Application Note: AZD015

Radiated - Immunity Guidelines for ProxSense Designs

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1 Introduction

1.1 The need for Radiated-Immunity

Wireless data transfer have increased significantly in recent years, be it with cellular telephones, WiFi networking, gaming consoles etc. This fact increases the probability of ProxSense based designs to be exposed to high levels of RF-radiation greatly. In addition, a large number of unintentional RF transmitters exist in the real world, such as lightning, arcing of contactors and of brushes on electrical motors, spark plugs and products not conforming to EMC standards. To ensure market acceptance and a low percentage of RF-related problems in the field, a certain amount of immunity to RF-radiation is required. ProxSense devices have been designed to ensure fairly high inherent Radiated-Immunity. However, this does not immediately guarantee Radiated-Immunity for the whole system in which the ProxSense device is used. A holistic Radiated-Immunity design approach is required to ensure the best chances of achieving the required level of immunity, with the ProxSense device but one part. The purpose of this application note is to give guidelines to help our clients design for Radiated-Immunity, and also give some background information.

1.2 Relevant International Standards

The most prevailing global standard for commercial Radiated-Immunity, also called Radiated Susceptibility, is **IEC 61000-4-3**. This has been preceded in previous years and decades by IEC 801-3. A large number of product family immunity standards call upon 61000-4-3 as the basic test method for Radiated Immunity. The following European standards are typically applicable to ProxSense based products, and call upon IEC 61000-4-3.

EN 55024: Information Technology Equipment (ITE) and Telecoms product family immunity standard

EN 61326-1: Laboratory Equipment product family immunity standard

EN 55103-1: Professional audio, video & lighting product family immunity standard

EN 50130-4: Alarms & security product family immunity standard

EN 55104-2: Household Appliances product family immunity standard

For general purposes **IEC 61000-4-3** stipulate immunity to radiated fields with a frequency between **26MHz and 1GHz** (although **80MHz** is mostly used as starting point), and fields levels of 1V/m, 3V/m, 10V/m, or 30V/m respectively. (A fifth, unspecified special X level is also accommodated, where required). To ensure protection against RF-radiation from digital radio telephones and other such intentional transmitting devices, recent editions of IEC 61000-4-3 calls for testing in the **1.4GHz to 6GHz band.** The standard does not stipulate a continuous sweep in this band, but rather testing for Radiated Immunity at the specific frequencies used by digital radio telephones and other such intentional transmitters in the geographical area where the product under test will be deployed.

For typical commercial products using ProxSense devices, a test level between **3V/m and 10V/m** are relevant. **IEC 61000-4-3** further requires that the above field is **AM-modulated at 80% depth and 1kHz modulation frequency**. The last requirement is an effort to simulate modulation of data used in real world radio transmissions, especially in digital data transmissions.

Interestingly, in the US, the FCC do not seem to have a specific standard for Radiated Immunity. Part 15.17 of the FCC rules only advise that electronic products should be designed with immunity to intentional and unintentional transmitters in mind. In terms of military applications, MIL-STD-461E RS103 stipulates the relevant test methods and radiated field levels required for military products.

It should be noted that IEC61000-4-3 only applies to commercial products, and not to products where product malfunction / failure due to RF-radiation could result in loss of life or large scale financial loss. Stringent international and local standards and directives cover Medical, Maritime, Avionics, Machinery and Automotive applications, and should be referred to.

1.3 Low cost in-house test methods

Formal Radiated Immunity testing is normally done on an Open Area Test Site (OATS), in a fully anechoic chamber, in a semi-anechoic chamber or in a GTEM cell which has been certified for conformance with an OATS. All of these require substantial capital outlay and are expensive to operate, reflected in the cost to book them. Therefore, a real need exist for cheaper, alternative test methods which can be used either during the design phase, or to remedy a Radiated Immunity failure. Below lists a number of possible methods:

- The first and most obvious, is to use cellular telephones. These typically emit up to 2W of RF-power around the 900MHz (EU), 1800MHZ (EU), 1900MHz(US) and 2.45GHz (US) bands. It should be kept in mind that cell phones are designed to radiated away from the user’s head, and that field levels close to the phone are normally well in excess of 30V/m, so it is a severe (but relevant!) test.
- WiFi routers make good 2.45GHz sources and is a relevant test.
- Zigbee or BlueTooth transceivers, which emit in the 2.45GHz band. Higher power Zigbee devices typically emit 20dBm or 100mW.
- All legal Industrial, Scientific and Medical (ISM) band transmitters. Typically, these emit in the mW range, but they can still be useful, especially to test for immunity at lower frequencies such as 370Mhz and 433MHz.

- Two way radios, also known as walkie-talkies. These units typically emit a few Watt of RF-power, and thus can be quite useful. Ensure that the units are license exempt, or if not, that the required license is up to date as required by local standards.
- When using the above, make sure that the transmitter is placed as many positions as practically possible relative to the product under test. This include variations in height. Also change the orientation of the product under test. In environments other than an OATS, anechoic- or semi-anechoic chamber, reflections from conductive and semi-conductive surfaces can easily result in points where the radiated fields cancel, creating a field null. Such nulls can give a false positive result for RF-immunity.
- E-field and H-field probes to inject fields at the frequency of interest into specific sections of the circuit under test. These probes must be used with a signal generator, and possibly an amplifier. In the case of the latter, relevant legal and health limits need to be adhered to.
- Small TEM cells, which can be manufactured from PCB material in a DIY manner. A number of web references exist. Once again, all legal and health limits must be adhered to.

In all the above, extreme care must be taken not to exceed local legal limits for generated RF-radiation. Severe consequences, including loss of life, might result if these limits are exceeded. If unsure, consult an EMC specialist.

1.4 A margin to ensure conformance

Although most commercial products only have to be immune to radiated fields of between 3V/m to 10V/m, most EMC guides and authorities advise to test at higher levels, to ensure conformance at other labs, should the need arise. This stems from the fact that a fair amount of uncertainty exist during Radiated Immunity testing about the exact level of the radiated field over the whole product under test, even if the relevant standard is followed to the letter. Therefore, if a particular product only just passes at say 3V/m, it is very likely that a 3V/m retest at a second lab, maybe requested by a client, will result in a fail.

In addition, due cellular telephone use of bands above 1GHz and the large scale use of WiFi at 2.45GHz, it is advisable to test above thoroughly above 1GHz, to ensure the least number of in-field Radiated Immunity problems. We recommend testing up to 30V/m and 6GHz where possible.

2 Schematic design / component selection guidelines

2.1 Decoupling & capacitor selection

The first line of defence against RF-radiation is proper capacitive decoupling of IC's, as is almost common knowledge among electronic designers today. Digital circuits require stable supply rails for proper operation. However, a slightly lesser known fact is that most surface mount capacitors have a very strong frequency dependence, and only decouple for a finite frequency band. Figure 1 illustrates the typical impedance for a surface mount ceramic capacitor. Due to self-inductance of surface mount capacitors, their impedance have a definite resonant point, above which the inductance dominates, and impedance increases with frequency. As the ceramic capacitor value decrease, the resonant point shifts up in frequency. In other words, where the 100nF of Figure 1 have a minimum at around 25MHz, a similar size 100pF will typically have a minimum around 1GHz.

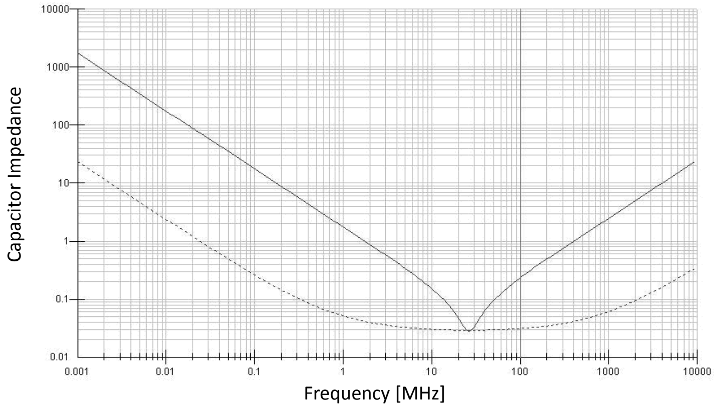

Figure 1: Typical impedance vs. frequency for a surface mount 100nF, 0402 size ceramic capacitor

From the above, it is clear that if we want to decouple from say 100kHz to 3GHz, we need a range of capacitor values, with the impedance curves overlapping. Ideally, if cost and space is not at a high premium, we recommend using 10pF, 100pF, 1nF, 100nF and 1μF. For cost and space constrained designs, a combination of 100pF and 1μF could be sufficient. (But could also result in expensive fault-finding and redesign due to RF-immunity failure.) Use 0603 or 0402 sized decoupling capacitors where possible.

2.2 RC and LC-filters

As we go up in frequency, and require smaller value/size capacitors to shunt interference energy, the resonant bands get narrower, as illustrated in Figure 2. This could potentially cause problems, as proper decoupling only occurs for a narrow band.

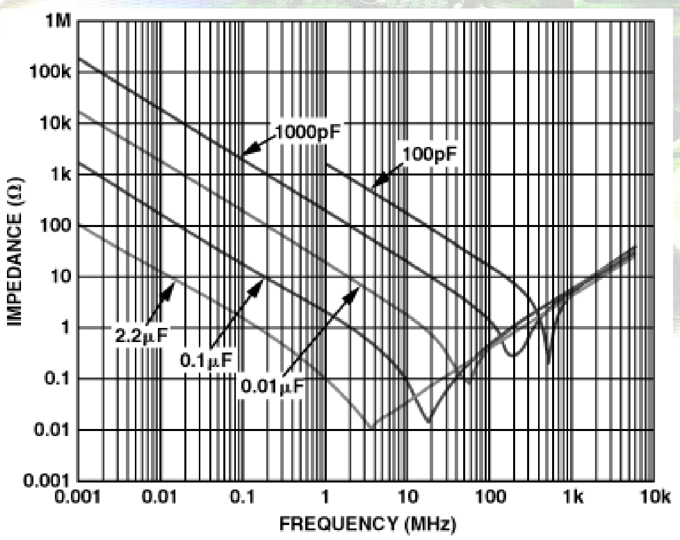

Figure 2: Decrease in decoupling band as ceramic capacitor value decreases

An alternative approach to overcome the above is to use a low-pass RC or LC filter, especially on supply lines to IC's. Figure 3 illustrates the classical single stage, first order low-pass RC filter, and the typical frequency response of the gain, or output relative to input. The cut-off frequency f_c is inversely proportional to the capacitor and resistor value. We recommend using values of 5Ω and 100nF, which should result in a cut-off frequency of around 300kHz.

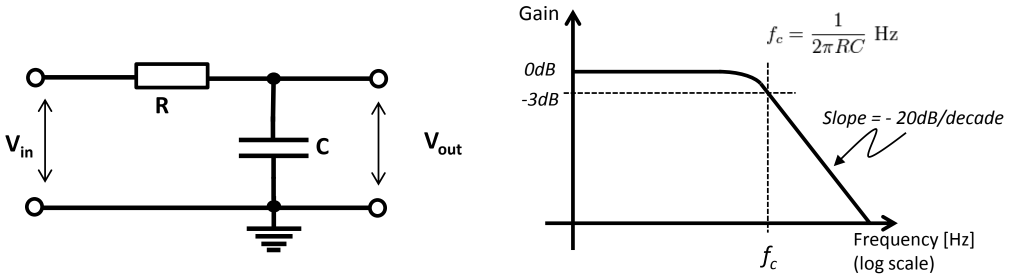

Figure 3: Classical single stage RC low-pass filter as alternative to using only capacitor decoupling

Although single stage RC-filters work fairly well, and are cost effective, a sharper roll-off might sometimes be required. For instance, if an offending frequency lies close to the data transfer rate within a product, a sharp roll-off is required to ensure the data is not filtered along with the offending frequency. Sharper roll-off can be achieved in two ways. The first is to cascade more than one stage of first order filters, like the single stage RC. The second is to increase the order of the filter by using more than one energy storage element. Figure 4 illustrates a classical, single stage, second order low-pass LC filter, and typical ideal frequency response. A word of caution on LC filters. As they are resonant circuits, an amount of damping is required to ensure the output is not exceedingly high at the resonant frequency point around f_c . It is advisable to insert a small resistor (few Ω) in series with the inductor.

The roll-off can be further increased to -60dB/decade by using a third energy storage element, such as found in T-type and π-type LC filters. However, the design of these are fairly involved, and lies beyond this application note. Please refer to relevant Filtering textbooks / web references.

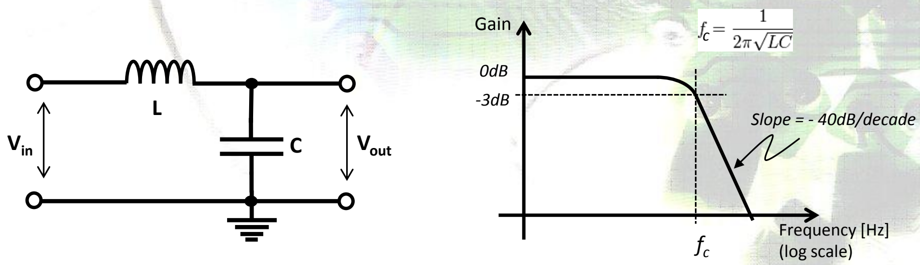

Figure 4: Classical single stage, second order LC low-pass filter

2.3 TVS diodes etc.

Transient voltage suppressor (TVS) diodes are most often used to protect against ESD and high voltage surges. (Other trade names are Transzorbs and Transils). However, they can also be used with fair effect against radiated disturbances, due to their inherent junction capacitances. Especially on data lines, TVS diodes can help with immunity against both ESD and RF. The author have experienced a case where a simple change from an LM324 op-amp to an LMX324, which have its inputs protected by internal 3.5kΩ series resistances and back to back, triple stack protection diodes solved a Radiated Immunity failure which resisted all other attempts.

2.4 Unused / Do Not Place Components

Often in a design, components will be placed on the schematic only because they may be required in future. These are then marked as Do Not Place (DNP's). Care should be taken with DNP's where Radiated Immunity is concerned. For instance, if the DNP is an IC, it will typically require a supply. Therefore, a Vcc line will run towards the DNP site. But in practice it will not be connected to a load, and can act as an excellent RF-antenna, resulting in noise coupled directly onto the Vcc rail of the product. One method to overcome this is to use solder-links or 0Ω resistors to couple/decouple unused Vcc, or other, lines associated with DNP components. This also applies to digital communication lines as used for SPI or I^2C busses, typical in ProxSense designs. Figures 5 and 6 illustrate the above. Naturally, the links or 0Ω resistors must be placed as far away as possible from the DNP, or on both ends of the line to be decoupled, to avoid antenna creation.

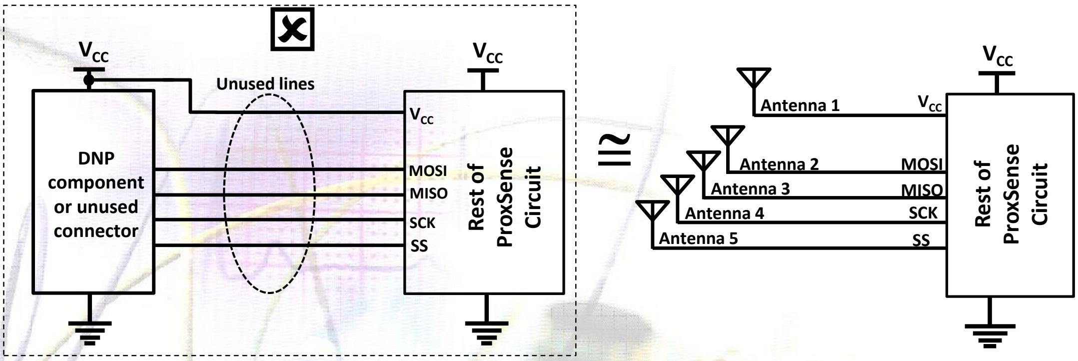

Figure 5: Unused lines towards DNP components or unused connectors may create RF-antennas

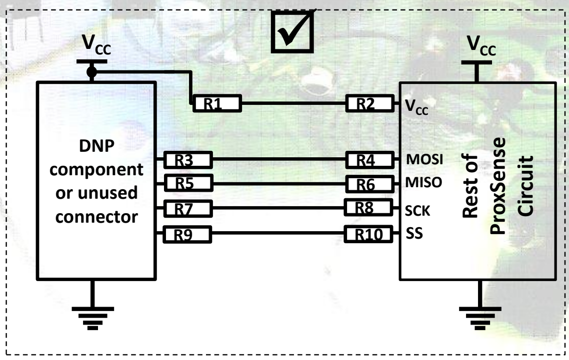

Figure 6: Using 0Ω resistors or solder links to decouple unused lines, to avoid RF-antenna creation

3 PCB layout guidelines

3.1 Grounding & stitching

Radio frequency currents induced by radiated interference follow a simple rule when deciding where to flow. Avoid inductances, seek capacitances. However, the effect of this simple rule is quite complex, as troubleshooting Radiated Immunity failures often show. It is extremely difficult to visualize out of hand how and where coupled / induced currents will flow, and where not. However, what we can do is make sure we provide the lowest possible impedance path for interference currents that have been shunted to ground, and which are returning to the source of interference energy. It is no use to employ decoupling capacitors, or filters, and present high parasitic inductance in the return path from the decoupling capacitors or filters. Interference currents will not be shunted by the capacitors or filters, but seek alternative paths with less inductance, often through an IC, resulting in a failure under RF-radiation. It is imperative to provide the lowest possible parasitic inductance ground connection to ensure Radiated Immunity.

For instance, consider the example in Figure 7. Even though a decoupling capacitor is placed right at the ProxSense IC, the return path back towards the interference source have only a thin track as ground connection, with high parasitic inductance. However, it is only a short hop from the IC's ground to a wide ground track. In all probability, RF-currents will not be shunted by the decoupling capacitor, but flow through the IC and back along the low inductance path, resulting in interference coupled onto the IC supply.

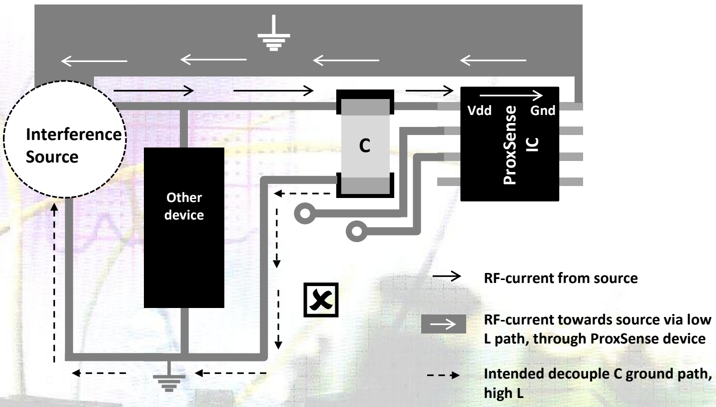

Figure 7: Example to illustrate importance of low inductance ground

Ok, so what makes a good ground? The following can be used as guide:

- Thin ground track = BAD
- Wide ground track = GOOD
- Ground plane with a large number of slots to accommodate other lines = OK
  (But connect sections where possible with via's and tracks on the opposite layer)
- Solid ground plane only interrupted by via's = BEST
- Solid ground plane only interrupted by via's, "stitched" to gnd opposite = BEST of the BEST

ProxSense IC's which have an ICTRL pin, such as the IQS316, require care to be taken with the grounding of the resistor connected to this pin. The reference current for IC operation, including clock frequencies, is set by this resistor. Therefore, should the ground around ICTRL and the associated resistor conduct high transient currents, and have a high ground impedance, the subsequent ground bounce will adversely affect IC operation.

The last bullet point above refers to another important aspect of grounding. Overlapping sections of ground on different layers should be "stitched" together with via's. This is often seen in RF-transceiver designs and boards. It aids greatly in ensuring a minimum inductance ground. Also, it provides alternate current paths through ground sections which have only one entry and exit point. Such "flapping" pieces of ground are effectively useless, and are more likely to function as a capacitively tuned pickup antenna, introducing noise onto ground, than a proper grounding path. Figures 8 and 9 illustrate the concepts around stitching. Another important layout aspect for ProxSense circuit is illustrated in Figure 8. **Grounded copper should not be placed close to, or underneath, Cx lines or electrodes, as this will significantly reduce touch sensitivity.**

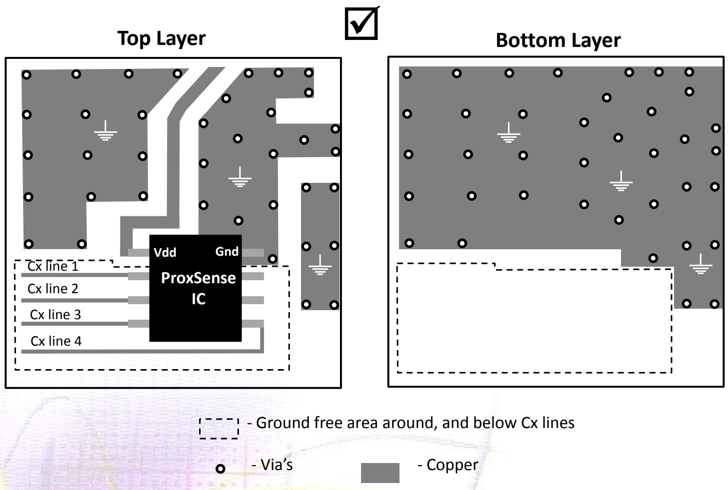

Figure 8: Stitching ground sections on different layers of a PCB

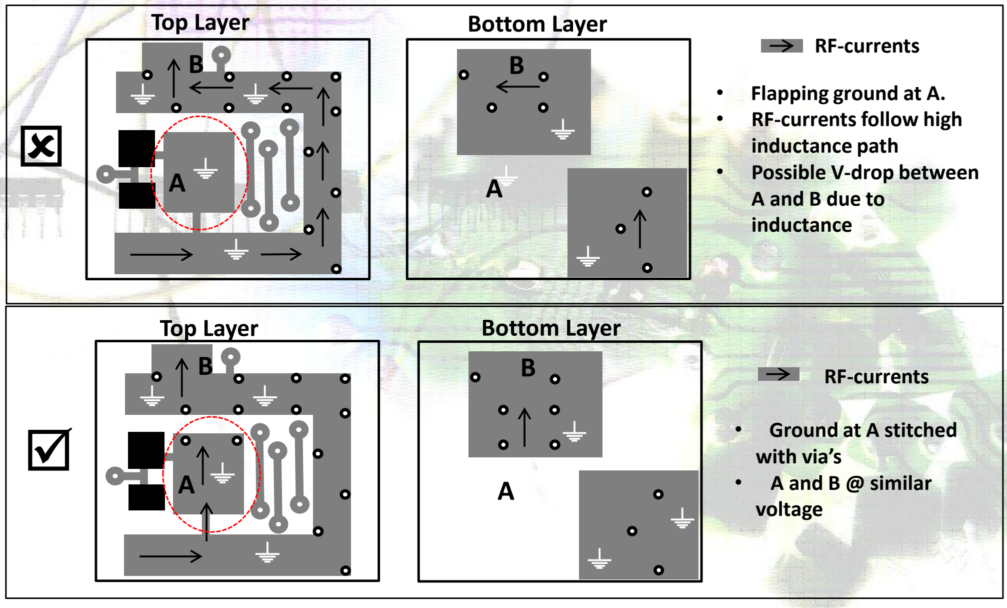

Figure 9: “Flapping” ground sections should be avoided, and stitched if possible

3.2 Loops & following the current path

If RF-radiation only propagated via electric fields, tracks forming loops or semi-loops would not have been a concern as pick-up antennas. However, electromagnetic energy always propagate as a combination of electric and magnetic fields. It is impossible to predict how energy will shared between the electric and magnetic waves for all possible applications of ProxSense devices and their environment. Therefore, a track forming a loop or a semi-loop is as liable to couple RF-energy into the ProxSense circuit as an un-terminated track which forms a quarter wave E-field antenna. Loops should therefore be avoided as far as possible.

Often, loops on the supply rails are not evident at first glance. A good method to identify loops is to "follow the current". Start at a supply point, or possible interference source point, and try to follow the lowest inductance path for the current from and back to the source. This often highlights loops which would have been missed otherwise.

3.3 Tracks as receiving E-field antennas

As mentioned in the Schematic Guideline section, un-terminated tracks make excellent E-field antennas. During layout, these should be avoided as far as possible. Care should also be taken with tracks which are terminated on one end in a series inductance, and connected to the rest of the circuit at the other end. The inductance effectively decouples the track on its end for RF, meaning it is an un-terminated track connected to the remainder of the circuit.

Conflicting requirements exists for Radiated-Immunity and Capacitive Sensing with regards to un-terminated tracks. Tracks to capacitive sense plates used for proximity or touch sensing are un-terminated by default, or only capacitively terminated. Inserting a discrete inductor into the sense plate line will in general reduce the amount of RF-energy picked up by the line. However, this will reduce touch sensitivity significantly if the inductance is too large. The following are recommended as a guide:

- Keep tracks to sense plates as short as possible
- Make tracks to sense plates as thin as possible (Which maximise the distributed L_{Track})
- If discrete inductances are used in severe cases, do not exceed 100μH.

3.4 Decoupling sites

If decoupling capacitors are not placed correctly, all the effort to choose the correct capacitor values can be negated. As illustrated in the above section on grounding, one should always aim to provide the decoupling capacitor with minimum inductance on its feeding and return paths to the energy or interference source. In conjunction with this requirement, one should place the decoupling capacitor as close as possible to the ProxSense device, with a minimum inductance path, as illustrated in Figure 10. The reason for the last requirement is two-fold. Firstly, if the decoupling capacitor is far away from the IC, radiated interference can couple into the long tracks between capacitor and IC. Secondly, should interference somehow be coupled via another path onto the IC's internal supply rail, a decouple capacitor which is too far away and present too much inductance will result in the interference currents not being shunted via the capacitor to ground, but flowing through the IC to ground. The last case is particularly applicable to the internal regulator pins (V_{dd}) of ProxSense devices. In summary:

- Place decouple caps as close as possible to ProxSense device.
- The lowest value capacitance must be closest to the Vdd /Vddhi pin.
- Ensure that minimum inductance paths exist between decouple cap and ProxSense device.
- Ensure that minimum inductance paths exist for feeding and returning between the decouple capacitor and the main voltage supply.

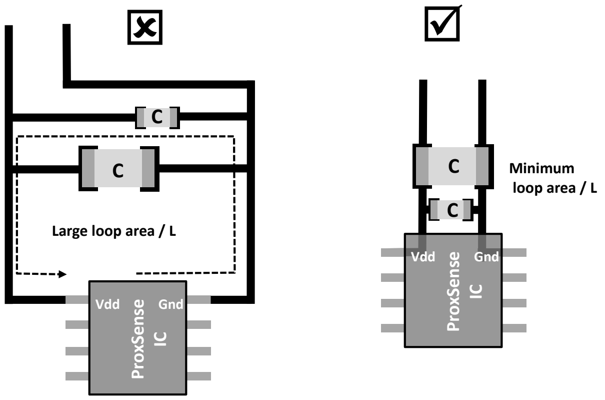

Figure 10: Ensure minimum inductance path between decouple cap and IC

3.5 Digital communication lines: lengths and routing

It goes without saying that digital communication lines are especially susceptible, and should be kept as short as possible. Avoid routing communication lines in areas where a protective ground plane, or at least some ground sections are not available on the opposite layer. If pull-up resistors, RC-filters or LC-filters are used to improve the immunity of the communication lines, their placement should be carefully considered. For instance, if a master needs to indicate to a slave that a communication session is starting by pulling a certain line low, the pull-up resistor should be on the slave side. Chances of communication errors because the line is low at the master side due to interference is not high, but an erroneous low at the slave side due to RF-radiation will cause communication failure. Often, the best approach is to duplicate filters and pull-up/pull-down resistors at both ends of long digital communication lines, with adjustment of the component values as required.

3.6 Good practice: Energy flow

In terms of general board layout for Radiated Immunity, it is good practice to follow the energy flow across a board, and make sure it follows a consistent direction as far as possible. Situations where the power supply is split over three sections of the board, with the ProxSense device somewhere in the middle, and communication lines running through power supply sections should be avoided.

4 Use of IQSxxx RF-Detection functionality

4.1 Last resort

Azoteq ProxSense devices include the ability to detect high levels of RF-radiation, and halt logic outputs to ensure false touch or proximity annunciations do not occur. However, this should be used as a last resort to ensure Radiated Immunity, as it effectively disables the touch functionality. We advise to only use RF-Detection of IQSxxx devices once all the guidelines presented here, as well as other remedial sources, have failed to result in Radiated Immunity as required.

4.2 RF – Detection on IQSxxx devices: How it works

Firstly, a relevant antenna needs to be connected to the RF-pin of the ProxSense device. If high levels of radiation at the antenna frequency are present, sufficient energy will be coupled into the RF-pin to trip an internal dc-blocked comparator circuit. The state change of the comparator is noted by the main processor of the ProxSense device, resulting in touch and proximity measurements being ignored for a fixed period. Please note that we recommend placing a 51Ω resistor between the RF-pin and ground as a matching impedance between antenna and the internal RF-detection circuitry. A dc-blocking capacitor in not necessary, as this is already realised within the ProxSense device.

Detection distance is very much dependent on the antenna connected to the RF-pin, the RF-source (frequency and power), environment and ProxSense device settings. However, to give some idea of feasible distance, we have tested the IQS127 on an AZP110 board with a 900MHz band GSM phone, with typical power output on the order of 500mW (27dBm). A simple ¼ wave wire antenna was connected to the RF-in of the IQS127. Average detection distance was around 0.3m or 30cm. Seen against measurements which showed that the cellular phone needs to be within a few cm to trigger a false proximity or touch annunciation, 30cm seems to be quite sufficient.

4.3 Choosing an antenna for RF-detection

Given the wide frequency band for which Radiated Immunity needs to be established (80MHz – 1GHz, and smaller bands within the 1.4GHz to 6GHz band), it is impractical to utilize an antenna or combination of antennas that covers the whole band for RF-detection. Especially for frequencies below 300MHz it is very difficult, and potentially costly, to realize an antenna on the PCB, or one that fits within the product enclosure. The same goes for omni-directional antennas. Most antennas which can be realized within the space and cost budgets of products containing ProxSense devices will be fairly directional, and only detect RF-radiation from specific directions. Installing a sweeping radar dish or array of antennas to cover all directions in not very practical!!

We therefore recommend that the lowest frequency which constitute a big threat in the geographical area where the product will be sold, be identified. For instance, if the target market is Europe, cellular telephones radiating at 900MHz and 1.8GHz are probably the biggest threat. Once the main threat frequency has been identified, a simple ¼ wave monopole antenna realized on the board is advised. Ideally, this antenna should be orthogonal to a substantial ground plane on the board (at least $\lambda_{eff}/4$ from RF-pin on each side), as illustrated in Figure 11. The areas alongside and below the antenna trace should be kept clear, for at least λ_{eff} /4 on both sides of the trace. Also shown in Figure 11 are the main reception areas covered / not covered by such an antenna.

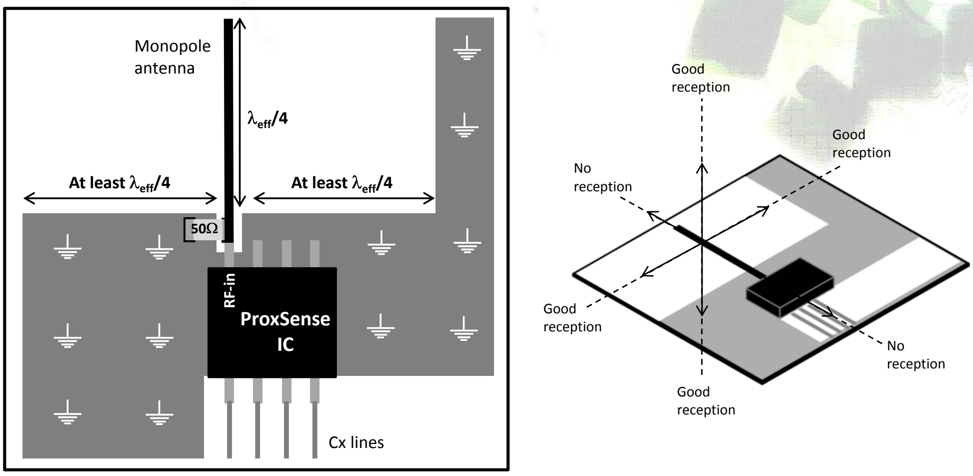

Figure 11: Using a simple ¼ wave PCB monopole to detect RF at the main threat frequency.

If enough space do not exist to realize a monopole orthogonal to the ground plane, the antenna can be bent at right angles, as shown in Figure 12. It should not be brought closer to the ground plane than $\lambda_{eff}/8$, otherwise performance will degrade significantly. The receiving null along the length axis of the orthogonal monopole is partially cancelled in the bent monopole, with a bit more omni-directionality. However, the price for this is possibly less gain and efficiency.

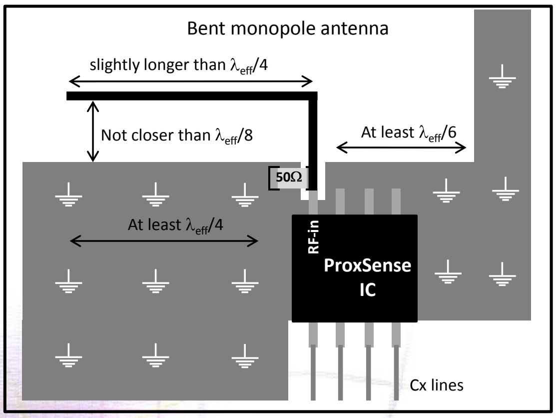

Figure 12: 90° bent ¼ wave PCB monopole to save space

So how do we calculate the required length of a PCB realised antenna? If the antennas were thin wires in air, this would have been simply one quarter of the speed of light ($3 * 10^8$ m/s) divided by the threat frequency in Hertz. But since we use a track on PCB, the FR4 dielectric comes into play. Wavelengths are shorter in dielectrics. To avoid an unnecessary long discussion, we simply advise to multiply the free-space wavelength above by 0.75, which gives a close enough approximation. Table 1 below list effective quarter wavelengths ($\lambda_{eff}/4$) for some common frequencies.

Table 1: Effective wavelengths and ¼ wave lengths for PCB monopoles

Frequency	Effective wavelength (λ_{eff})	Effective ¼ wavelength ($\lambda_{eff}/4$)
433MHz	520mm	130mm
900MHz	250mm	62.5mm
1.8GHz	125mm	31mm
2.45GHz	92mm	23mm

When realizing a monopole for the main threat frequency, it is advisable to first make the length slightly longer than that calculated. For instance, for 900MHz, realize a track of 75mm length. The motivation is tuning of the antenna to ensure it operates optimally at the intended frequency. It is always easier to cut some copper off, than to add. When tuning the antenna, using a network analyser to measure insertion loss, or a cellular phone and monitoring RF-detection in the ProxSense graphical user interface, it should always be done with the PCB in the final enclosure. Metal and dielectric materials in close proximity to the antenna will detune and reduce gain significantly. Pieces of track length are removed (or added if you were too enthusiastic) until the insertion loss is at a minimum, or the most consistent RF-detection is obtained at the required frequency. For production purposes small segments (1mm) can be joined with 0402 0Ω resistors as DNP, since the required approximate length will be known. Figure 13 illustrate the concepts surrounding tuning of the monopole.

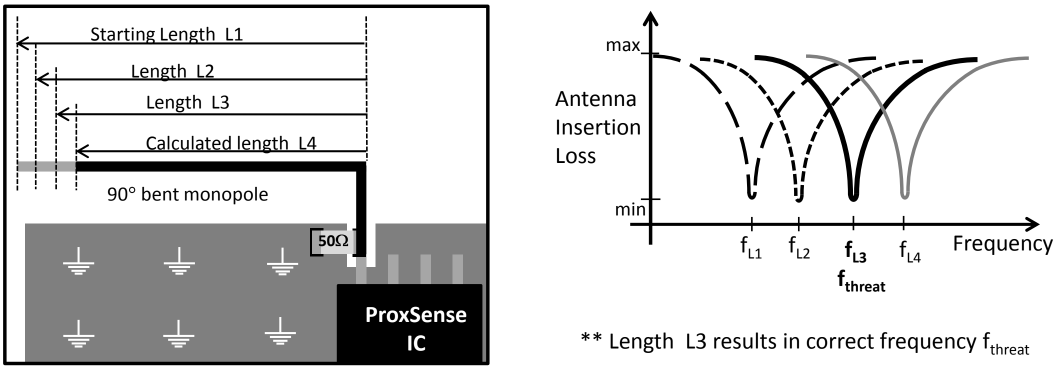

Figure 13: Tuning a PCB ¼ wave monopole.

If the above lengths for ¼ wave monopoles are not feasible in a design, the monopole can be meandered, as shown in Figure 14. However, the reduction in size comes at the price of reduced bandwidth, gain and efficiency, and tuning becomes more important, with matching to 50Ω possibly necessary.

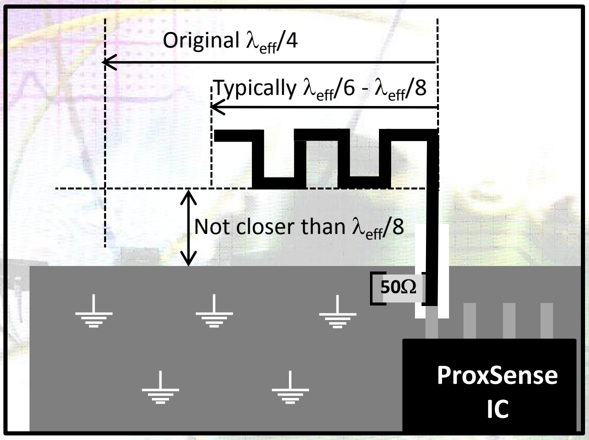

Figure 14: Meandering a 1/4wave monopole to reduce size.

In all the above, it is important to note that a substantial ground plane is required for a ¼ wave monopole. If it is not present, the antenna will probably still work, but becomes very sensitive to changes in its environment, resulting in unstable performance.

But what about frequencies other than the main threat frequency identified? For lower frequencies, the ¼ wave monopole will function as a short monopole. What this means is that the radiation resistance of the antenna will decrease significantly, and it's reactance will increase. It will not work very well. But RF-energy will still be coupled onto the RF-pin. Whether this is sufficient to trigger RF-detection early enough can only be investigated on a case by case basis. Frequencies above the main threat frequency will be detected fairly well. For instance, if a 900MHz ¼ wave monopole has been realised, it will be a ½ wave monopole at 1.8GHz, and sufficient RF-energy should couple into the RF-pin to allow acceptable RF-detection.

Naturally, the number of other antenna's which can be used successfully for RF-detection is quite vast, and the details regarding their design and use justify a separate, dedicated Application Note.

Most alternatives beyond the above simple ¼ wave monopoles are more complex, require matching, and careful implementation. Table 2 below lists some alternatives.

Table 2: Various alternative antennas for RF-detection

Antenna Type	**Advantages**	**Disadvantages**
Half wave Dipole	More efficient, do not need large ground plane	Size Requires Balun to connect to ProxSense device RF-in
Helical	Very compact	Tuning critical Narrow bandwidth Matching network
Small Loop antenna	Compact Magnetic antenna, not detuned by dielectric material changes close to antenna	Tuning is critical Low efficiency Matching required
Inverted F	Reasonably compact Fair efficiency Fairly omni-directional	Matching and loading must be correct Narrower bandwidth
Chip Antenna	Very small	Low gain High Cost Must be used strictly according manufacturer specifications

5 Tips to solve Radiated - Immunity non-conformance

5.1 Decoupling: Removal and systematic replacement

One of the first things to do while investigating a Radiated Immunity failure is to remove all decoupling capacitors followed by a rerun of the Radiated Immunity test. If the result is the same, the decoupling capacitors did not do much. Experiment with different decoupling values, and combinations. If all feasible decoupling combinations have been tested without improvement, chances are that the RF-energy is not coupling in via any supply lines.

If the result is worse with no decoupling capacitors on the board, replacing the decoupling capacitors systematically might identify the most susceptible part of the circuit. This can then be further investigated with various alternative values of decoupling capacitors, or filters.

5.2 Review of PCB layout, current paths

It seems obvious, but many an engineer will attest to after-the-fact-obvious layout errors which caused Radiated Immunity failure, and somehow slipped through reviews before prototype production. Review the layout once again, systematically, in detail and with point to point reference to the schematic. Follow the possible paths that interference current might follow from and towards sources, and scan for loops and ground sections which might experience an increase in voltage due to interference currents etc. For ProxSense devices with an ICTRL pin, review grounding around the pin, and it's associated resistor, again, ensuring the lowest possible ground impedance is achieved.

5.3 Isolation of functional blocks

If the above measures do not help, it might be worthwhile to isolate functional blocks, and test each on their own, and in combinations, for Radiated Immunity, as below. This should be done with the original PCB, with as few as possible changes to the functional block being tested. Please note that all tracks to functional blocks not being tested should be cut / removed. A number of PCB's will thus be required.

- Test the power supply on its own, with a relevant dummy resistive and LED load.
- Test the processor block, while supplied with the correct voltage from a battery supply. If possible, use an array of LED's to create a "Christmas tree", with a recognizable sequence driven by the processor.
- Test the ProxSense block, while supplied with the correct voltage from a battery supply. If required, provide it with a processor that are right alongside the ProxSense device. Disconnect Cx lines one by one to check if RF-energy couples in via those paths.
- If there are long digital communication lines on the board, test these by continuously running a certain data set back and forth, and which lights up an LED or set of LED's after each successful data transfer cycle.

5.4 Identifying offending section with series R

Often, Radiated Immunity failure mechanisms are resonant in nature, with a high quality factor Q. If resistance is added to the interference current path, the quality factor will decrease, and the resonant amplitude along with it. This will not take the failure mechanism away, but weaken it. Insert series resistances in various part of the circuit, without changing the basic circuit functionality, and test for a slight improvement in Radiated Immunity. This can help identify the offending section of the circuit, which can then be investigated further.

5.5 Shielding

If it can be proven that RF-interference do not couple in via long supply leads, and all other options have been exhausted, it might be necessary to use metal or ferrite shielding to ensure a pass. Shielding thickness should be chosen for the lowest main threat frequency. It should be thicker than at least 2 skin depths at this frequency. Often, it is not necessary to shield the complete PCB, but only sections. Even a flat piece of metal inserted into the product enclosure at a specific point can result in pass. If possible, ground the shield.

6 Summary

- RF-radiation is a serious threat for capacitive sensing circuits, and immunity must be established.
- IEC 61000-4-3 is the basis for most testing, although it is advisable to test beyond it, up to 30V/m and 6GHz.
- Low cost in-house test methods are valuable, and should be used during development.
- A series of decoupling capacitors are required to properly shunt interference over the relevant frequency band/s.
- Basic RC and LC filters are low cost and can improve Radiated Immunity significantly.
- Care should be taken with DNP and unused connectors to not inadvertently realise RF-antennas.
- Correct grounding and “stitching” thereof is crucial. Take care with ICTRL resistor grounding.
- Loops should be avoided, and can be identified by “following the current”.
- Care should be taken with Cx lines to not inadvertently realise RF-antennas.
- Decoupling capacitors should be placed and routed correctly.
- Communication lines are especially susceptible, and pull-up/down resistors and filters need to be placed correctly.
- RF-Detection of IQSxxx devices must be a last resort.
- It is recommended to identify the biggest threat frequency for the intended product, and to choose the antenna to be connected to the RF-pin based on this frequency.
- Although a multitude of possible antennas are available, a simple ¼ wave monopole should suffice in most cases.
- Antenna tuning and verification should always be within the final enclosure.
- In solving a Radiated Immunity failure, the following should be considered:
    - Systematic decouple capacitor removal and replacement
    - Repeat of PCB layout reviews
    - Functional block isolation and immunity testing
    - Searching for offending sections with series resistance insertion
    - Use of shielding

7 Document History

Version & date:	***Author:***	***Remarks:***
v1.0, July 2011	*J.D. van Wyk* *Sr. Application & Development Engineer*	*Creation*
v1.1, Aug 2011	*J.D. van Wyk* *Sr. Application & Development Engineer*	*Update with ref to ICTRL pins*

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