MAX32570 Contactless PCD AFE Tuning Guide

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Introduction

To optimize the performance of the MAX32570 contactless NFC PCD peripheral the Analog Front End (AFE) and Digital Baseband (DBB) must be tuned to match the antenna, enclosure, and the complete system.

AFE Tuning Prerequisites

Important: Before attempting any AFE tuning the following items must be completed. Failure to correctly follow these prerequisites, will render any tuning work completely useless, and will require the tuning to be repeated.

Antenna Selection and Contactless Product Design Considerations

The limitation of the reading range of a contactless PCD system is governed by its antenna, therefore it is a prerequisite to design or select the antenna properly to support the desired application. Many contactless applications follow the operating volume defined by EMVCo, and there is a fundamental limitation of the antenna size that can support such EMV operating volume. For MAX32570 IC, the antenna size is suggested to be larger than 4cm by 4cm.

Beyond the size, antenna parameters such as geometric shape, number of turns, and trace width affect antenna properties including inductance and resistance. The coupling coefficient of the antenna is primary determined by its size and shape. Designing or selecting the NFC antenna is a compromise between the final product's form factor and its performance.

The loading effect of system components on the antenna must be considered when selecting or designing the antenna. Metallic shielding or any metal that is within the range of the antenna, will affect the shape of the magnetic field, and detune the effective matching between the PCD and PICC. Ferrite materials can be used in the systems design to help control the shape of the magnetic field distribution. However, an in-depth discussion of these design topics is beyond the scope of this document.

Antenna Matching Network

After the antenna is defined, a proper matching network must be designed to guarantee that there is adequate power delivery, reasonable bandwidth, and carrier amplitude levels are within the proper range at the receiver pins. The design should follow the MAX32570 PCD Antenna Matching Design Guide. AFE tuning can only start after antenna matching network design is completed.

In some cases, if adequate performance cannot be achieved via the AFE tuning alone, it is necessary to modify the matching and retune the AFE.

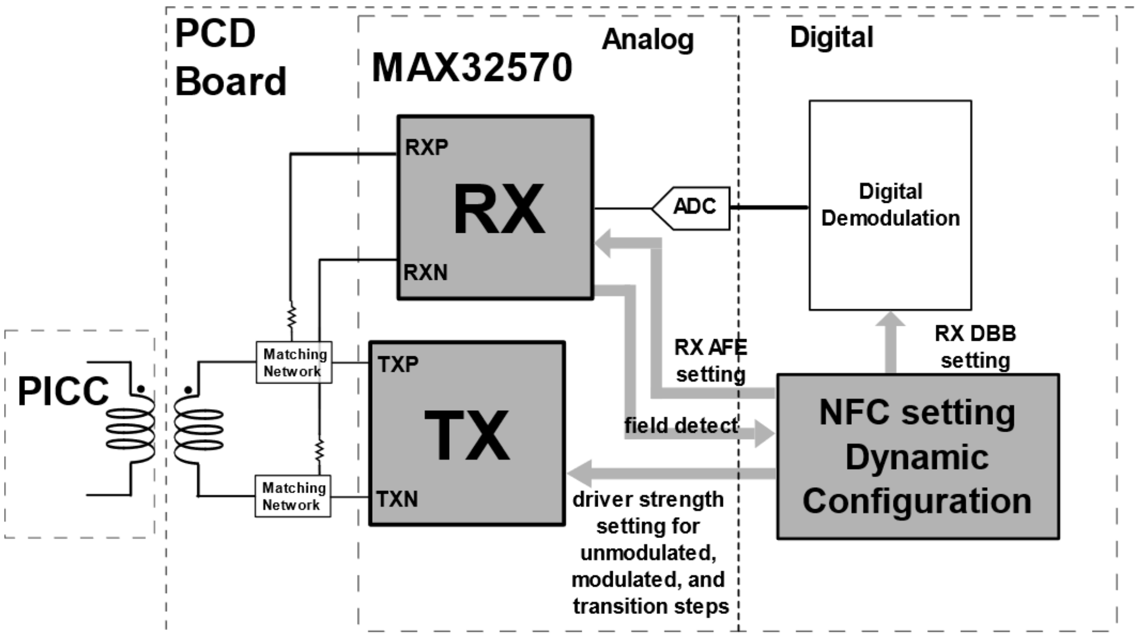
Use the Device Test Environment (DTE)

It is highly recommended to use the DTE example during the tuning procedure detailed below. The DTE provides a convenient means to adjust the AFE parameters and perform specific operations. The DTE example is include with the Contactless Support Package and is available directly from Maxim Technical Support. Please refer to the MAX32570 EMV DTE User's Manual for full details.

Tunable AFE Parameters

The MAX32570 Contactless PCD RF driver provides an analog configuration structure which contains key parameters to configure the driver for specific applications and antennas. This configuration structure is detailed in the MAX32570 NFC PCD RF Driver API documentation. Once the AFE tuning is successfully completed, these values should be recorded and used by the application to configure the contactless AFE for the system's specific needs.

Error! Reference source not found. shows the block diagram of the NFC analog front end of MAX32570



for reference purposes.

Figure 1: Block diagram of the NFC analog front end of MAX32570

Dynamic AFE Configuration based on Field Detect Level

Thanks to the computing power of the integrated MCU, the NFC AFE and DBB parameters of MAX32570 can be dynamically configured based on the Field Detection (FD) level. Due to the loading effect from targets (cards, mobile phones, Reference PICCs etc.), the 13.56 MHz carrier field amplitude seen by the reader receiver varies with loads at different target distances. It is possible to optimize each AFE settings separately to handle different distances and for different targets through a parameter called field loading level index, which is dependent on the current FD level.

The following paragraphs detail how this feature is tuned, using the routine as implemented in the DTE example. Figure 1 shows an illustrative example of the settings matrix defined in emvl1_app.c in the DTE source code.

```
mml_nfc_pcd_analog_params_matrix_t evkit_antenna_112x76_matrix = {
    .fd_thresholds          = { 180, 170, 140},
    .fd_dyn_trigger_a       = { 125, 125, 125},
    .fd_dyn_math_a          = { IQ_MATH_Q_MINUS_I,  IQ_MATH_Q_MINUS_I,  IQ_MATH_Q_MINUS_I},
    .fd_dyn_trigger_b       = { 125, 125, 125},
    .fd_dyn_math_b          = { IQ_MATH_Q_MINUS_I,  IQ_MATH_Q_MINUS_I,  IQ_MATH_Q_MINUS_I},
    .fd_dyn_trigger_f       = { 100, 100, 100},
    .fd_dyn_math_f          = { IQ_MATH_CH_I,       IQ_MATH_CH_I,       IQ_MATH_CH_I},
    .fd_dyn_trigger_v       = { 125, 125, 125},
    .fd_dyn_math_v          = { IQ_MATH_Q_MINUS_I,  IQ_MATH_Q_MINUS_I,  IQ_MATH_Q_MINUS_I},
    .fd_dyn_sttm_a          = { 0x00000000, 0x00000000, 0x00000000},
    .fd_dyn_stfm_a          = { 0x7F000000, 0x7F000000, 0x7F000000},
    .fd_dyn_sttm_bfv        = { 0x06060606, 0x06060606, 0x06060606},
    .fd_dyn_stfm_bfv        = { 0x7F060606, 0x7F060606, 0x7F060606},
    .fd_dyn_gain            = { 12,  12,  12},
    .fd_dyn_atten           = { 0x1F, 0x1F, 0x1F}

};
```

Figure 1: Sample NFC Dynamic Settings Matrix

`Loading Level(LL) Index` is defined to designate different loading regions used for the analog parameter matrix. In the above array matrix, it serves as the index for the columns. In this example, `LL Index` of 0 represents the first column, 1 the second, and 2 the third, as these are standard C arrays.

The parameter `fd_thresholds` set the region boundaries represented by `LL Index`. It has a range from 0 - 255 with each step corresponding to 13 mV seen at RX pin of the MAX32570 based NFC reader. These boundaries should be set experimentally by displaying the FD level through the DTE. These settings are highly dependent on the overall system and environmental conditions including the target PICC: contactless cards typically have less loading than cell phones with card emulation, which are different from the EMV-Test PICC as well. Adequate `fd_thresholds` values must be found experimentally if the provided default values are not acceptable for specific system and environment combination.

As the sensed FD level crosses below a FD threshold, the `LL Index` increases by 1. For example, if the first element of the FD Thresholds array is 180, and the current FD level drops from 185 to 175, `LL Index` increases from 0 to 1. The example implementation limits `LL Index` to the number of columns in the array, defined by `FD_THRESH_NUM_STEPS` in the header file `mml_nfc_port.h`. Using the DTE Analog Setting Menu, the user can set the values of the FD thresholds array and display the currently sensed FD level. The DTE sets `FD_THRESH_NUM_STEPS` to 3, but as this is public code, it may be set to any desired value. It is recommended to use the smallest number of steps required to meet EMV or other specifications.

To determine optimal boundaries, it is recommended to place the target at all the positions of interest and monitor the corresponding FD levels. For example, for 3 positions of interest with FD levels tested as 185, 175, 165 correspondingly, 180 and 170 would be good `fd_thresholds` to set as their boundaries. With `fd_thresholds` set, the AFE parameters such as Analog Receiver Gain, Decoding Trigger Level, Transmit Power Drive (High,Low and transition steps at both rising and falling edges) can be configured dynamically for each region.

In different situations, system integrators desired to have different steps or regions than provided in the library. To allow for this, the function `mml_nfc_pcd_field_level_detection_callback()` was moved into the public source file `mml_nfc_pcd_port.c`. This allows full customization of analog parameter selection for every call to `mml_nfc_pcd_transceive()`. The `mml_nfc_pcd_analog_params_t` used by the RF driver was simplified as a result.

The basic function of `mml_nfc_pcd_field_level_detection_callback()` is to decide which analog parameters to use for the current transceive. Once decide, they are set by calling `mml_nfc_pcd_set_analog_config()`. The DTE example ships with a full implementation of this function as a starting point but is easily customized for specific applications.

Analog Receiver Gain

The gain directly affects the received signal magnitude seen at the demodulator, the higher the gain: the larger the signal magnitude. Typically, the gain is set at the maximum value to better receive small signals when cards are at further distances. In some cases, due to large loading effects, or tight coupling of the PICC with the PCD's (Reader's) antenna, the signal may saturate. In the EMV Level 1 Analog certification process, there are test cases related to maximum modulation amplitude at the EMVCo reference PICC. For these cases at short distance (0 cm and 1 cm), the signal magnitude seen at demodulator may saturate. Saturation of the signal magnitude does not by itself lead to decoding errors. To maximize the reading distance with minimum modulation amplitude PICCs, at short distance such saturation is unavoidable unless utilizing the Dynamic gain configuration and setting the gain in `fd_dynamic_gain` lower at the corresponding LL Index when the target is at short distance.

The receiver gain has a range from 0 – 12 with each step increasing the gain by 3 dB, providing a total range from 0 – 36 dB.

Baseband IQ Combiner Math

The receiver down converts the RF signal to baseband with I and Q output channels, which are subsequently converted to digital domain for demodulation and decoding. The first step is to combine the two channels with one of the following five math operations: I, Q, I-Q, Q-I, I+Q. Practically, for most PCD designs working with most types of cards and mobiles, the switched load modulation is amplitude modulation dominant (over phase modulation). For that reason, four options I, I-Q, Q-I, I+Q will all work reasonably well for most cases, and I-Q or Q-I give best performance for the demodulation. However, depending on the overall loading conditions when a target switches from unmodulated state to modulated state, the optimal combiner math will vary. It is recommended to start with the default setting of I-Q, and check with different targets and positions to determine an optimal math for PCD and application requirements.

Decoding Trigger Levels

The Decoding Trigger Levels function like oscilloscope triggers: the received signal must cross this threshold to be triggered and decoded. As an ADC output waveform at down-converted baseband shown in Figure 2 (This shows the waveform if IQ combiner math is I, for other math selections the waveform could be slightly different), the ideal trigger level position is around the middle point of the modulation signal amplitude. If they are set too high no signal will trigger the demodulator, too low and noise or interference will trigger the demodulator erratically.

The available range for Trigger Levels are 0 - 127. The demodulator uses this as a signed value, as it is required to detect both positive and negative peaks. The values correspond to ADC codes, they do not equate directly to a specific voltage amount. This depends on the analog gain which scales the amplitude of the received signal. Therefore: if the Trigger Level cannot be adjusted high enough to avoid noise, the gain should be reduced. Likewise, if the Trigger Level cannot be adjusted low enough to receive small or distant signals, the gain should be increased.

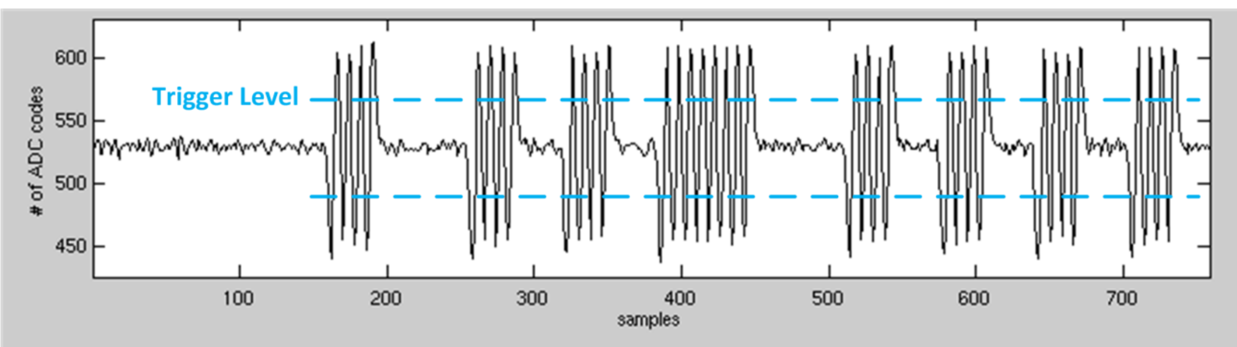


Figure 2: The role of Trigger Level in Demodulating the Received PICC Signal

Trigger Levels are separate for different type of signals (e.g. Type A, Type B and Type F), as they utilize different modulation schemes. For challenging reader antennas or products, dynamic decoding trigger level is very useful in order to cover good performance at all positions within the operating volume of interest.

Transmit Power and Driver Settings

The transmitted radio frequency power at 13.56MHz from the PCD antenna to the field, or the power delivered to the PICC, is adjustable by the drive strength setting of the MAX32570 NFC transmitter. This RF field can power up any PICC, and for EMV applications it must deliver adequate power within the defined operating volume as described in EMV Contactless Book D, and EMV L1 PCD Analogue Test Procedure both publicly available from EMVCo, with the version number 3.0.

The MAX32570 driver strength setting has 128 steps, i.e. 0 – 127, or 0x00 – 0x7F. The setting effectively changes the output load looking at the NFC transmitter, and the delivered RF power increases monotonically, but not linearly, as the driver strength setting increases. To test the field strength, any pick-up coil, reference PICC or any PICC with exposed antenna pins can be used to measure the field's AC voltage amplitude or its DC voltage after rectifying circuits. The EMV Analogue Tests require the field strength be validated by DC voltage generated after the rectifying circuits on the EMV-Test PICCs. In the MAX32570 DTE, RF power of unmodulated state is set through Driver High, and that of modulated state is set through Driver Low. In the dynamic AFE settings matrix, the driver high is represented by STFM[31:24], and Driver Low is represented by STTM[31:24], as shown in Figure 4. STTM stands for steps to modulation and STFM stands for steps from modulation. Other bits in STFM and STTM are configuring the transition steps at the rising and falling edge of each modulation, as shown in Figure 4, and more details will be explained in later section. For different modulation type, our DTE has separated settings, in the DTE dynamic setting matrix (Figure 2), `fd_dyn_sttm_a` and `fd_dyn_stfm_a` are responsible for type A transmitter setting, `fd_dyn_sttm_bfv` and `fd_dyn_stfm_bfv` are responsible for type B transmitter setting.

In practical NFC system design, with the antenna size is usually preferred to be small, the drive strength is set to the maximum value of 127, as the minimum RF power requirement at long distance is likely to be the criteria most difficult to meet. However, in some cases it may be necessary to lower the driver strength to meet the maximum RF power requirement at short distance. For portable PCD systems relying on battery power, it is normally desirable to have lowest power consumption possible during NFC operation. To realize such dynamic power configuration, additional user defined dynamic power control program is needed, and more details on how to implement intelligent dynamic power configuration will be included in separate document. Without changing the DTE program, it is recommended to have all the values in Dynamic Driver High array the same, as changing Driver High will affect FD level and confuse the LL Index.

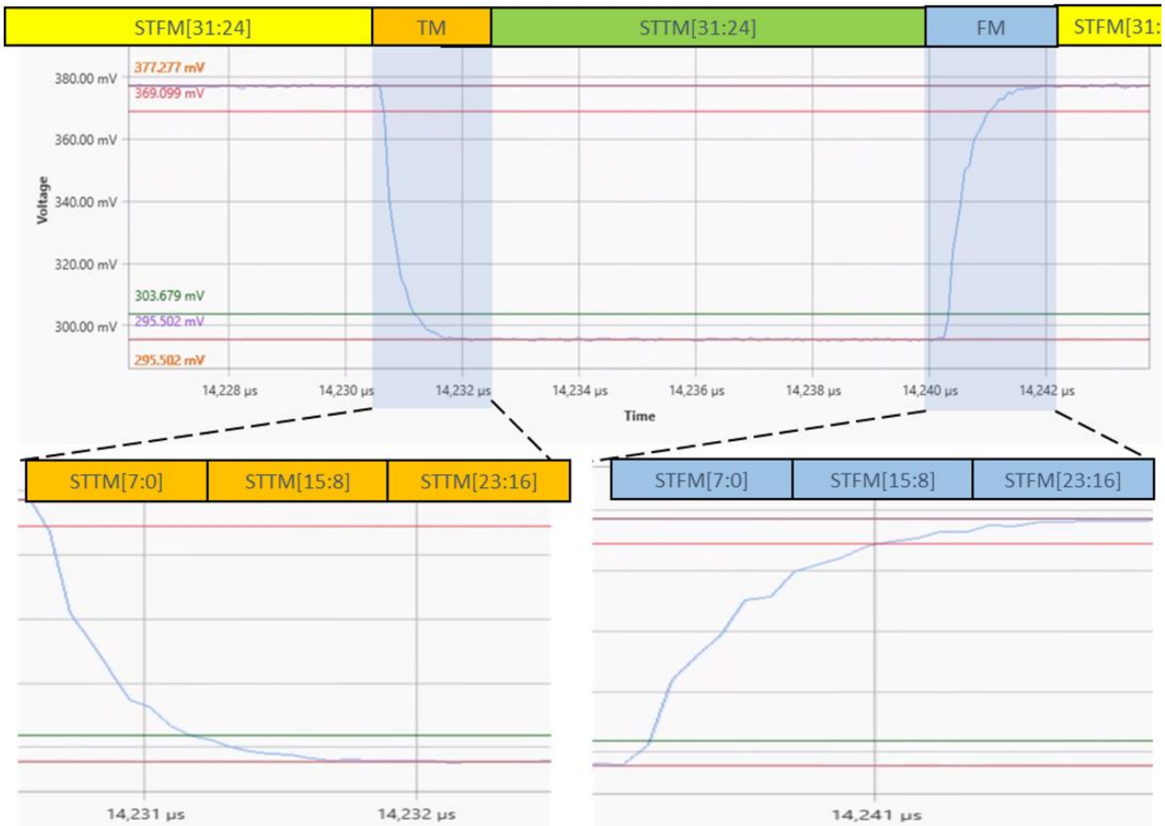


Figure 3: An example showing the driver setting sequence STTM and STFM throughout a modulation; in this example the type B waveform was captured through EMVCo PICC1 in EMV 3.0.

Type B Modulation Depth and Drive Low

EMV requires Type B PCD -> PICC modulation index to be within the range of 9-15% within the operating volume. More specifically, the modulation index must be within [9+0.25z, 15-0.25z] for z = [0, 1, 2, 3, 4], where z is the distance from PCD to PICC. It should be noted that while EMV has strict requirements for this modulation depth, most Type B PICCs in the market will easily tolerate a wide range of modulation index.

In MAX32570, the amplitude modulation for type B transmitter is realized by lowering the driver strength setting during the modulated state. This value must be paired with the Transmit Power (Drive High) and must be tuned to an optimal value that can meet the EMV or other requirements. The desired value of Driver Low, or STTM [31 : 24] strongly depends on the application's specific PCD antenna and matching network, and even the PICC antenna. Therefore, empirical tuning is necessary to guarantee a proper setting for modulated driver strength (Drive Low). Note this tuning requires a target PICC of interest (e.g. EMV-Test PICC) as the modulation index is a parameter observed at the PICC rather than the PCD.

For some systems and antennas EMV compliance can be easily met using one driver strength setting for type B modulation at all distances. However, if the system or application requires a smaller antenna, loading effect becomes more significant and affects the modulation index severely. For example, a value which measures 12% at 3 or 4 cm could become 6% at 0 cm. This violates the EMV requirements for modulation index. To compensate, Adaptive Modulation Control (AMC), which sets the Drive Low at different LL Index, must be implemented. The parameter `fd_dyn_sttm_bfv [31:24]` is the parameter array applied in the corresponding LL step. After `fd_thresholds` are determined, the AMC must be configured to set the modulation depth correctly.

Transition Steps Settings for Waveform Shaping

Three transition steps between driver high and driver low can provide extra flexibility to shape the waveform of rising and falling edges for each modulation, and fine tune the system to pass the criteria of undershooting, overshooting and monotonic edge required by EMV or other standards. This is a new feature in MAX32570 comparing to our previous generation product. As shown in the zoomed-in subplot in Figure 4, the three transition steps at falling edge are set by STTM[7:0], STTM[15:8] and STTM[23:16] , and the three transition steps at rising edge are set by STFM[7:0], STFM[15:8] and STFM[23:16]. Each step represents one 13.56MHz sample, i.e. 73.7ns.

For most designs at most card reading distances, setting the driver strengths of all the transition steps to the same value of driver low (STTM[31:24]) will be sufficient to generate a smooth waveform. If any criteria fail for the waveform, the rising/falling edge can be fine tuned through adjusting those transition steps. It must be noted that different target and different reading distance have different loading effect, therefore such adjustment may only be optimal for certain targets and reading distances.

Tuning Proceedure

1. Prerequisites

Before attempting any AFE tuning the prerequisites must be completed. Antenna matching condition (Impedance of the matching network) must be verified, and DTE must be checked if working properly.

2. Adequate Power Delivery

First set the driver strength at 127 (highest setting), and check if the power is sufficient to meet the minimum power requirements within the operating volume of interest. If not, the matching network or antenna design must be adjusted. If yes, check if such power exceeds the maximum power requirement within the operating volume of interest and lower down the driver strength setting if necessary. Once the power setting is fixed, also check the signal amplitude at the RX pins and adjust the dividing resistors at RX if necessary.

3. Calibrate Transmitter and Modulation Index

First check if a fixed modulated driver strength setting can meet the modulation index requirement for all distance. If not, Adaptive Modulation Control must be utilized. Setting up Adaptive Modulation Control requires two steps.

A. `fd_thresholds` setting

Turn on Display Field Detect Level in the DTE. This will continuously display the current field level and loading level index while the desired test device, e.g. EMVCO Reference PICC, is placed in the field. Observe the level at various distances from the antenna, at a minimum, 0, 1, 2, 3, and 4 cm. Make note of these levels, the values at the different distances will be used to fill in the `fd_thresholds` array.

For example, with one PCD antenna the FD levels were recorded as shown in Table 1. Observing analog behavior at these distances show modulation depth issues at 1, and 0cm. Therefore, the boundaries identified by `fd_thresholds` of 180, 170, 140 were chosen. These roughly correspond to distances of greater than 2cm: FD Level of 180 and above, and less than 2cm: FD Level of 170 and below.

Distance of PICC from Reader Antenna (cm)	Field Detection Level
4	204
3	190
2	178
1	160
0	130

Table 1: Example FD Level Data

It is important to note, that due to the way the index is calculated, ANY level lower than 170 will use the values in the last column. Just as any level higher than 180 will use the values in the first column.

Because there are only three defined regions in this example, they are separated by two boundaries. For any N number of regions, there will always be N-1 boundaries. Therefore, the last value in the `fd_thresholds` array is unused. In this example, 140 is never used, however, it is included as representative level slightly higher than that found at 0cm distance where loading effects are most pronounced. This way, if another boundary is found to be required based on further testing, it will be easy to add. For most antenna designs, two different indexes/thresholds are sufficient for AMC. Under the condition when it needs to consider multiple PICCs, for example, EMV 3.0 has 3 PICCs, the FD levels for each PICC has to be recorded and combined into one table, and the procedure to define `fd_thresholds` array remains the same.

B. `Driver Low` setting for modulation index

After identification of the critical boundaries for `fd_thresholds` the array of Drive Low, or `fd_dyn_sttm_bfv[ 31:24 ]`must be set. For example, on the antenna associated with Table 1, for each distance the desired Driver Low level is found through experiment with the PICC, and then `fd_dyn_sttm_bfv[ 31:24 ]`used by this PCD design is subsequently set to `0x0D 0x0B 0x06`, along with `FD_dynamic_drive_high set to the default maximum value 0x7F 0x7F 0x7F,` can achieve good type B modulation index range around 10 to 13 percent for all distances. For now, the transition steps settings are all set to equal Driver Low, therefore,

```
fd_ dyn_sttm_bfv = { 0x0D0D0D0D , 0x0B0B0B0B, 0x06060606 };
```

```
fd_ dyn_stfm_bfv = { 0x7F0D0D0D , 0x7F0B0B0B, 0x7F060606 }.
```

C. Transition steps setting for waveform shaping

If any signal integrity test case fail, transition step setting can help improve the waveform shape. For example, with the PCD associate with Table 1, rising edge overshoot and monotonic test cases fail at 0cm. In this case the corresponding element of `fd_ dyn_stfm_bfv` can be adjusted. After a few round of iterations, 0x7F5A5550 provides one best waveform shape that can pass such test case. So the final value of `fd_ dyn_stfm_bfv ={ 0x7F0D0D0D, 0x7F0B0B0B, 0x7F5A5550}.`

4. Optimizing Receiver Settings

Start with the default receiver settings with highest receiver gain of 12, combiner math of I-Q, default trigger levels then check if the PCD can read all the targets of interests (different cards, mobile phones, and EMV-Test PICC) within the operating volume of interest. If the DTE shows constant errors for any card at any distance, adjust the `fd_dynamic_gain` and `fd_dynamic_trigger(A,B,F)` correspondingly until it can read properly for all the positions and types of interest. If the PCD does not respond at all at long distance for certain target, that means the gain is too low or the trigger level is too high, increase the gain or lower the trigger level correspondingly. If the performance is still not satisfied, change to different combiner math and see if it works better for the desired targets and applications.

Other Considerations

In general, the AFE tuning procedure described in this document should be sufficient for most applications. The contents of this document may expand in the future including specific challenging cases that require more complicated trimming, for example, multiple iterations of collaborative tuning between the matching network and AFE settings.