IWR/AWRx RF Design, Fabrication and Validation Guide

1 Summary

This application note is meant to help AWR/IWRx mmWave sensor designers navigate the series of tasks and key concerns when designing, manufacturing and validating a new mmWave sensor design. This note is only concerned with the RF portions of the design and covers only basic sensor bring-up tasks. It is most useful for PCB designers who do not have experience with RF PCB design at mmWave frequencies.

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3 Glossary

TBD

4 Introduction

The intention of the application note is to follow what would be a complete RF design flow from start to end. However, depending on the application, sensor designers will need to decide for themselves how many of these steps and to what extent they are followed based on time available for design/simulation time, lab test time and sensor validation required. For example, while TI recommends performing simulation and subsequent lab validation of any new antenna design, depending on the accuracy required, it may be found during basic sensor bring-up that the sensor is producing ranging-estimation, or angle-estimation, or velocity estimation that meets the intended requirements without the need to further evaluate the antenna design.

RF PCB design and simulation flow and key concerns will be covered first. This includes a brief overview of key antenna design requirements and how they map to radar equation budgets and FMCW radar processing. This also includes a discussion on extending and modifying the BoosterPack EVM designs with custom antenna.

Next PCB manufacturing concerns are covered. This includes discussion of CAD to CAM RF design documentation and how to evaluate PCB fabricators for RF fabrication quality.

Then mmWave sensor validation is discussed. This section will deal with strategies for evaluating the performance of a mmWave sensor against its target application environment. This includes basic lab, mmWave sensor, target setup and test application software that is required.

Finally antenna and transmission-line validation is discussed. This section deals with how to properly evaluate the difference between the intended designs compared to the final, fabricated results.

5 RF Design and Simulation

This section is a brief overview of key antenna design requirements and how they map to radar equation budgets and FMCW radar processing. This also includes a discussion on how to best re-use the BoosterPack EVM designs with custom antenna.

5.1 Key Antenna Design Requirements

Knowledge of basic antenna metrics is necessary for an mmWave sensor designer to understand the antenna performance requirements needed for their sensor. These terms are taken from the IEEE Std 145-2013 “*Standard for Definitions of Terms for Antennas*”.

Gain: Gain, G of an antenna in any given direction (across $\theta,$ elevation and ϕ azimuth) is defined as the ratio of radiation in that direction to the radiation intensity that would be produced if all of the power accepted by the antenna were isotropically radiated (radiated by a perfectly spherical radiation source).

$$G(\theta,\phi) = \frac{I(\theta,\phi)}{I_{Isotropic}} \qquad (1)$$

Radiation intensity from an isotropically radiating source is calculated as:

$$I_{Isotropic} = \frac{P_O}{4\pi} \qquad (2)$$

Combining these two relationships yields the following equation.

$$G(\theta,\phi) = \frac{4\pi \cdot I(\theta,\phi)}{P_O} \qquad (3)$$

Note that gain, unlike directivity defined below, does not take into account overall efficiency of the antenna. This gain definition is only concerned with comparing maximum possible intensity in any direction with the power accepted by the antenna independent of the method used to feed it. In this manner it acts as antenna metric that is system independent.

Intensity: Intensity, $I(\theta,\phi)$, is the power radiated from the antenna in any given direction per solid angle. Intensity can be integrated across a given θ, elevation and ϕ azimuth, to determine the total radiated power in that given sector of space around the antenna.

Efficiency: Efficiency of an antenna, η , is defined as the ratio of power input P_O accepted by an antenna from its feed line (not reflected) compared to the power actually radiated, P_R, by the antenna into free space. Impedance mismatch, dielectric losses and thermal losses can all contribute to decreased efficiency.

$$P_R = \eta \cdot P_O \qquad (2)$$

Directivity: Directivity of an antenna, D, is defined as the ratio of power radiated in any given direction compared to the average radiation intensity across all directions.

$$D(\theta,\phi) = \frac{4\pi \cdot I(\theta,\phi)}{P_R} \qquad (3)$$

Average radiation intensity is defined as, $Iavg = P_R/4\pi$. Directivity takes into account the efficiency of the antenna as designed into the system as well as the antenna specific radiation pattern.

Radiation Pattern: The spacial distribution of any quality of the electromagnetic field generated by an antenna. Due to the in-phase and out-of-phase combination of electromagnetic waves antenna radiation patterns take on a form where there are one or more “lobes” of local maximum power output and “nulls” of local minimum power output.

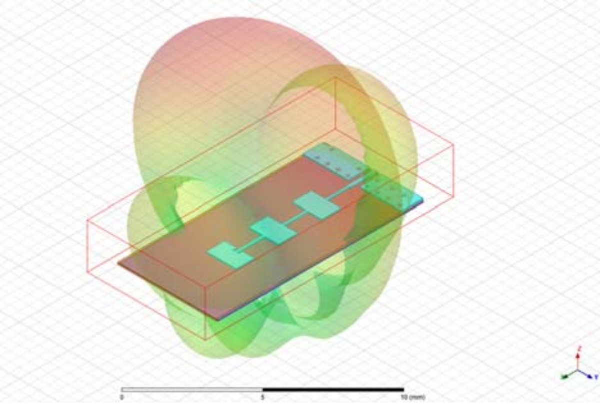

Figure 1 - Example Radiation Pattern, Showing Gain (dB) of IWR1443 Boosterpack, 3D Polar Plot 3-Element Series Fed Patch – Note Primary Lobe in the E-plane

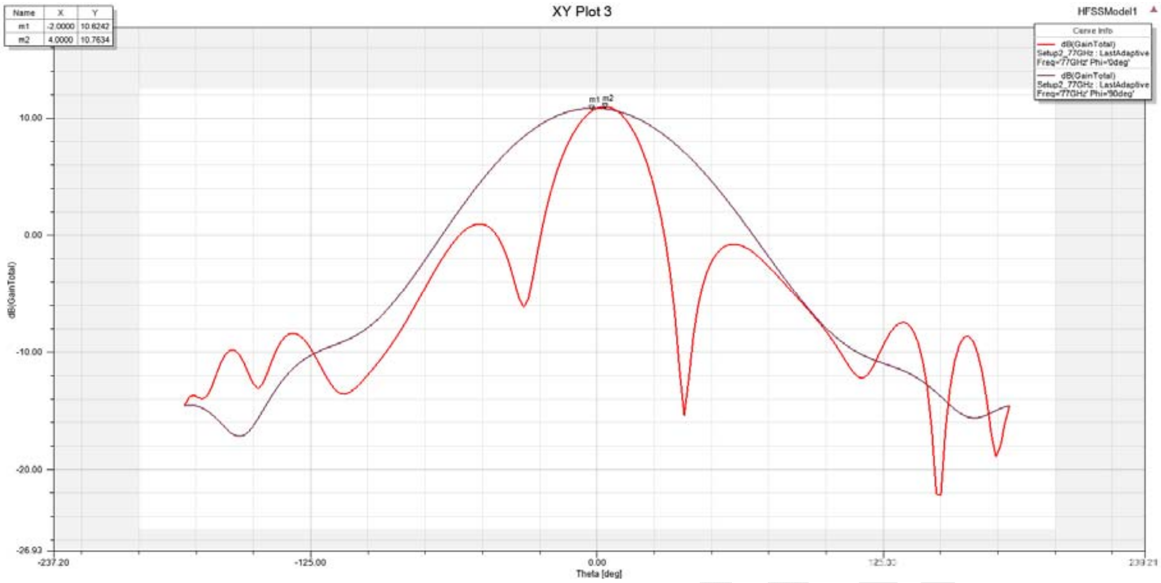

Figure 2 - Example Radiation Pattern, Showing Gain (dB) of IWR1443 Boosterpack, 3-Element Series Fed Patch (showing only maximum E-field and H-field plane contours)

Equivalent Isotropically Radiated Power (EIRP): This is defined as the gain of an antenna in a given direction multiplied by the total power accepted by the antenna from the connected transmitter. This metric compares the actual antenna radiated power to the radiated power that would result from the same accepted power being presented to a hypothetical, perfectly spherical, isotropic radiation source.

$$EIRP(\theta,\phi) = G(\theta,\phi) \cdot P_O \qquad (4)$$

Scattering Parameter (S-Parameters) and Bandwidth: Scattering parameters relate the power delivered to a matched network to the power transmitted through it and reflected from it as a function of frequency. A transmitting antenna can be considered as a 1-port device, where the amount of power reflected from the antenna from the feeding transmission-line can by analyzed. An S11 ratio below a given threshold can be used to determine the associated antennas bandwidth – the frequency band where power is mostly accepted by the antenna vs. bands where power is mostly reflected away from the antenna and not radiated.

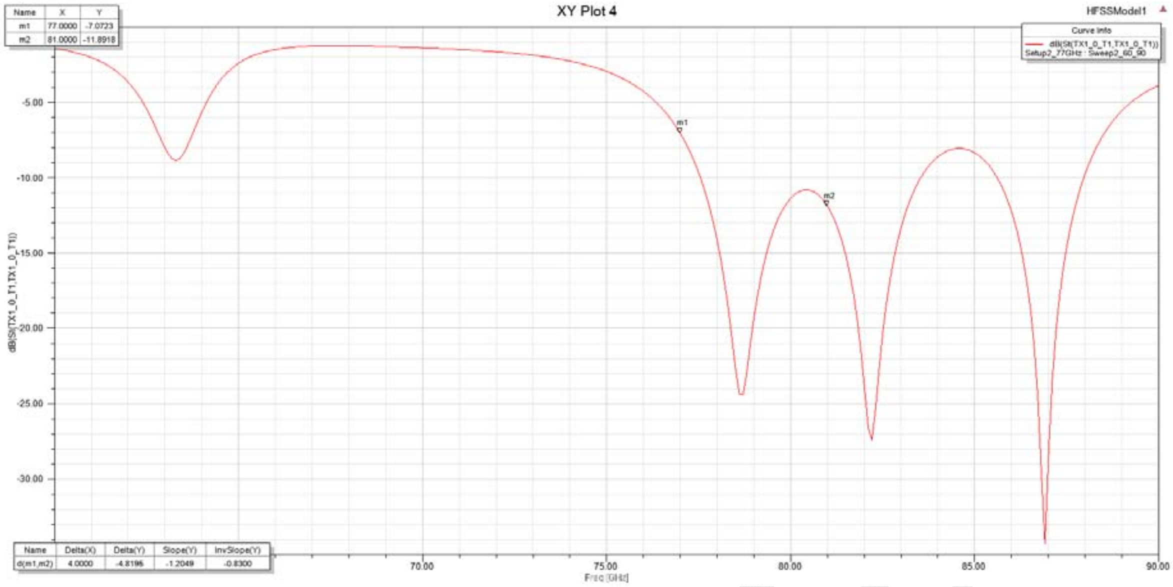

Figure 3 - Example S11 Plot - IWR1443 Boosterpack, S11 Plot of 3-Element Series Fed Patch, Markers at 77GHz to 81GHz, showing 4GHz of bandwidth

Beam-width or Field-of-View: This is a radiation power analysis which determines key angular offsets which contain the direction of maximum power up to some key metric. The goal is to provide a metric which characterizes where the antenna is most "directional". One metric is the **Half-Power Beam-Width** which measures the angular offset between the maximum power of the main lobe to one-half of the maximum power, or 3dB point when measuring power dB. As an example, the below maximum H-field contour between markers m5 and m6 is showing a 92 degree half-power beam-width. Likewise the E-field, between markers m3 and m4 is showing a 40 degree half-power beam-width.

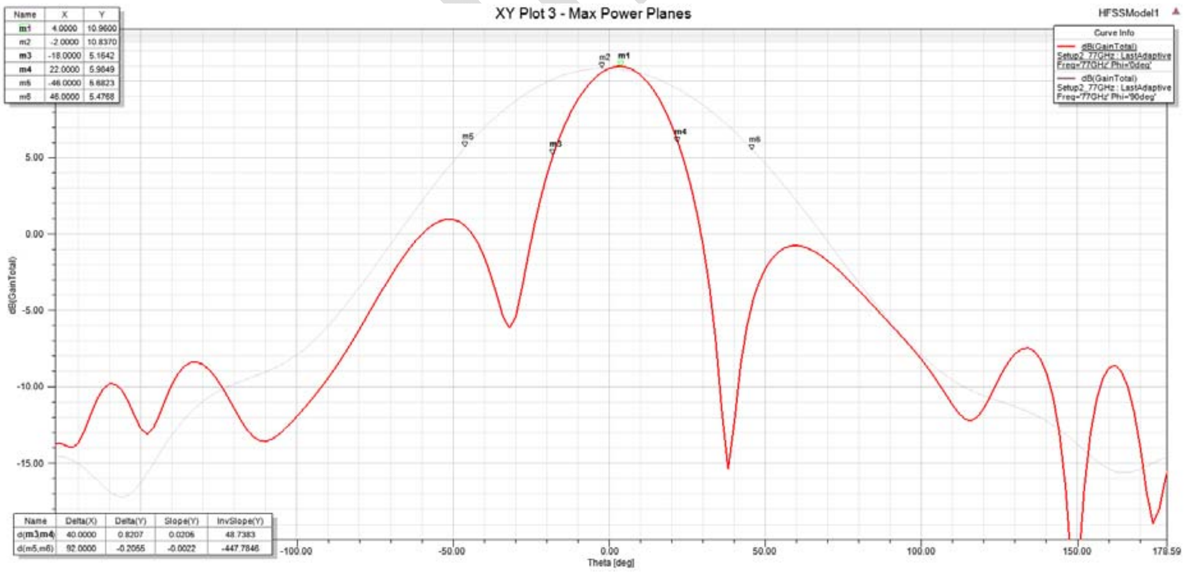

Figure 4 - Example Radiation Pattern - IWR1443 Boosterpack, 2D Rectangular Plot 3-Element Series Fed Patch, Markers Showing Approximate Half-Power Beam-Width of E-plane and H-plane and Peak Power

5.2 Typical Antenna Design Tradeoffs

When selecting between antenna designs there are some typical tradeoffs which must be balanced based on the intended application.

Gain vs. Beam-width: Gain and beam-width are inversely proportional. An antenna with higher gain will have higher directionality, which means that the beam-width will be narrower than a lower gain design. In many applications such as line-of-sight range-finding, or fluid-level measurements in confined spaces, this can be used to reduce “clutter”, or extraneous returns. Given the narrow beam-width, targets with larger angular offset from the center of the main lobe will receive and return very little power compared to the directly in front of the main lobe.

Gain vs. Aperture/Area: Gain and antenna area are directly proportional. An antenna with a larger area will have a higher gain. This can be an advantage since more power can be radiated. This comes with the draw-back of requiring more PCB space for planar antenna design, which may drive up PCB area.

Gain vs. Bandwidth: Some antenna types exhibit an inversely proportional gain vs. bandwidth property. An antenna with higher gain will tend to have a lower bandwidth. This means that there is an effective upper limit placed on gain due to efficiencies being driven too low. In the case of applications that can make use of lower bandwidth FMCW chirps this limitation will not be as big of a consideration since the antenna could be designed to operate just at that smaller target bandwidth of the chirp.

5.3 Mapping Antenna Design Requirements to mmWave Sensor Requirements

All FMCW mmWave sensors work on the underlying principle that a transmitting antenna can radiate out an RF “Chirp” signal and an associated receiver antenna can detect the resulting chirp echo reflected from a target. The received chirp reflection is mixed with the transmitted chirp and the resulting IF signal is sampled to determine range, angle and velocity to the target. The application note “*Programming Chirp Parameters in TI Radar Devices*” (http://www.ti.com/lit/an/swra553/swra553.pdf) covers this process and how to combine with proper chirp configurations.

5.3.1 Radar Equation Used to Determine Minimum Gain and Directivity

If too little energy is radiated from the transmit antenna, or too little energy is incident to the target, or too little energy is incident to the receive antenna the sensor ADC will not have enough IF amplitude to resolve the target above the noise floor and target detection will fail. Significant signal to noise ratio, or SNR, is required to resolve the target in the resulting IF FFT spectrum.

All of these parameters are combined in the “Radar Equation” to help designers perform a radio link budget analysis. The result is an equation that can answer the fundamental mmWave sensor question of how far away and how small an objects radar cross section can be before the sensor is unable to resolve it above the noise floor.

$$Range_{MAX} = \sqrt{\frac{P_{TX} \cdot D_{RX} \cdot D_{TX} \cdot c^2 \cdot \sigma_{Target} \cdot N_{Chirps} \cdot T_R}{f_C{}^2 \cdot (4\pi)^3 \cdot kT \cdot NF \cdot SNR_{detect}}} \qquad (5)$$

Where:

- P_{TX} is the transmitted output power, incident to the antenna in dBm.
- D_{TX}, D_{RX} is the transmit and receive antenna directionality, respectively – this takes into account antenna efficiency as well as directional gain – unit-less gain.
- $c,$ speed of light in free-space in meters/second.

- σ_{Target}, is the radar cross section, which is a unit-less gain factor relating incident power to reflected power of a target object.
- f_C, frequency of the chirp ramp - can be averaged across bandwidth, changes due to frequency will be relatively small across bandwidth of chirp.
- N_{Chirps}, number of chirps in a chirp frame
- T_R, chirp ramp time in seconds, combined with number of chirps this provides an average power coefficient
- k, Boltzman's constant – providing a temperature dependent falloff in performance of the receiver signal path
- T, temperature in Kelvin - provides kT thermal coefficient along with Boltzman's constant
- NF, is the noise figure of the receiver path - This coefficient takes into account the noise introduced by the stages of the receive signal path like the low-noise amplifier (LNA), low-pass and high-pass filtering and the ADC sampling.
- SNR_{detect}, minimum signal to noise ratio for minimum detection rate of target. A reasonable target value is 20dB of SNR.

In terms of antenna and transmisson-line design, there are only a few terms that can be optimized for the radar equation:

- P_{TX} is the transmitted output power, incident to the antenna in dBm.
- D_{TX}, D_{RX} is the transmit and receive antenna directionality, respectively – this takes into account antenna efficiency as well as directional gain.

All of the other terms are determined by the chirp parameters, target, environment or mmWave sensor device native performance.

The power delivered to the antenna, P_{TX}, is a function of programmed transmit power backoff, PCB transmission-line losses and transmission-line to antenna reflections and BGA to transmission-line reflections. Maximizing P_{TX} is the goal. Therefore minimizing losses and reflections along the RF path to the antenna and maximizing programmed transmit power is ideal. The chirp bandwidth, f_C, is a function of chirp configuration, but it should be taken into account during the antenna design phase if possible so that the bandwidth of the antenna can be optimized around the intended chirp bandwidth region. This is done by minimizing S11 in the frequency region the chirp will occupy.

Directivity D_{TX} and D_{RX} are entirely a function of the antenna design and transmission-line design. Depending on the use-case a wider or narrower beam-width may be required. A wider beam-width will provide a larger sensitive field of view for transmit power and reflected target power to be received. As discussed above, this larger beam-width will also come at the cost of lower gain in any one direction. Directivity vs. Beam-width will need to be balanced against the intended application. Directivity also is a function of overall antenna efficiency. As seen in the example, gain charts shown in Figure 4 above, the gain, and therefore directivity, of an antenna will drop off as a function of azimuth and elevation angle.

5.3.2 Antenna Array Placement

In the case of a mmWave sensor operating in multiple inputs and multiple outputs (MIMO) mode, the physical separation between the antenna elements constrains the angular estimation capabilities of the sensor.

Maximum Unambiguous Angular Range: this is the maximum angular displacement that can be measured with a set of receive antenna. It is a function of d, the distance between receive antenna and λ, the wavelength of the chirp. In a 2D plane this is calculated as:

$$Angle_{Max} = arcsin\left(\frac{\lambda}{2 \cdot d}\right) \qquad (6)$$

Minimum Angular Resolution: this is the minimum angular separation two objects can have and still be unambiguously detected by the sensor. This is a also a function of of d, the distance between receive antenna and λ, the wavelength of the chirp. It is also a function of the number of transmit antennas N_{TX}, and the number of receive antennas N_{RX}, and of the angular displacement of the target objects θ.

$$Angle_{Res} = \frac{\lambda}{d \cdot N_{TX} \cdot N_{RX} \cdot cos\theta} \qquad (7)$$

5.4 Custom Antenna Design Options

Depending on experience with mmWave RF design, mmWave sensor designers have a few options when it comes to acquiring application specific antennas. Starting with the requirements derived from the sections above and constraints of the TI supported RF substrate stack-ups, designers can:

- Create their own antenna
- Have a third-party RF design firm create an antenna
- Use one of the TI provided reference antenna designs

If a designer is familiar enough with antenna design concepts and simulation tools then the best way to start a custom antenna design is to reference the IWR1443 and IWR1642 BoosterPack EVM boards. These boards can serve as a reference RF layout design that can be extended to work with a custom designed antenna. Please see the *IWR/AWRx RF Hardware Design Guide* (**TI LIT NUMBER TBD**) for more information about the supported RF stackups, RF package to PCB transition, and GCPW transmission-line and recommended RF design re-use strategy.

The general flow is to assume the same layer 1 and layer 2 RF substrates and then completely re-use the BGA to PCB transition footprint and GCPW transmission-line RF fan-out. The custom antenna is then designed and a transmission-line feed path can be laid out to interface the antenna to the GCPW fan-out for best impedance and phase match to the antenna. The recommended process for third-party designers is the same.

If one of the TI provided reference antenna meets the design requirements, then no re-design is necessary and these can be integrated into the new design. The TI provided reference antenna designs assume the substrate and GCPW reference limitations as discussed above for custom designs.

5.5 Antenna Simulation

Depending on experience with mmWave RF design, mmWave sensor designers have a few options when it

6 RF PCB Fabrication

PCB fabrication concerns from the RF perspective are covered in this section. This includes a discussion of CAD to CAM RF design documentation and how to evaluate PCB fabricators for RF fabrication quality. The goal here is to describe the key points to bring up and align on with a selected PCB fabricator to achieve first pass success when fabricating mmWave PCB.

6.1 Assessing PCB Fabricator Experience with RF Substrates

Currently TI only supports two RF substrate stackups for mmWave sensor designs. These are Rogers RO3003 and Rogers RO4835 LoPro substrate designs presented in the mmWave HW Design Guide (**TBD TI LIT NUMBER).** RO3003 substrate is used on TI internal validation boards and is a higher RF performance (and higher cost) RF substrate than the RO4835 LoPro used on the BoosterPack EVM designs.

Designers should discuss with their PCB vendor the vendor's experience with fabricating PCB with Rogers substrates. Rogers fabrication documentation covers material storage, material handling and material processing techniques. All of these recommendations must be followed to achieve consistent performance when utilizing these materials.

Rogers fabrication documentation:

- RO3003: https://www.rogerscorp.com/documents/634/acs/Fabrication-Guidelines-for-RO3000-and-RO3200-Series-High-Frequency-Circuit-Materials.pdf
- RO4835 LoPro: https://www.rogerscorp.com/documents/2270/acs/Fabrication-Guidelines-RO4000-Series-RO4003C-RO4350B-RO4835-Laminates.pdf

Designers should discuss whether their PCB fabricator is taking delivery of copper-clad substrates directly from the RF substrate vendor or performing on-site plating of the substrates. Using the copper-clad substrates from the RF substrate vendor reduced variability in performance of the copper plating, therefore decreasing variability in the final RF design as well.

Sequential lamination of RF and non-RF substrate core and pre-preg material is typically required for completing RF designs such as the BoosterPack EVM. Designers should discuss with their PCB vendor the vendor's experience and capabilities when fabricating mixed material sequential stackups. Different core and pre-preg materials typically have different curing requirements and procedures and may not always be compatible.

6.2 Identifying RF Critical Dimensions

RF signal paths exhibit high sensitivity to small geometry changes such as:

- Substrate thickness
- Metal thickness
- Metal roughness
- Plating
- Via placement tolerance
- Etch tolerances (LDI vs. LPI masks)
- Air gap tolerances
- Solder-mask tolerance (LDI vs. LPI accuracy)
- Sequential stack-up layer registration

Substrate thickness directly determines performance of the RF structures. RO4835 LoPro and RO3003 substrates should maintain their designed thicknesses as received from Rogers. However, improper handling or fabrication steps can damage these substrates causing delamination and other adverse effects which will severely impair any RF structure performance.

Overall etch tolerances must be controlled so that the line widths, air gaps and planar antenna structures stay close to their designed dimensions. TI recommends using laser direct imaging (LDI) etch-mask over more common liquid photoimageable (LPI) etch-mask because LDI enables tighter tolerances fabrication. Reference the HW design guide (**LIT NUMER HERE).**

In the case of solder-mask in RF regions, like near the RF BGA, it is critical that the solder-mask registration and thickness must be tightly controlled. Solder-mask will have different dielectric properties compared to the RF substrate and the free-space surrounding the PCB. Because of this, changes in thickness or registration can have an effect on variability of RF performance PCB to PCB. TI recommends using LDI solder-mask over more common LPI solder-mask because LDI enables tighter tolerances fabrication. Reference the HW design guide (**LIT NUMER HERE**).

Over and under plating of top-layer copper can result in phase and loss/reflection variations. TI mmWave BoosterPack designs use a 0.5 oz/inch^2 LoPro copper. Rolled copper may be used as well. RF designs cannot use electro-deposited (ED) copper since the variation in final thickness and roughness is too large. Immersion silver plating is used over RF sections of the board where solder-mask cannot be applied. Reference the HW design guide (**LIT NUMER HERE**).

Via distances, for example, the microvia ground stitching surrounding the BGA and GCPW structures are critical to creating balanced ground return paths around these structures. A uniform offset in one axis may result in an imbalance in E and H-field distribution which will change the impedance of the structure.

6.2.1 Determining Absolute Tolerance Limits

Absolute tolerance limits on each dimension and placement can only be derived from margin studies using RF simulators and EM theory. The process involves sweeping various parameters, through a reasonable tolerance limit and determining how the parameter changes effects the performance of the structure. For example, designers can simulate with different air gaps, via placement distances, line widths and see the resulting change in GCPW impedance or antenna gain or directionality. Such studies are beyond the scope of this application note.

6.3 RF Critical CAD to CAM Documentation and Verification

Designers are encouraged to clearly document the areas of the PCB that are RF design critical along with the intended design dimensions for each of these locations. Controlled impedance trace dimensions and stack-up thicknesses for high-speed digital signals are typically dictated and verified by a PCB fabricator. However, RF design dimensions should be dictated completely by the PCB designer and verified after fabrication.

In the case of these mmWave sensor designs the areas around the RF signal BGA footprints, the RF signal transmission-lines and the antennas must be carefully milled, drilled and etched. Ideally the tooling error must be constrained to zero-mean error around the designed dimension. Typical PCB fabrication error will result in a low variance skew in one direction of the tolerance window. PCB designers will need to discuss methods with their fabricator for bringing this skew as close as possible to the designed dimensions.

It is recommended that PCB designers explicitly ask for a small sample run of PCB to be used for process inspection purposes. Any problems meeting critical RF design dimensions can be dealt with before proceeding to larger volume production. This process can be repeated until the zero-mean error between fabricated and designed dimensions are achieved.

A report of critical RF design dimensions should be presented to the PCB fabricator part of the the PCB CAD and CAM board design documents and files. The PCB fabricator should be explicitly asked to verify what the expected tolerances are going to be for each of the critical dimensions.

TODO: Include PCB layout fabrication note examples.

7 Sensor RF Performance Validation

This section will deal with evaluating the performance of a new mmWave sensor against its target application environment. This includes a description of the lab, mmWave sensor, and target setup and test application software that is required.

Sensor performance validation can cover the entire range of sensor hardware and software subsystems. However, this section will only deal with the items effected by PCB RF hardware design and fabrication issues.

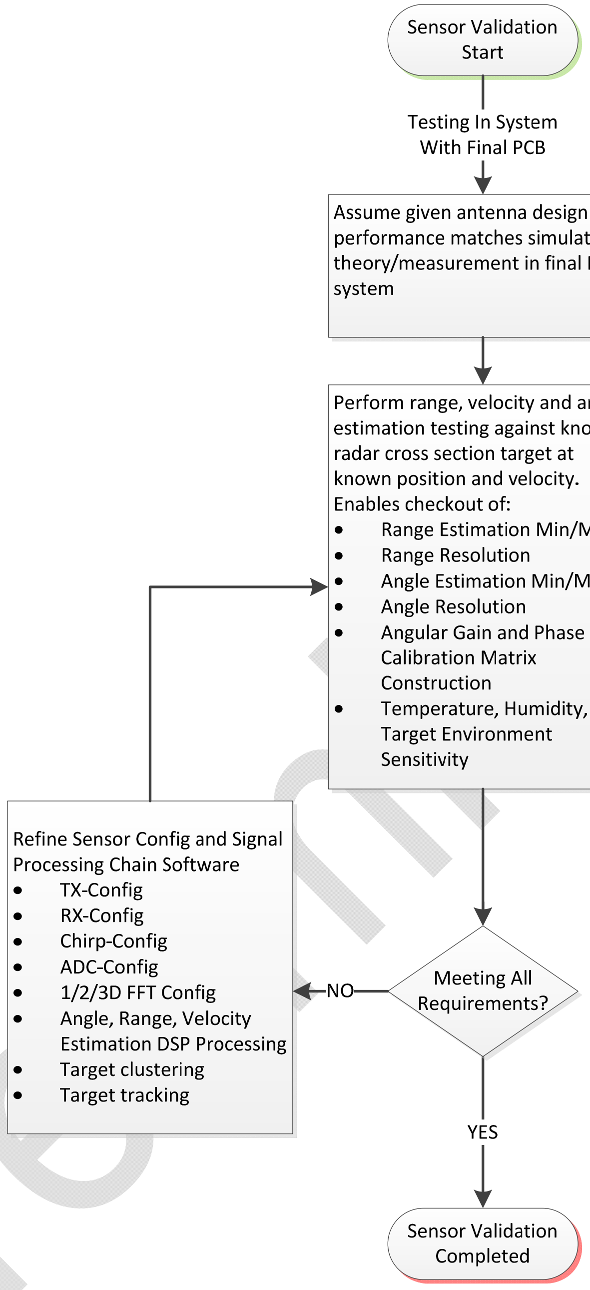

Figure 5 – Example Sensor Validation Flow

7.1 Basic Sensor RF Hardware Checkout

After fabrication and assembly and initial programming of a new mmWave sensor a basic sensor checkout should be performed to ensure functionality and performance of the RF sections of the design.

Initial testing can be as simple as turning the sensor on in a baseline environment and retrieving a range FFT of the IF ADC data with no target present. A target can then be introduced to that environment and the range FFT measurement repeated. The target should be clearly visible with significant SNR at the appropriate range bin of the FFT. The exact frequency bin the target will resolve to should be a function of the FMCW radar IF signal equations. See the white paper "*Fundamentals of Millimeter Wave*" (http://www.ti.com/lit/wp/spyy005/spyy005.pdf) for the basic FMCW radar equations.

Radiated testing should be done in a zero reflection environment if possible or at least an environment with minimal, known reflections. If too many reflections are present in the environment it may be difficult to narrow down target returns from environment returns during initial testing.

This is just one, quick example scenario to verify that the device and PCB subsystems are working. Depending on the range estimation, angle estimation and velocity estimation requirements of the sensor, additional experimental procedures will need to be formed to validate each of these requirements. Target type, range, orientation, azimuth and elevation angle should all be chosen to best emulate the intended operating environment of the sensor.

Additionally, at this initial validation stage, initial chirp configurations should be experimented with the target environment. The application note "Programming Chirp Parameters in TI Radar Devices" (SWRA553) should be referenced. Also, the mmWave Sensing Estimator tool should be used to create initial chirp configurations. Additional experimentation will be required to determine the different chirp parameters that will yield best result.

7.1.1 Basic RF Validation During Manufacturing

The basic RF checkout setup above can also be applied as a bare-minimum RF checkout procedure during manufacturing as well. ADC IF Range FFT can be taken of a precisely placed, bore-sight, target with a small sample population of "golden" sensor PCB samples which have passed all other testing. The resulting IF FFT spectrum from these "golden" sensors can be referenced as the "qualifying" IF Range FFT for that target, PCB, and chirp configuration.

Other sensors can be qualified against this "golden" dataset by putting the new sensor into the "golden" software and target state. The IF Range FFT data set of the new sensor can then be compared to the "golden" sensor data. A marginality percentage can then be applied to the "golden" data to create a pass/fail boundary across FFT frequency and power. Boards can be deemed "accepted" if they fit within that margin and "rejected" if not.

This is just one example of a basic RF manufacturing quality test.

7.2 Basic Angle Estimation Validation

Following from the basic range estimation validation setup a basic angle estimation setup can be formed. There are only small changes to the experimental A known angle offset from antenna bore-sight is given to the experimental target object. In addition the hardware must support at least two receive antenna.

7.3 Basic Velocity Estimation Validation

TBD

8 Antenna Performance Validation

This section deals with how to properly evaluate the differences seen between the designed and fabricated transmission-line and antenna performance.

TBD

- Discuss coupon-board and cal kit structures that can be included on PCBs to validate the transmission-line and antenna designs

- Discuss measurements of the transmission-line cal kit structures and what important metrics you get out of these measurements
    - Only way to enable de-embedding of transmission-line effects between device BGA for accurate antenna characterization

- Discuss conducted and radiated measurements of the antenna test kit structures and what important metrics you get out of these measurements
    - Only way to measure actual performance of the antenna design in isolation
    - Only way to validate that theory, simulation and manufacturing resulted in the required antenna design…or how far away the actual antenna performance is compared to the design intent
    - This feeds back into next design iteration for improvements if necessary

- Discuss sensor validation vs. isolated antenna performance testing

9 References

TBD

10 Revision History

Rev 1 - 2017/07/21 R. Rosales (rosales.r@ti.com)
- Initial draft
- Does not contain much on the RF PCB Design/Sim section
- Does not contain much on the Antenna Performance Validation Section

Rev 2 - 2017/07/21 R. Rosales (rosales.r@ti.com)
- Changed document title to “IWR/AWRx RF Design, Fabrication and Validation Guide”
- Added in Section 6 and 7 comments from discussion with Ross and Vaibhav
- Section 5 is still pretty much only outline
- Section 8 is still pretty much only outline

Rev 3 - 2017/07/25 R. Rosales (rosales.r@ti.com)
- Sentence structure changes in Section 6
- First filled out section 5
- Section 8 is just outline still

Rev 4 – 2017/08/xx R. Rosales (rosales.r@ti.com)
- Re-arranged the
- Need to add the Manufacturing Test section to the performance validation
- Need to add the In-System vs. Stand-Alone antenna test flows
- Add back in the flow-charts?

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