitor Electrolytic 100uF 10V Aluminum Radial	C24	1	100 μ F	PANASONIC	ECA-1AM101	Digikey	P5123-ND
Capacitor Electrolytic 220uF 50V	C25	1	220 μ F	PANASONIC	ECA-1HM221	Digikey	P5183-ND
Diode Transorb 33V 600W BI-DIR SMB	D9	1		Littelfuse	SMBJ33CA	Digikey	SMBJ33CALFCT-ND
Diode Ultrafast 100V 1A	D10	1	ES1B	Diodes Inc.	ES1B	Digikey	ES1B-FDICT-ND
Inductor Power Unshielded 470uH SMD	L4	1	470 uH	Pulse	P0752.474NLT	Digikey	553-1071-1-ND
Resistor 715 OHM 1/10W 1% 0603 SMD	R45	1	715	Rohm	MCR03EZPFX7150	Digikey	RHM715HCT-ND
Resistor 240 OHM 1/10W 1% 0603 SMD	R46	1	240	Rohm	MCR03EZPFX2400	Digikey	RHM240HCT-ND
Resistor 10 Ohm 1W 5% Metal Oxide	R54	1	10, 1 W	Stackpole	RSMF 1 10 5% R	Digikey	RSMF110JRCT-ND
Voltage Regulator 5 Volt	U7	1	LM317MDT	ST Micro	LM317MDT-TR	Digikey	497-1574-1-ND

3.5 PLC Device Interface

This section describes the circuitry directly connected to the Cypress PLC device (U2) and not part of the transmitter and receiver circuitry described above. In the schematic shown in [Figure 10](#), there are many components shown that are not required for the final system. However, they are useful for status indication and debugging. The BOM for this circuit is shown in [Table 7](#). It separates the required components from the optional components. Note that the key components are the same as for the high voltage board, except that the component numbering is different.

The 32.768 kHz crystal (Y1) is required for PLC communication because it is used for the precise timing of the network protocol and if selected, is also used for the timing of the FSK modulator and demodulator. On the other hand, the 24.00 MHz oscillator (Y2) is not required in most designs. It is provided as an optional clock source for timing the FSK modulator and demodulator because it generates a tighter frequency spectrum, which may help with designs that are marginal to meeting the FCC or CENELEC conducted emissions requirements. The selection between the FSK modem source is made by setting the CLKSEL pin ('1' = 32.768 kHz crystal, '0' = 24.00 MHz oscillator, internal pull-up).

Resistor R9 and capacitor C6 form a low pass filter that is used to filter the received 2400 bps demodulated signal, which is output on pin RXCOMP+. The filtered signal is then connected to the pin RXCOMP-, where it is further filtered and then deserialized.

Capacitors C11, C22, C26, and C39 are used for decoupling noise from the power supply. Similarly, C7 provides a cleaner signal from the crystal to the device, and C18 provides a cleaner internal analog ground reference for the modem.

The I2C interface requires pull-up resistors on the bus. If the external host does not have pull-up resistors, then R35 and R36 should be used. The recommended value for these resistors is 2.4-7.5 k.

The LEDs are optional for PLC status indication (DS2 = receiving, DS3 = transmitting, DS4 = band-in-use detection). The resistors (R15, R16, and R49) associated with these LEDs are for current limiting.

The DIP switch bank S2 is optional for setting the device's PLC address and I2C address, as well as selecting the modem's clock source. Push-button S1 with current-limiting resistor R2 is optional and is used to easily reset the device to the default state, instead of disconnecting and reconnecting power.

Figure 10. PLC Device Interface Circuit (on the Low Voltage Board)

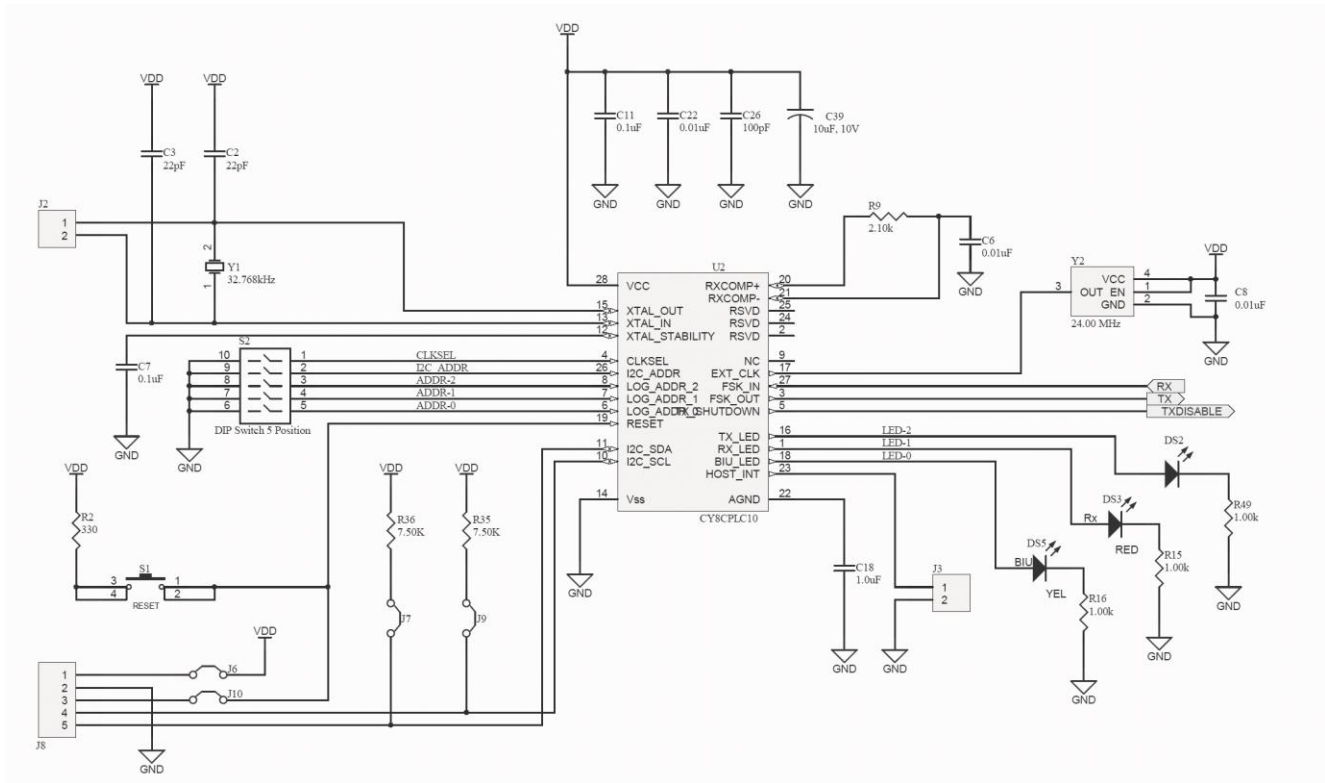


Table 7. PLC Device Interface BOM (on the Low Voltage Board)

Description	Designator	Qty.	Value	Manufacturer	MFGPN	Vendor	VPN
Discretes and Crystal							
Capacitor Ceramic 22pF 100V C0G 0603	C2, C3	2	22 pF	Murata	GRM1885C2A220JA01D	Digikey	490-1335-1-ND
Capacitor Ceramic 0.01uF 25V C0G 5% 0603	C6	1	0.01 μF	TDK	C1608C0G1E103J	Digikey	445-2664-1-ND
Capacitor Ceramic 0.1uF 25V X7R 0603	C7	1	0.1 μF	AVX	06033C104JAT2A	Digikey	478-3713-1-ND
Capacitor Ceramic 0.01uF 25V X7R 0603	C8	1	0.01 μF	AVX	06033C103JAT2A	Digikey	06033C103JAT2A-ND
Capacitor Ceramic 0.1uF 25V X7R 0603	C11	1	0.1 μF	AVX	06033C104JAT2A	Digikey	478-3713-1-ND
Capacitor Ceramic 1.0uF 16V X7R 0603	C18	1	1.0 μF	PANASONIC	ECJ-1V41E105M	Digikey	PCC2354CT-ND
Capacitor Ceramic 0.01uF 25V C0G 5% 0603	C22	1	0.01 μF	TDK	C1608C0G1E103J	Digikey	445-2664-1-ND
Capacitor Ceramic 100pF 25V X7R 0603	C26	1	100 pF	AVX	06031A101JAT2A	Digikey	478-1146-1-ND
Capacitor 10uF_10V	C39	1	10 μF, 10 V	Vishay	293D106X9010A2TE3	Digikey	718-1121-1-ND
Resistor 2.1k 1% 1/10W 0603	R9	1	2.10k	Rohm	MCR03EZPFX2101	Digikey	RHM2.10KHCT-ND
Power Line Controller	U2	1	CY8CPLC10	Cypress Semiconductor	CY8CPLC10	Digikey	CY8CPLC10-28PVXI-ND
Crystal 32.768kHz 12.5pF	Y1	1	32.768 kHz	ECS Inc.	ECS-3X8X	Digikey	X1123-ND
I2C, Jumpers, and LEDs (Optional)							
LED Blue	DS1	1	Blue	Rohm	SML-E12BC7TT86	Digikey	511-1589-1-ND
LED Green Clear 0805	DS2	1	LTST-C170KGKT	Lite-On	LTST-C170KGKT	Digikey	160-1414-1-ND
LED Red Clear 0805	DS3	1	LTST-C170KRKT	Lite-On	LTST-C170KRKT	Digikey	160-1415-1-ND
LED Yellow Clear 0805	DS5	1	LTST-C170KSKT	Lite-On	LTST-C170KSKT	Digikey	160-1416-1-ND
Header, 2-Pin	J1	1		MOLEX	09-65-2028	Digikey	WM18823-ND
Header 2-Pin 0.1 Centers	J2	1		Sullins	PEC02SAAN	Digikey	S1012E-02-ND
Header 2-Pin 0.1 Centers	J3, J6, J7, J9, J10	5		Sullins	PEC02SAAN	Digikey	S1012E-02-ND
Power Jack 2.5x5.5mm Male	J4	1		CUI, Inc.	PJ-002A-SMT	Digikey	CP-002APJCT-ND
Header 5-Pin Locking 0.1Centers	J8	1		Amp/Tyco	640456-5	Digikey	A19471-ND
Mounting Hole	MT1, MT2, MT3, MT4	4					
Resistor 330 1% 1/10W 0603	R2	1	330	Yageo	RC0603FR-07330RL	Digikey	311-330HRCT-ND
Resistor 402 OHM 1/10W 1% 0603 SMD	R14	1	402	Rohm	MCR03EZPFX4020	Digikey	RHM402HCT-ND
Resistor 1.00k 1% 1/10W 0603	R15, R16, R49	3	1.00 k	ROHM	MCR03EZPFX1001	Digikey	RHM1.00KHCT-ND
Resistor 7.50k 1% 1/10W 0603	R35, R36	2	7.50 k	Rohm	MCR03EZPFX7501	Digikey	RHM7.50KHCT-ND
Pushbutton Switch	S1	1	TL3301AF160QG	E-Switch	TL3301AF160QG	Digikey	EG2526CT-ND
DIP Switch 5 Position DIP-5	S2	1		E-Switch	KAJ05LAGT	Digikey	EG4429-ND
24MHz Oscillator	Y2	1	24.00 MHz	Crystek	C3290-24.000	Digikey	C3290-24.000-ND
	Y2 (2nd Source)		24.00 MHz	Citizen	CSX750FCC24.000M-UT	Digikey	300-7214-2-ND

4 Summary

The on-board circuitry described in this Application note has to be used for designing both High power and Low power PLC designs. It provides explanation on selection of critical components too for meeting performance and compliance requirements.

Document History

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Document Number: 001-55427

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	2759493	FRE	09/03/2009	New Spec.
*A	3123303	FRE	12/29/2010	Added the Bill Of Materials for all of the circuits. Added a description of the components that are not in the TX or RX path, and not in the power supply. Added more details for proper selection of critical transmit, receive, and coupling components. Updated the low voltage board receive filter and transmit path capacitors.
*B	3366253	ADIY	09/08/2011	Removed reference to CY8CLED16P01, CY3276, and CY3277 Added sub-headings in Transmit Signal Path and Receive Signal Path sections. Updated Figure 9
*C	4525870	ROIT	10/14/2014	Removed reference to obsolete PLC Kits CY3272, CY3273 and CY3275 in all instances across the document. Updated High Voltage Board Design: Updated Figure 2. Updated Power Supply: Updated Figure 5. Updated Power Path Component Requirements: Updated Protection Circuit: Updated Figure 6. Updated Low Voltage Board Design: Updated Figure 8. Updated Signal Path Component Requirements: Updated description (Replaced L1 with L2). Updated Power Supply: Updated Figure 9. Updated to new template. Completing Sunset Review.
*D	5480373	SNVN	11/16/2016	Updated Figure 8 Updated template
*E	5791933	AESATMP9	06/30/2017	Updated logo and copyright.

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