

PAC5220WP A11 PCB Design Guidelines

Power Application Controller™

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OVERVIEW

The PAC5220WP Power Application Controller is a complete Wireless Power Consortium (WPC) Low-Power Transmitter solution. The PAC5220WP enables a low-cost and flexible solution for system implementations of a WPC A11 Wireless Power Transmitter.

Active-Semi provides an Evaluation Kit (EVK) that allows serves as a reference design for customer systems, as well as an evaluation environment for them to analyze the application's performance. The PAC5220WP comes with pre-loaded firmware that supports the WPC Low-Power Transmitter specification, version 1.1.2.

As customers design their own PCBs based on this solution, there are key design criteria that should be followed to ensure that their implementation meets all the required performance, efficiency and EMI goals of the application.

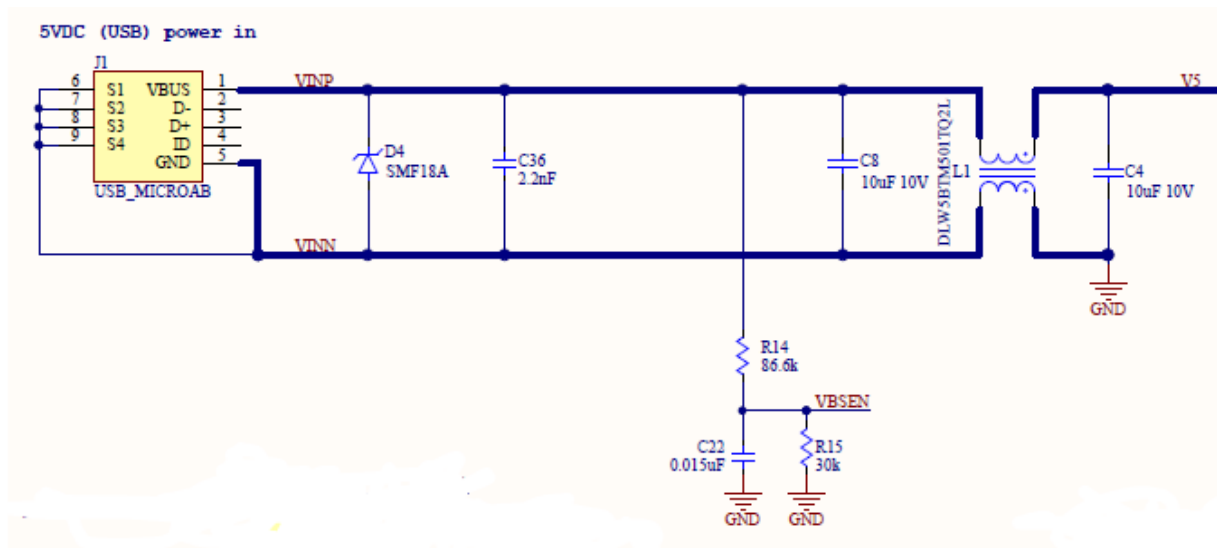
This guide specifies these design criteria, to meet customers' needs. Topics such as filtering, layout and component selection are addressed.

DETAILED CIRCUIT DESCRIPTION

The WPC A11 transmitter circuit can be divided into several major functional blocks. These blocks will be described in more detail later in this document:

- **Power Input** – This section provides the physical connection to a 5V DC power source, which is typically a USB mobile phone charger.
- **ACT6311 Boost Converter** – This circuit provides a 6.5VDC supply to power the PAC5220WP IC. It uses a low power monolithic boost converter from Active-Semi.
- **H-Bridge Power Stage** – The H-bridge consists of power FETs arranged in an H-bridge to drive power to the coil. It includes a resonating capacitor to form a series resonant circuit with the coil, as well as gate driver components.
- **Active Rectifier** – A discrete active rectifier is used to demodulate the amplitude-modulated communication signal sent from the receiver back to the transmitter.
- **Communications Filter** – To remove any remaining switching (carrier) frequency from the demodulated communications data, a single OpAmp is used to implement a multi-pole active filter.
- **PAC5220WP** – The heart of the WPC transmitter is an Active-Semi PAC5220WP Power Application Controller IC, with pre-loaded firmware for the WPC A11 Low-Power Transmitter.

Power Input



The A11 design is intended to operate from a 5VDC power source. Typically, this is from a USB power adapter of the type used to charge mobile phones.

The 5VDC power is input from a micro-USB type B connector. The USB data lines are not used. Note that the USB shield is connected to the ground pin of the USB connector to help minimize EMI emitted from the cable.

An 18V TVS diode is placed across the input power to suppress any transient voltage spikes. This protects the rest of the circuit from spikes that can be generated, for example, from inductive effects during connection and disconnection of the charger.

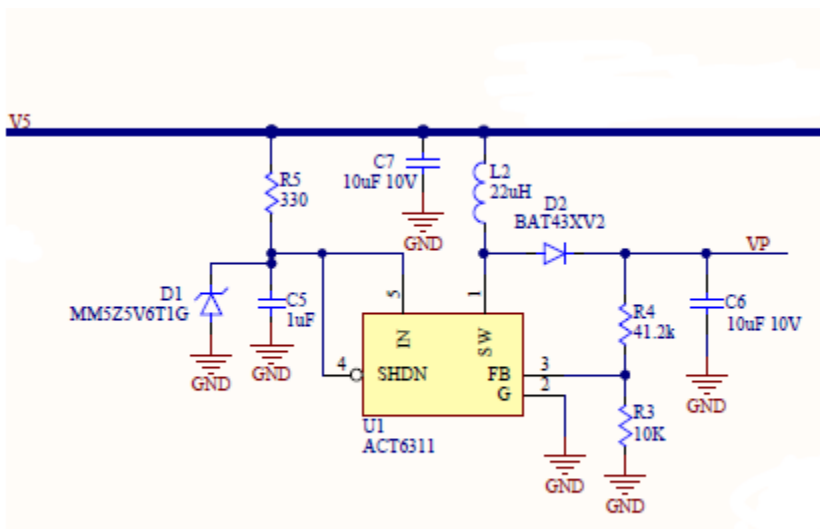
An EMI filter circuit, consisting of a common-mode choke (L1) and three ceramic capacitors is used to control radiated emissions. Testing has shown that most of the radiated EMI comes from the power cable. The most problematic frequencies are fairly low, 30-50MHz, so a large filter is needed to attenuate these signals.

The common mode filter should have as low a series resistance as possible (so as to not reduce system efficiency) and the highest impedance possible, within the constraints of physical size and cost. Murata DLW5BTM501TQ2L (19 milliohm ESR and 500 ohm impedance) and TDK ACM7060-701-2PL-TL (17 milliohm ESR and 700 ohm impedance) are recommended and have been shown to provide good EMI performance. The addition of a small ceramic capacitor (C36) of a few nF in parallel with the larger 10uF capacitor helps reduce EMI at higher frequencies.

A voltage divider circuit formed by R14, R15, and C22 attenuate and filter the incoming power supply voltage so that it can be measured by an analog input channel of the PAC5220WP (VBSEN). This measurement is used for under-voltage protection, over-voltage protection, power limiting for power sources unable to provide full charging power to the load, and foreign object detection.

High current paths are shown in the schematic as boldface traces. These paths should be routed as directly as possible using wide copper areas.

ACT6311 Boost Converter



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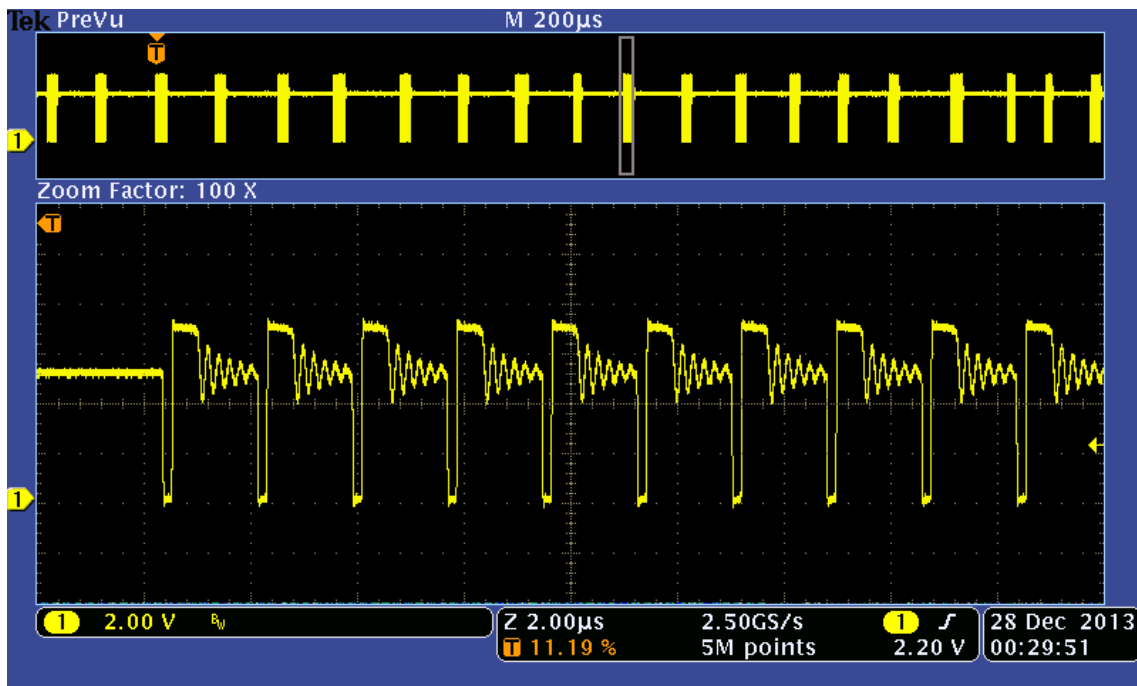
Since the VBUS voltage of USB power may drop as low as 4.5V, and the PAC5220WP device requires a minimum voltage of approximately 5.5V, a small boost converter circuit is used to generate a ~6.5V local power supply (VP). This supply is not used for the main power path to the H-bridge; it is only used to power the PAC5220WP and provide gate drive voltage to the H-bridge. The load current of the boost circuit is typically less than 50mA.

The boost circuit uses an Active-Semi ACT6311 IC. For details of the ACT6311 device, refer to the ACT6311 datasheet.

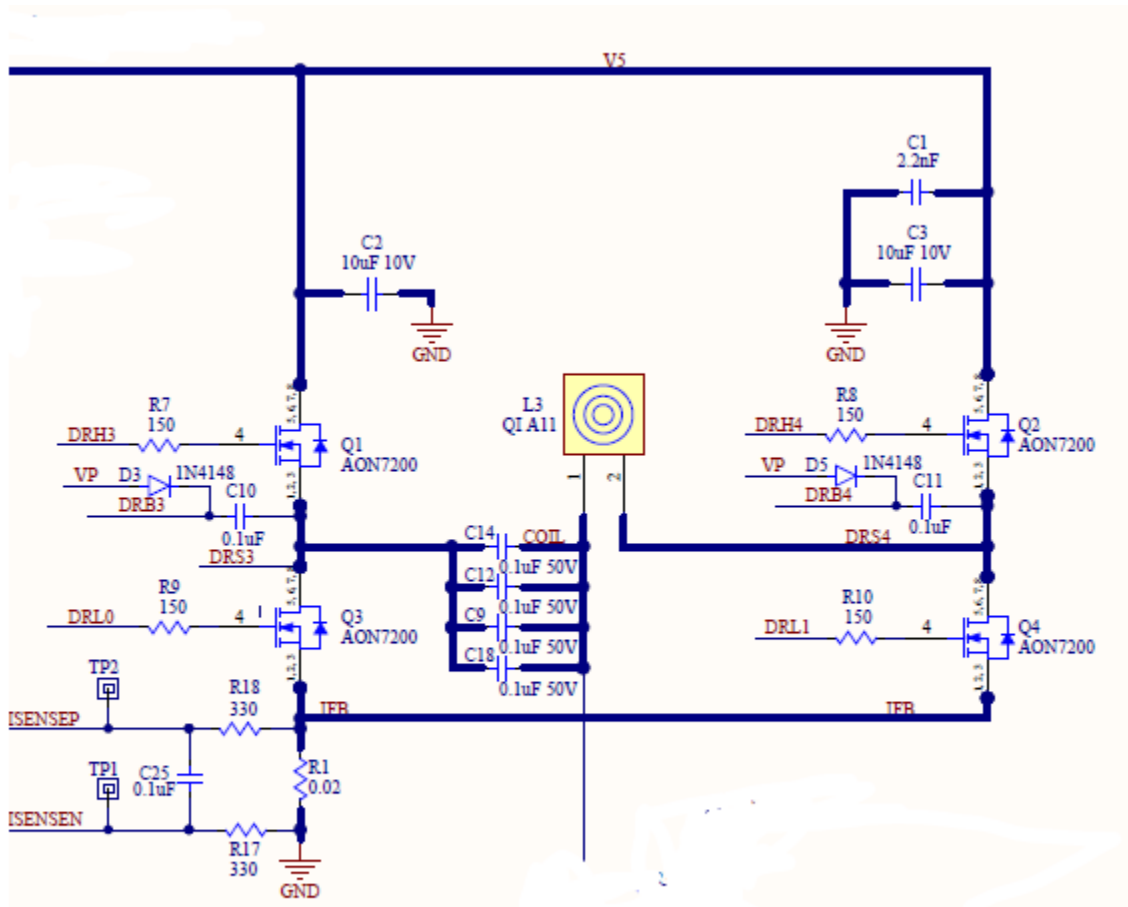
Since the ACT6311 can only tolerate up to 6V on its power supply input, a small series resistor and Zener diode are used to limit the input voltage to 6V in the event of a sustained overvoltage on the input power supply. In typical operation only 700 μ A passes through the series resistor.

The boost inductor should be sized to accommodate 300mA of peak current. A 1210-sized inductor, such as the Taiyo Yuden CBC2518T220M, should be used. 10 μ F ceramic capacitors are recommended at the input and output of the converter, as shown. The output rectifier should be a Schottky type.

The boost converter may run in a burst mode, or continuously depending on load. The waveform below shows the switch node (pin 1 of the ACT6311) during burst mode operation.



H-Bridge Power Stage



The H-bridge output stage drives the WPC type A11 coil.

Connected in series with the coil is a common-mode choke. This choke helps reduce radiated EMI. In some applications, this choke may not be needed it depends on many factors, including the desired margin to radiated EMI limits, and the selection of FET and switching speed detailed below. For highest efficiency, the resistance of this common mode choke should be as low as possible, and it must have very low impedance below 240kHz (the frequencies that power is transmitted). Active-Semi has tested and recommends the use of a Murata DLW5BTM101TQ2L common-mode filter here.

The coil is connected in series with a capacitor (actually four capacitors in parallel) which forms a circuit that is resonant at about 100kHz. These resonating capacitors are critical to the performance of the circuit. The total capacitance must equal 400nF, +/- 5%. The use of four 100nF, 5%, type C0G (also called NPO) capacitors rated at 50V or higher is required for optimal performance and efficiency. These capacitors are typically size 1206.

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It is possible to replace some of the capacitors with X7R 100V types, at the expense of efficiency. The use of only X7R capacitors alone is NOT recommended, as efficiency will be lower due to higher ESR of the capacitors, and capacitance shift may cause operational failures or even WPC certification failure.

For high efficiency, the FETs used for the H-bridge should have low $r_{DS(ON)}$ and low total gate charge. They should be rated for a minimum of 20V V_{ds} , and 12V V_{gs} .

Selection of the proper FETs, as well as sizing the series gate resistors (R7, R10 above) is critical for both optimum efficiency and controlling EMI. For the highest efficiency, switching times need to be kept short; however, fast switching results in EMI that may cause radiated emissions to exceed CISPR or FCC class B limits. There needs to be a compromise made between the desired radiated EMI and efficiency.

In addition, firmware dead time settings need to be optimized for a given FET/resistor combination. Because of this, it is recommended that only FETs tested by Active-Semi are used.

A minimum of two 10 μ F ceramic capacitors plus a small capacitor (a few nF) should be placed between V5 and ground near the power FETs (these are C1-C3 above). The AC current loop formed by these capacitors, the FETs, current sense resistor, common-mode filter, and coil needs to be kept as short and as low resistance (wide copper paths) as possible.

These high current paths are highlighted in in the schematic above.

Coil current is sensed by the 20 milliohm sense resistor R1, and filtered by R17/R18 and C25. Coil current measurement is used by hardware for over-current protection, and firmware for foreign object detection, the control loop and communications. Component values should not be changed, as firmware is calibrated for these values. The current sense resistor should be capable of passing 2A of continuous current.

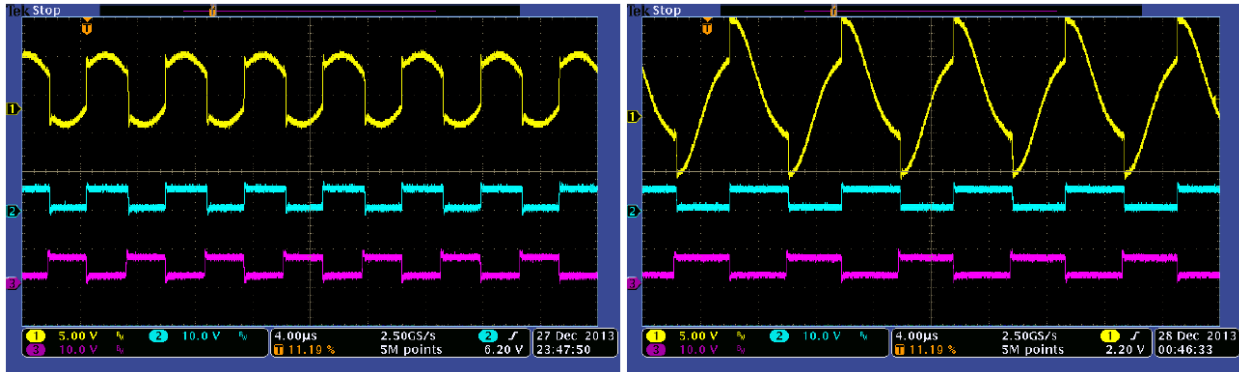
The current sense resistors (R1, R17, and R18) should be placed very near the power FETs to minimize parasitic resistance in the high current path. The differential sense signals from R17 and R18 should be routed as a pair to the PAC5220WP differential input pins to help reduce noise pickup. The filter capacitor (C25) should be placed near the PAC5220WP pins.

C10/D3 and C11/D5 form bootstrap circuits to generate high-side gate drive voltage.

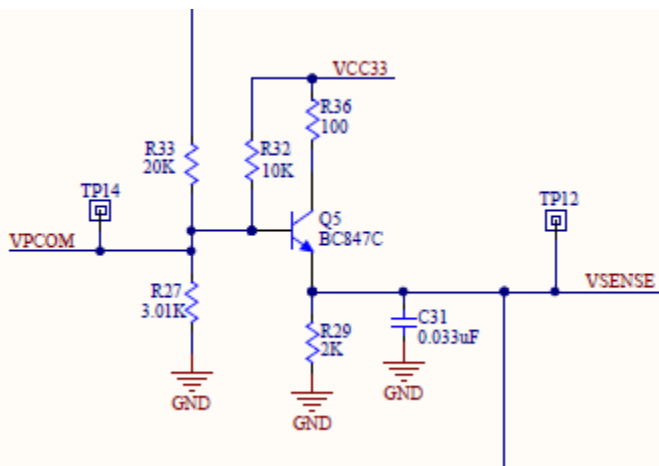
The waveforms below show the coil voltage (yellow) and the two H-bridge outputs DRS3 (blue) and DRS4 (magenta) during power transfer.

The waveforms on the left are taken at a low power level, and the one to the right is at 5 watts. Note the difference in coil waveform and lower drive frequency.

At very low power levels the drive duty cycle will also be reduced.



Active Rectifier

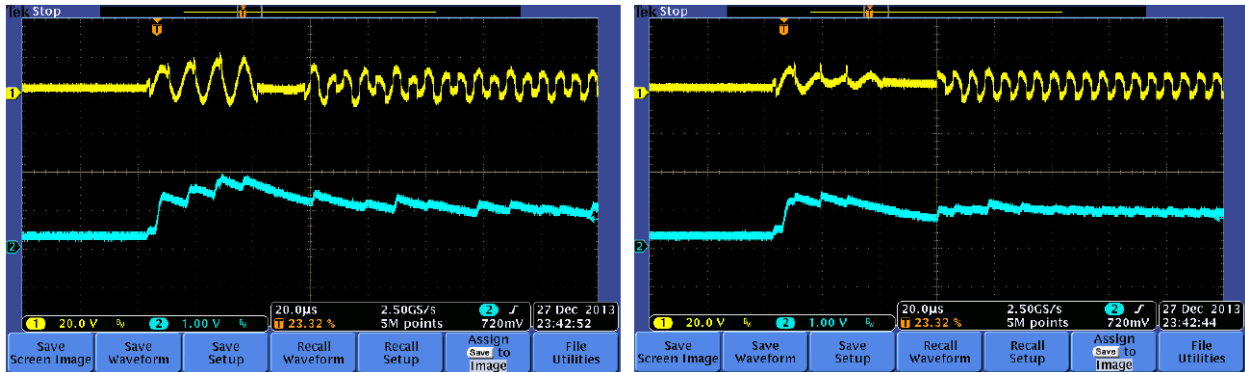


The active rectifier circuit samples the waveform at the resonant node of the H-bridge, and performs peak detection. This is one of the methods used to receive data transmitted back from the receiver to the transmitter. It is also used during analog ping to determine if something is placed on the transmitter coil.

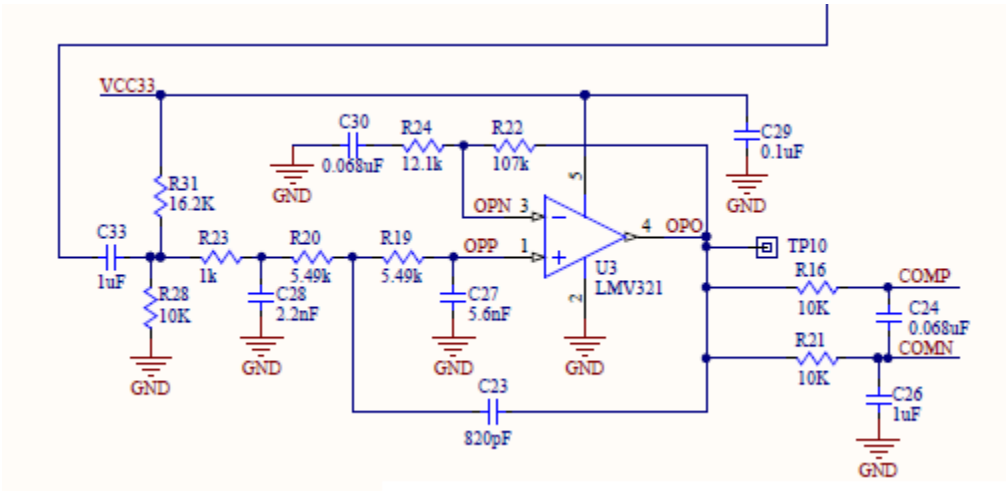
Component values should not be changed, as they are critical for communications.

Note that the NPN transistor chosen (BC847C) has an hFE (beta) of 420 (nominal). A generic NPN transistor with a lower hFE will not work well and may result in failure of WPC certification testing.

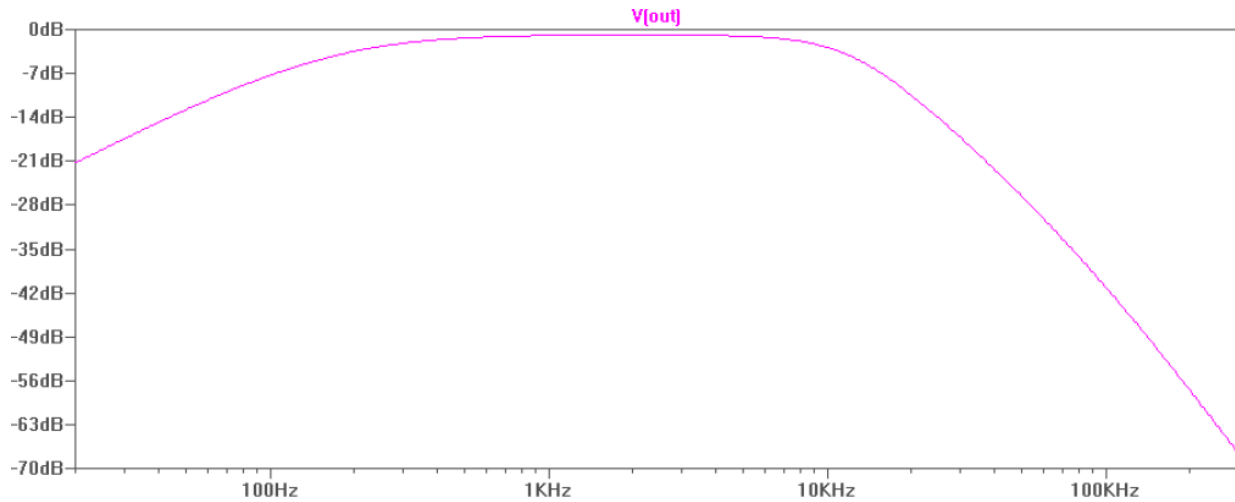
The waveforms below show the coil voltage (yellow) and the rectifier output VSENSE (TP12, blue) during analog ping. The waveforms on the left are when there is no receiver placed on the transmit coil; the right shows a receiver placed, and the resultant lower amplitude.



Communications Filter



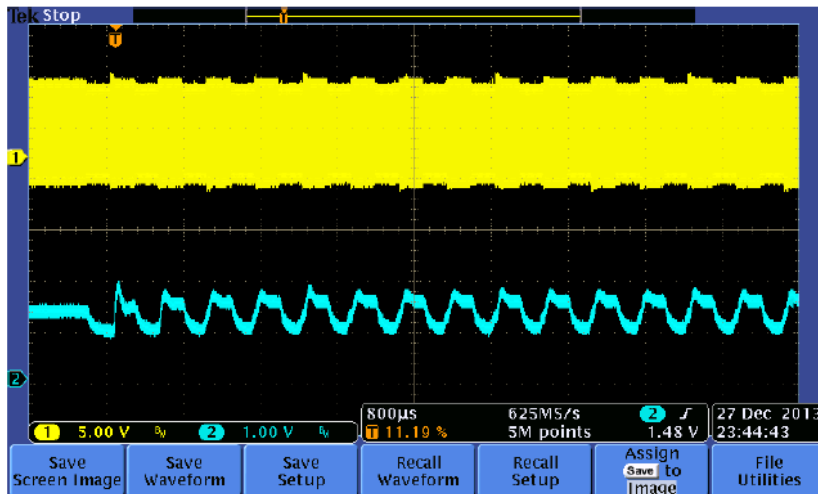
To recover the communications signal from the receiver to the transmitter, an active filter circuit is used to strip away any carrier frequency that remains after the active rectifier. This circuit provides a steep roll-off at 11kHz, and a more gradual roll-off below 200Hz.



It is important that component values be exactly duplicated to achieve the same response. Failure to correctly implement the filter will result in communications failures that may prevent passing WPC certification testing.

An inexpensive LMV321 OpAmp or similar low-voltage OpAmp is recommended.

The filter output is applied to a passive filter and integrator, and routed to a differential analog input on the PAC5220WP.

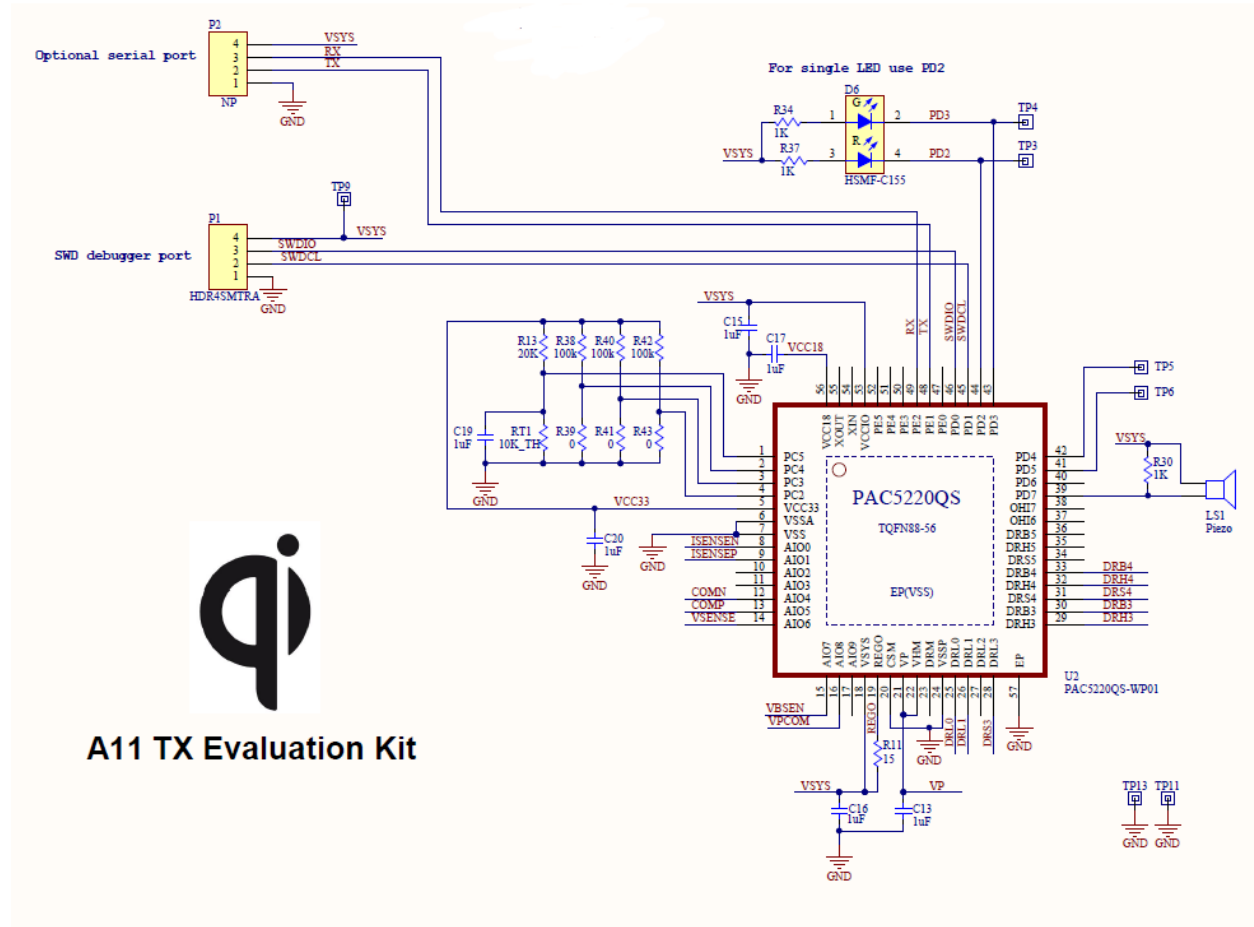


The waveforms shown above show the coil voltage (yellow) and the output of the active filter (TP10, blue) at the beginning of a communications packet during power transfer.

The shape and amplitude of the filter output will change dramatically depending on the receiver coil modulation method, power level, and coil coupling.

In some cases, there may be nearly no communication waveform visible. In these cases, communication data is recovered from the coil current.

PAC5220WP



A11 TX Evaluation Kit

The PAC5220WP provides the control, power management, and power drive functions of the transmitter. Firmware implements the required communication protocol and WPC power regulation functions. For details about the PAC5220, refer to the PAC5220WP user guide and the PAC Family User Guide.

1uF bypass ceramic bypass capacitors should be placed near pins 18, 20, 53, and 56. Ensure that the exposed pad in the center of the PAC5220 is connected to ground.

The EVK has an optional piezoelectric buzzer and a bi-color LED connected to port pins. They are used to indicate to the user the status of the WPC charger function. These devices are powered by the PAC5220WP VSYS (5V) regulator output to protect them and the PAC5220WP from overvoltage applied to the USB power input. They may be omitted if not needed.

If a regulated 5V supply is available (with no risk of overvoltage), VSYS may be directly connected to the 5V input supply (named V5 in the EVK schematic), and R11 may be removed. This will provide slightly higher efficiency.

If in-system programming of the PAC5220 flash memory is required, the PD0 (SWDIO) and PD1 (SWDCL) pins must be accessible to connect a firmware download cable. This can be implemented using

a connector (the EVK uses a 0.100 header), or test points accessed during board-level automated testing.

Similarly, the serial port on the PAC5220WP may be accessed to provide customization of the standard firmware features. Ports PE1 (TX) and PE2 (RX) are used for this communication. Connection to a serial interface cable to a PC allows customization of firmware features, using a GUI program provided by Active-Semi.

A thermistor (RT1) is used to sense the temperature near the transmit coil. Power transmission is disabled if the temperature exceeds approximately 45 °C. This thermistor used is an NTC thermistor with a R25/85 value of 3570K. The EVK uses a Vishay NTCS0805E3103JMT thermistor.

If the temperature sensing feature is not needed, RT1 may be omitted. Port PC5 needs to be pulled up to V3P3 if the thermistor is not used.

Pins PC2, PC3 and PC4 can be used for board-level feature configuration of the LED blinking, dead-time and FOD threshold (see the EVK user guide for more information). Since designs may have different layout, FETs this may affect the efficiency, and possibly the dead-time. If the default values for this application are sufficient, then these signals may be connected to ground.

PCB DESIGN GUIDELINES

To provide good efficiency and EMI performance, great care must be taken in the design of the PCB. For reference, the EVK PCB design is shown in Appendix B, layer by layer.

Although a successful design can be done using a 2-layer PCB, a 4-layer design is recommended. The use of 4 layers allows much wider copper areas, which minimizes resistance. It also allows more room for ground fills, and allows placing many of the signals on an inner layer, effectively shielding them from becoming EMI radiators.

Every milliohm of resistance contributes to loss of efficiency. Ensure that all high current paths (highlighted in the schematic diagrams above) are kept short and are routed by wide copper areas. Copper foils should be a minimum of 1 ounce [0.035mm] (after plating), and vias should be plated to a minimum thickness of 0.001 [0.025mm].

One inner layer should be dedicated to a solid ground plane.

The other inner layer can be used for routing longer high-current paths, such as the V5 and IFB signals, as well as routing other signals.

The outer layers are used for mounting components and routing signals. For high current paths, direct routing on the outer layers is preferable to changing to an inner layer and then back, due to the added resistance of the vias.

When vias are needed to access an inner layer on a high current path, the use of many vias minimizes the resistance of the connection. A minimum of 6 vias is recommended at each layer change.

To help shield EMI, copper connected to ground should be poured over the outer layers and any inner layer space not needed for routing. Vias should be used to stitch the ground layers together.

EMI CONSIDERATIONS

Since an A11 WPC transmitter requires switching power signals at 100-205kHz into an unshielded coil, radiated emissions can easily become a problem, exceeding the mandated CISPR22 or FCC part B limits.

Entire books can (and have been) written about techniques to reduce radiated EMI in electronic products. Following are a few hints and techniques that may be helpful in getting the A11 transmitter to comply with radiated EMI testing limits.

There are three main considerations for controlling radiated EMI in the A11 transmitter:

- Control the rise/fall times, or switching speed, of the output stage
- Provide common-mode filters on the power input and coil output
- Keep current loops short and noisy signals shielded on the PCB design

Though radiated EMI can be controlled somewhat by shielding and filtering, the primary way to reduce EMI is to eliminate it at its source as much as possible. Even then, filters may likely be needed to prevent radiation from connected cables.

The main source of radiated emissions from the A11 transmitter is from the fast switching of the H-bridge that drives the coil. Fast switching means that high-frequency, high-current pulses circulate in the output stage, which radiate EMI at frequencies many times that of the coil switching frequency. So, controlling EMI must involve limiting the slew rate also called rise/fall time or switching speed of the H-bridge.

Unfortunately, slowing the switching of the H-bridge results in higher power losses during switching, so lower overall efficiency is the result. A trade-off needs to be made between these to get an optimum solution.

Limiting the slew rate of the H-bridge is accomplished by adding resistance to the gate drive circuit. Specific FET and resistor recommendations are made in the H-bridge Power Stage section above.

Though the H-bridge is the *source* of the radiated energy, most of it is *emitted* from the power cable between the AC adapter and the WPC charger. To help mitigate this, a common-mode filter on the power input is usually required, as described in the Power Input section above. In addition, the shield of the USB cable (the shell of the connector) should be connected to the negative power input at the connector.

Some energy is also radiated directly from the coil. This emission can be reduced by using a common-mode filter in series with the coil. Also, if a metal back plate is used behind the ferrite coil shield, connecting this to PCB ground can also help lower emissions.

The copper paths on the PCB can also act as antennas, directly radiating EMI. Placing components close together to minimize the length of high-current paths helps minimize this emission. Providing as much ground area as possible on the PCB helps shield emission from the high current paths.

When performing EMI testing, be careful about the power source (AC adapter) and cable being used. These may contribute significantly to the radiated EMI. It is wise to measure just the adapter and load

(phone or other device) without wireless charging to ensure that you are measuring emissions from the WPC transmitter, not the power source or device!

EFFICIENCY CONSIDERATIONS

The efficiency of the overall WPC system is a combination of the efficiency (or rather the *inefficiency*) of the coil coupling, transmitter, and receiver. It is difficult - nearly impossible, in the case of the coil coupling - to exceed 90% efficiency for each of these three components. Note that three components with 90% efficiency will give a total *system* efficiency of 73%.

Depending on tradeoffs made for lowering EMI, Active-Semi has measured system efficiency as high as 75% with the PAC5220WP EVK (including the efficiency of the transmitter, coils, and a WPC receiver). More typically, in a system configured for good radiated EMI performance, a system efficiency of 72% is attainable.

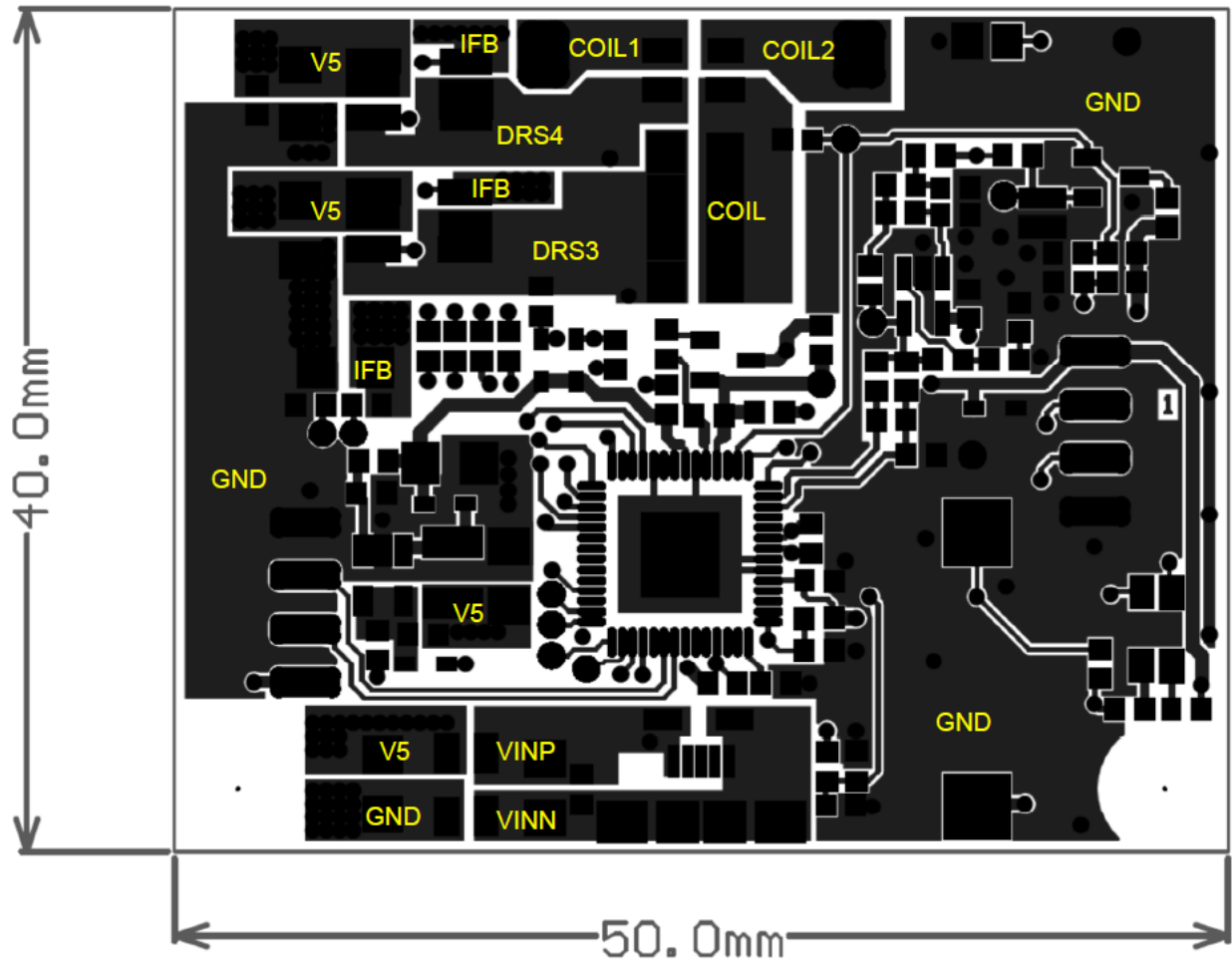
To get the highest efficiency possible, all sources of parasitic resistance must be minimized. Techniques for this are described in the PCB Design section above.

FET selection is also critical $R_{DS(ON)}$ must be as low as possible. For highest efficiency, switching speed should be fast, but needs to be limited to control EMI as described in the sections above.

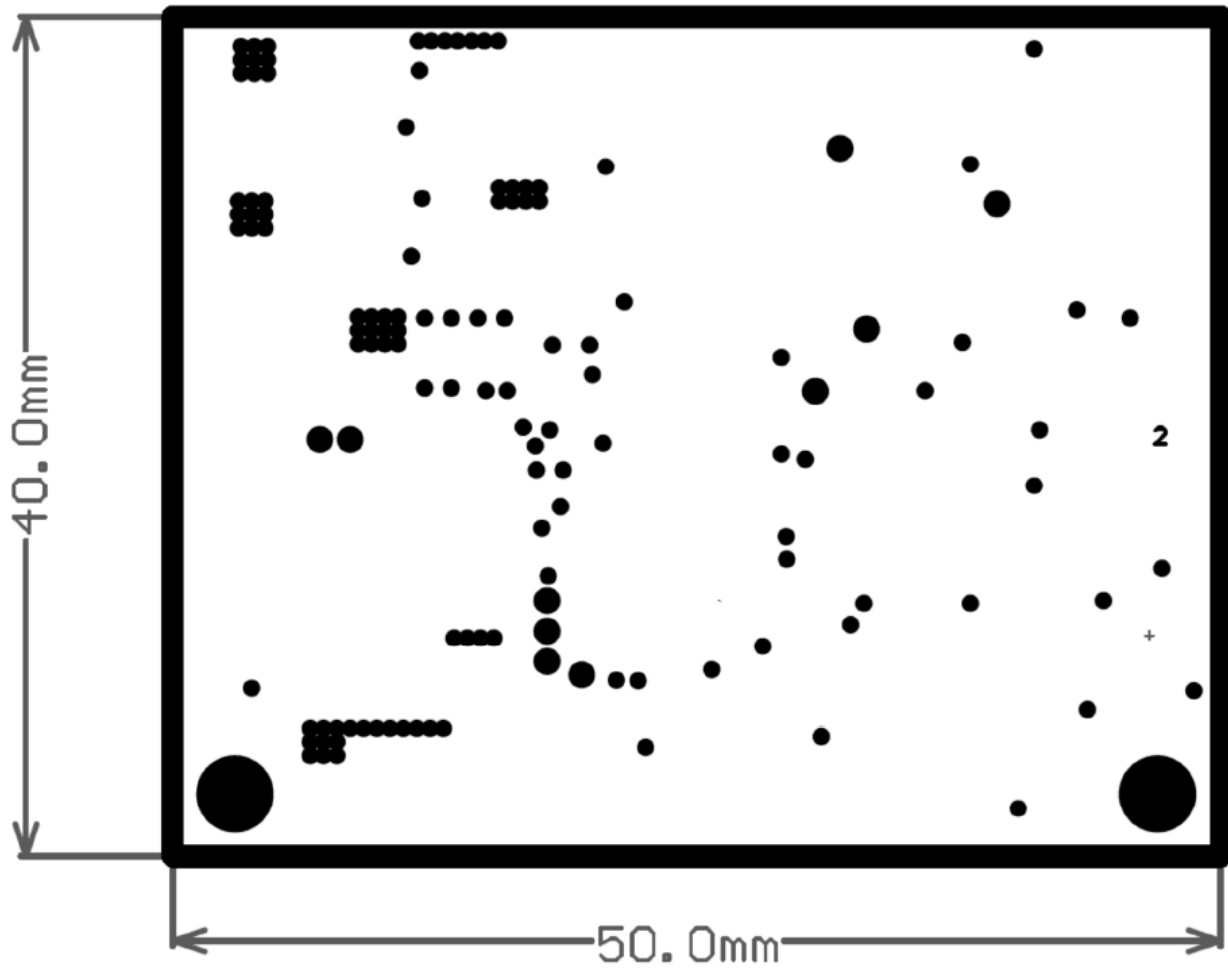
Do not neglect the voltage drop through the power input cable. Inexpensive USB cables have very high resistance, and can contribute as much as a 10% efficiency loss.

APPENDIX B – EVK PCB PLOTS

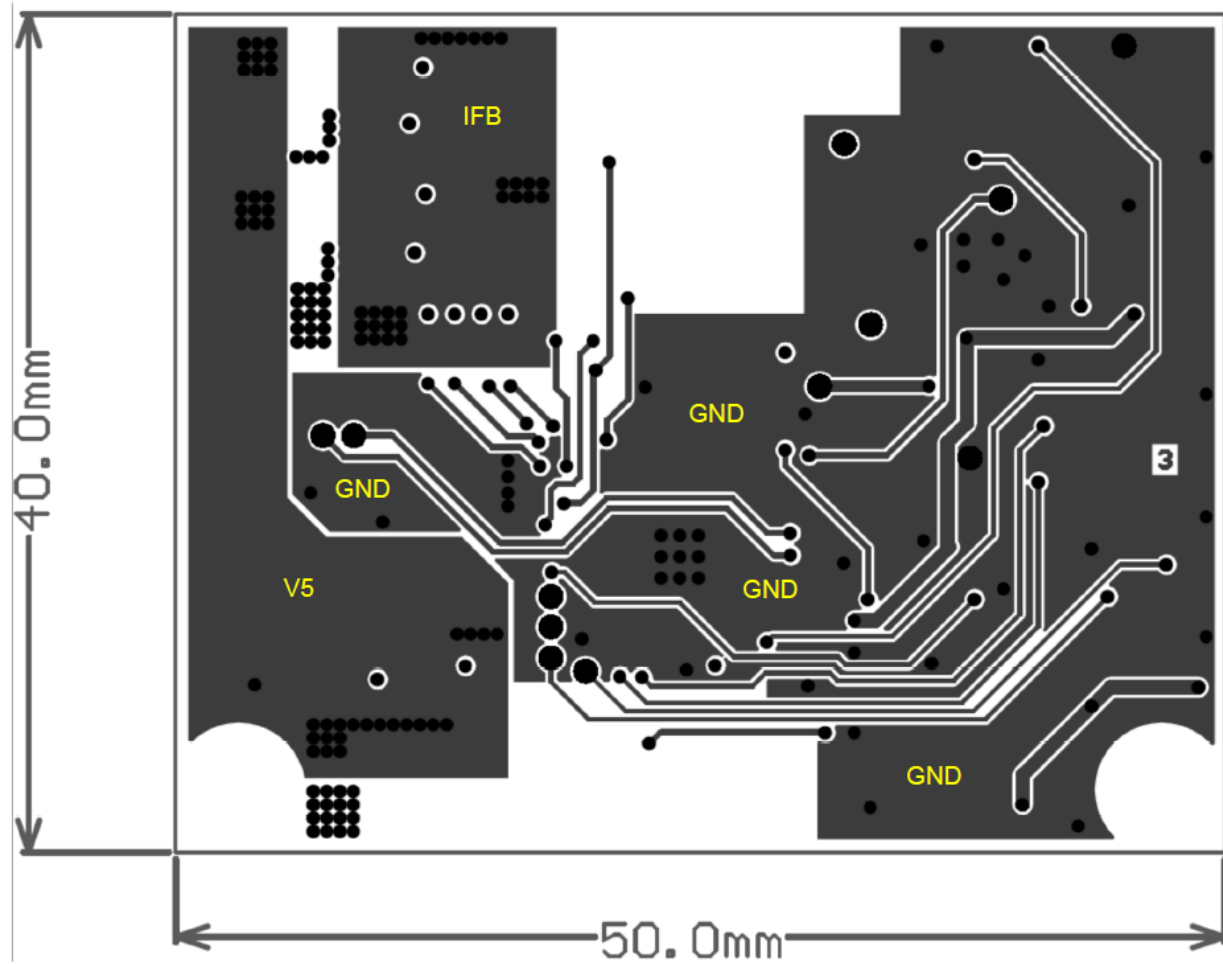
Layer 1 (top layer)



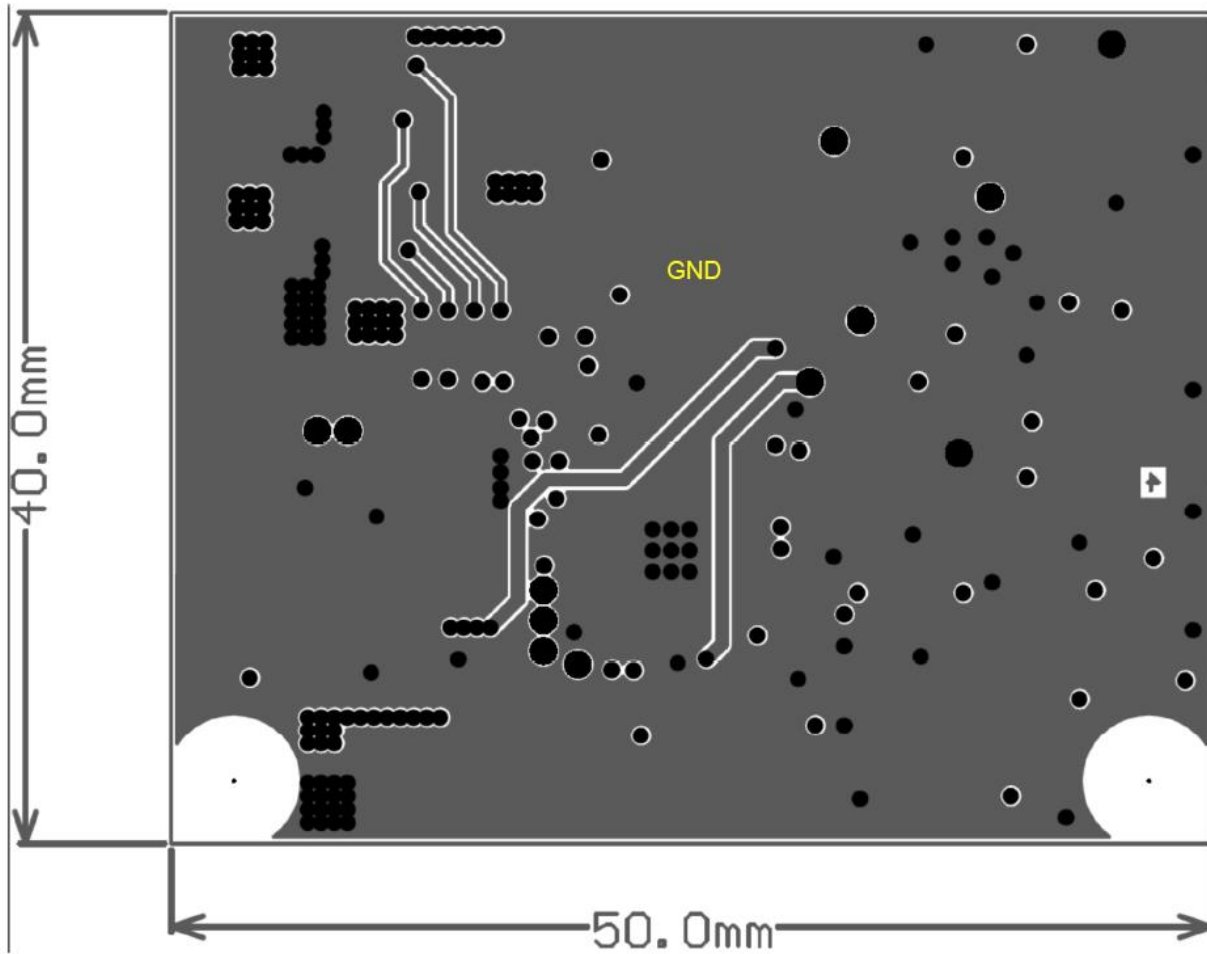
Layer 2 - Solid Ground Plane



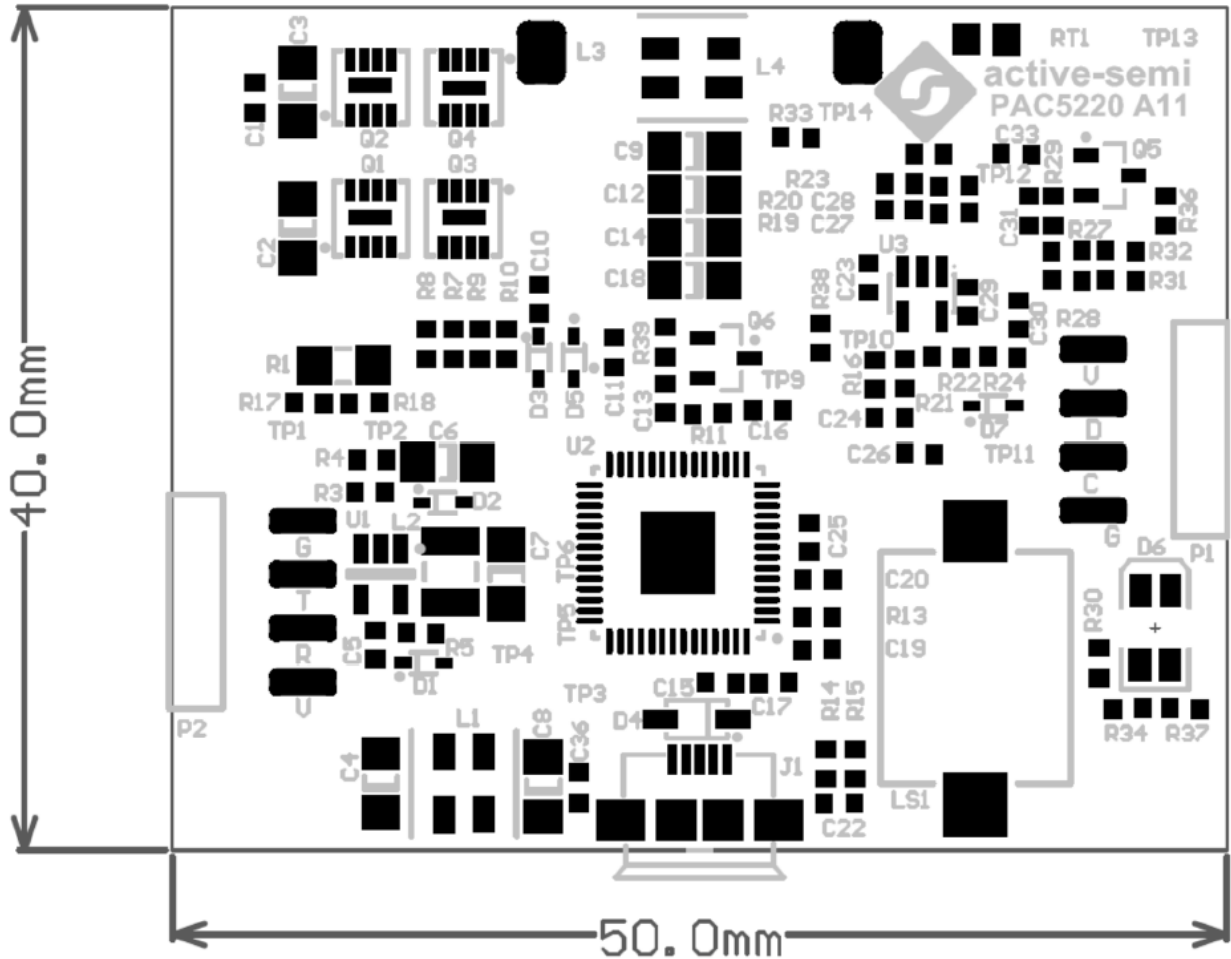
Layer 3



Layer 4 – Bottom Layer



Silkscreen (component placement)



ABOUT ACTIVE-SEMI

Active-Semi, Inc. headquartered in Dallas, TX is a leading innovative semiconductor company with proven power management, analog and mixed-signal products for end-applications that require power conversion (AC/DC, DC/DC, DC/AC, PFC, etc.), motor drivers and control and LED drivers and control along with ARM microcontroller for system development.

Active-Semi's latest family of Power Application Controller (PAC)[™] ICs offer high-level of integration with 32-bit ARM Cortex M0, along with configurable power management peripherals, configurable analog front-end with high-precision, high-speed data converters, single-ended and differential PGAs, integrated low-voltage and high-voltage gate drives. PAC IC offers unprecedented flexibility and ease in the systems design of various end-applications such as Wireless Power Transmitters, Motor drives, UPS, Solar Inverters and LED lighting, etc. that require a microcontroller, power conversion, analog sensing, high-voltage gate drives, open-drain outputs, analog & digital general purpose IO, as well as support for wired and wireless communication. More information and samples can be obtained from <http://www.active-semi.com> or by emailing marketing@active-semi.com

Active-Semi shipped its 1 Billionth IC in 2012, and has over 120 in patents awarded and pending approval.

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