How to use the active waveshaping (AWS) for EMVCo® and NFC Forum in the ST25R3916B/17B/19B/20B devices

Introduction

This application note is a guide for using the active waveshaping (AWS) in the ST25R3916B/17B/19B/20B (hereinafter referred to as the ST25R3916B family) devices. It provides to the user the explanations and how to use the registers that affect the waveform as environmental conditions change.

The examples and explanations in this document are based on the ST25R3916B device, but the techniques and tools can be used for other products of the same family.

1 Description

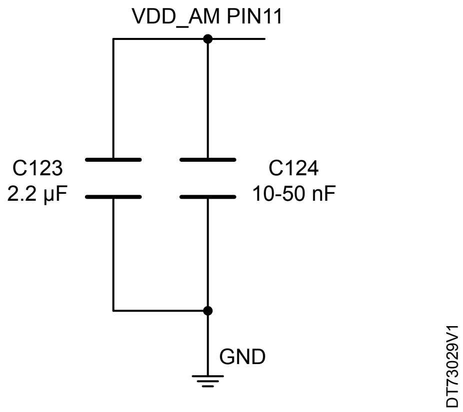
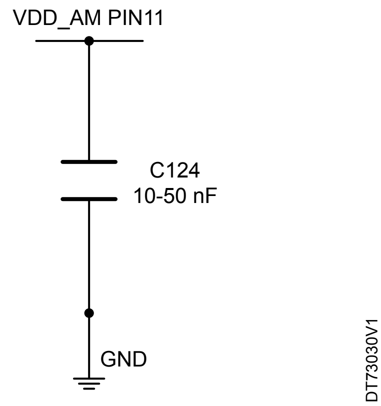
The ST25R3916B is an improved version of the ST25R3916 device, which keeps most features of its predecessor. Hence, the new active waveshaping features are not automatically enabled after powering-on the ST25R3916B device. The focus is to maintain the ST25R3916 behavior as far as the newly introduced features allow. The existing procedures and the software for ST25R3916 can be reused with few warnings:

- Special care must be taken with the Tx driver register 0x28h. In details:
  - d_res, which is the driver range in bits, is extended to any previous ST25R3916 setting, and cannot be applied one by one.
  - The modulation index in the same register is increased from 0 to 82%.
- The am_mod setting, used with the ST25R3916, does not produce the same modulation index for the ST25R3916B.
- act_amsink in register IO configuration register 2 can only be set to 1 when AWS is not used and a 2.2 µF capacitors is connected to VDD_AM

To use the ST25R3916B specific active waveshaping (AWS) functionality, the logic must be enabled in the auxiliary modulation setting as well as the corresponding AWS registers. Additionally, the external VDD_AM capacitor must be selected in a range of 10-50 nF, where typically 22nF is assembled on ST demo boards. The capacitor value is dependent on load and driver current consumption and needs to be evaluated case by case. The tendency however is to go for higher VDD_AM capacitor value when strong load/currents are to be expected in the application.

Note: Contrary to the recommendations for the ST25R3916, do not insert a 2.2 µF capacitor on the VDD_AM pin when using AWS.

Table 1. Pinout comparison between ST25R3916 and ST25R3916B

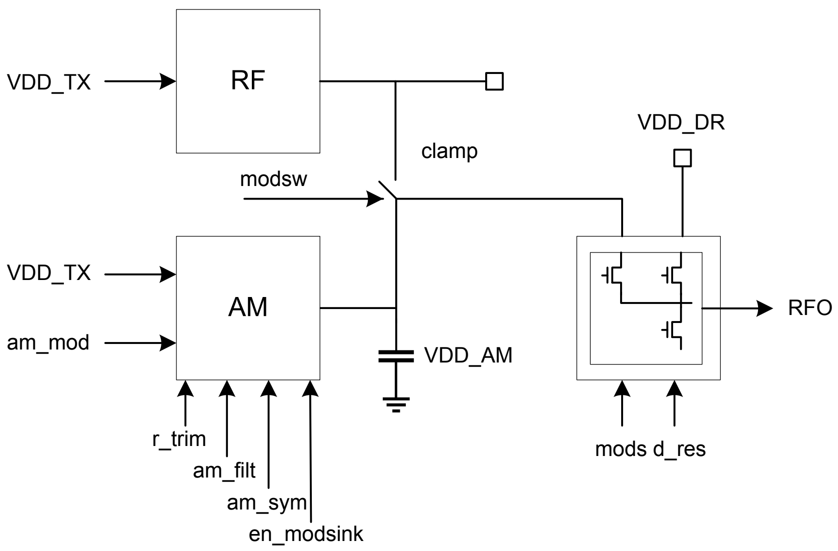
VDD_AM capacitor requirement for ST25R3916B in ST25R3916 non AWS mode	VDD_AM capacitor requirement for ST25R3916B using new waveshaping functionality (rgs_am=1)
	

2 AWS mechanism

The AWS mechanism consists of the RF and AM regulator. It includes the required logic and registers to “preform” the signal fed into the RF driver stage. Basic NFC modulation is achieved either by the hard switching on/off of the RF level, or switching from RF to an intermediate level as provided, for instance, by the AM regulator. The hard switching does not permit to actively model the waveform. The system response behavior therefore depends on physical limitations such as the antenna matching network, antenna parameters, or environmental factors that influence antenna properties.

The ST25R3916B family core registers for AWS are mainly related to the AM regulator block, including am_mod, am_filt, am_sym, bits. The am_filt sets the time constant for the first order filter for the AM reference, which subsequently is acting on the signal transition time. The am_filt thus controls the capacitance value of the RC time constant. A higher am_filt value prolongs signal transition time whereas a shorter value reduces it.

Figure 1. AWS mechanism



At driver level, a clamp function is added between RF and AM regulator, which aims to bring the AM level close to the RF level before the actual switching to RF level takes place. It improves the before mentioned drawbacks of a hard switching of the RF driver. The clamp is controlled by modsw bits in terms of to be defined carrier cycles. The mods bits at the driver stage block controls the switch between driving AM level and the full RF level derived from VDD_DR. The mods bits are defined in carrier cycles and need to start after the modsw switch from a timing perspective.

In the AWS register, all timer names that end with “1” (for example, Tmodsw1) represent the timer starts at the falling edge. Similarly, all timer names that end with ‘2’ (for example, tmodsw2) mean that the timer starts at the rising edge (end of modulation).

Typical preset values for slow, medium, and fast transients in OOK and ASK can be applied by setting them as listed in the table below.

Table 2. Preset values

Slow transient	Medium transient	Fast transient
AWS config 2: am_filt<3:0>=0xCh	AWS config 2: am_filt<3:0>=0x8h	AWS config 2: am_filt<3:0>=0x4h
AWS time 1 = 0x01h	AWS time 1 = 0x01h	AWS time 1 = 0x01h
AWS time 3 = 0x9Ch	AWS time 3 = 0x79h	AWS time 3 = 0x57h
AWS time 4 = 0x0Ah	AWS time 4 = 0x07h	AWS time 4 = 0x06h

While Table 2 shows typical settings for specific waveform characteristics, they may require further adjustments to achieve the desired waveform slope. Table 3 provides a more detailed table how to achieve the fastest and slowest waveform transitions.

Table 3. Waveform transitions

am_filt	tmods2	tmodsw2	Waveshape transition time
0	1	0	Fastest
1	2	1	-
2	3	2	-
3	4	3	-
4	5	4	-
5	6	5	-
6	7	6	-
7	8	7	Medium
8	9	8	
9	10	9	-
10	11	10	-
11	12	11	-
12	13	12	-
13	14	13	-
14	15	14	-
15	15	15	Slowest

The settings may require individual adjustment with the final antenna, which is described in this document.

The following registers need to be set to activate the specific AWS for the ST25R3916B:

- set register 0x28h in register SpaceB (auxiliary modulation setting register) to 0x94h
  - bit dis_reg_am=1
  - bit lm_dri=1 (only required for passive load modulation)
- bit rgs_am=1
  - set register 0x2Eh in register SpaceB (AWS configuration) to 0x08h
  - bit vddrf_cont=1

Depending on whether OOK (for instance NFC-A) or ASK (for instance NFC-B, NFC-F) modulation is transmitted, different register settings need to be applied.

OOK:

- set am_mod<0:3> in the Tx driver register to 0xFXh, which is the lowest VDD_AM level during modulation (82% modulation index)
- clear am_sym and set en_modsink in the AWS config 2 register by writing 0x1Xh, which activates the asymmetrical shape and strong sink during OOK.

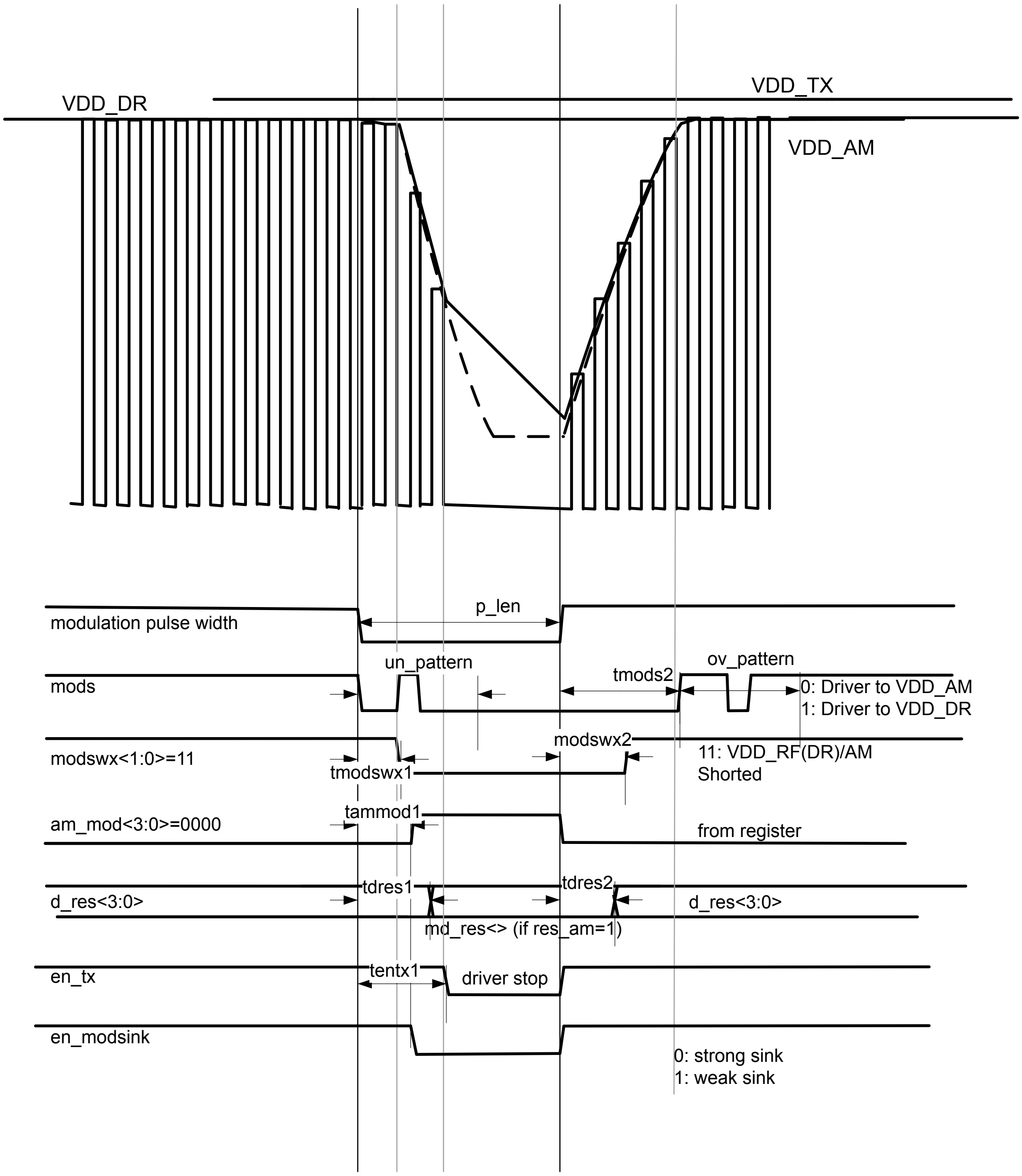
ASK:

- set am_mod<0:3> in the Tx driver register to the required modulation index, for example 0x4Xh, which correspond to ~12%.
- set am_sym and clear en_modsink in the AWS config 2 register by writing 0x2Xh, which activates the symmetrical shape and weak sink during ASK.

2.1 Timing related information when using OOK

The following graphic represents the interaction of bits and timings during active waveshaping in OOK modulation.

Figure 2. Bit and timing relation for OOK waveform



The modulation pulse width is defined by the number of 13.56 MHz clock periods with the p_len bits at address 0x05h in register space A. The default value as reflected in RFAL fits well for all baud rates and technologies and can of course be adapted if required. Undershoot and overshoot bits can be applied in addition to the AWS mechanism that is primarily responsible for forming the waveform. An undershoot pattern takes effect with the first falling edge pulse, whereas the leading bit or LSB of an overshoot pattern starts after tmods2 timing. It is recommended that the user first adjusts the waveform through the AWS registers before any additional over- and undershoot patterns are applied.

Mods2 and modsw2 define the switching periods of the driver to RF and clamp switch, respectively, and are explained in Section 2.1.1 Explanation of OOK waveform adaption for the rising edge

The VDD_AM modulation index is set by bits am_mod<3:0> and the correct setting is required for a 100% OOK modulation. The signal follows this VDD_AM level with a specific filter curve defined with am_filt bits. It is required to set am_mod to its highest value of 82% to allow a proper shaping of the signal.

The tdres<3:0> bits are not used in AWS mode. Moreover, they represent an alternative way to achieve a modulation pause by means of driver resistance change. Remember that in ST25R3916B the modulation pause is achieved by use of the VDD_AM regulator and tentx1 timing.

With tentx1 bits in AWS time 3 register, the time in fc periods can be set when the driver stops emitting a field. For NFC-A 106kbit/s a 100% modulation is required, thus at some point of time the driver needs to stop and start emitting an RF field. This can be accomplished by setting tentx1, otherwise the level of VDD_AM would be kept throughout the modulation pause. Tentx1 can also be used to influence the shape of the falling edge. The starting of the RF field on the other side is done automatically.

The ST25R3916B device can internally sink a certain amount of current. The current sink is used to drain additional power from the charged VDD_AM decoupling capacitors and therefore have a faster falling edge. The corresponding bit is called en_modsink. The en_modsink can be set to 1 or 0 to allow the device have a strong or weak sink depending on the modulation characteristic used. For an NFC-A 100% modulation, it is desired to discharge quickly the VDD_AM during the modulation pause. A strong sink in this mode thus supports this effect (See Figure 2). For NFC-B modulation, the modulation never stops, and the en_modsink is thus kept a 0 to activate a weak sink during modulation.

2.1.1 Explanation of OOK waveform adaption for the rising edge

When evaluating the characteristics of the antenna waveform, it is recommended to start off with a so called medium preset configuration for the transients. These settings can be depicted from Table 1 and can be applied for all technologies and baud rates. A medium preset means: the AWS filter settings and the switches are set to a value that represents the center of available adjustable steps. The usage and interaction of AWS registers, and bits are explained first by hands of NFC-A 106kbit/s rising slope. The focus for the rising edge must be set on the registers am_filt, tmods2 and tmodsw2. To better visualize the effect of each bit on the waveform, these three bits from the medium preset were slightly adapted as shown in the figure below.

Figure 3. Adapted medium preset values

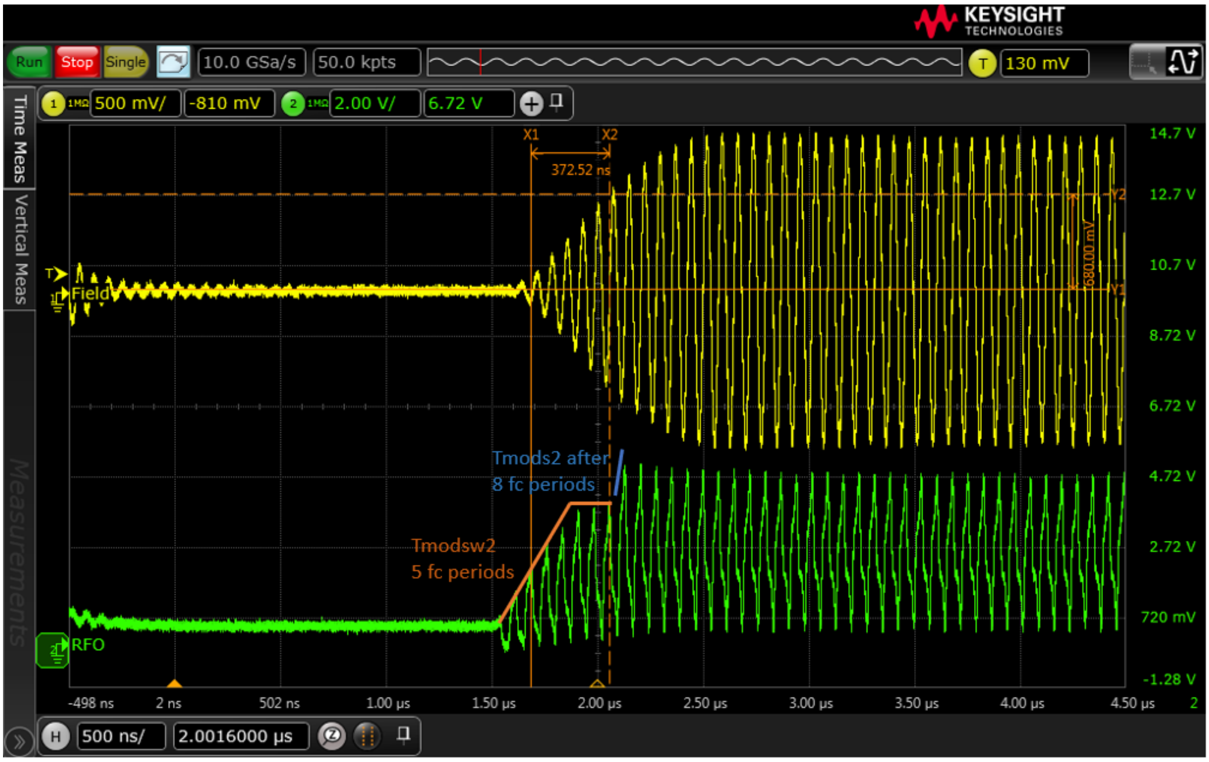
Transmit AM (tr_am)	OOK	R:0x0003 M:0x04 V:0x00
AM Modulation Index (am_mod)	82%	R:0x0028 M:0xf0 V:0xf0
AWS shaping symmetry (am_sym)	Nonsymerical shape (for OOK)	R:0x006f M:0x20 V:0x00
AWS enable strong sink (en_modsink)	Strong sink	R:0x006f M:0x10 V:0x10
AWS filter speed (am_filt)	0x09	R:0x006f M:0x0f V:0x09
AWS hard switch at rising edge (tmods2)	8 fc periods	R:0x0076 M:0x0f V:0x08
AWS soft switch at rising edge (tmodsw2)	5 fc periods	R:0x0077 M:0x0f V:0x05

The resulting waveform from Figure 4 is measured with an EMVCo reference PICC 2 with HLZ (high linear load) in close distance of the reader antenna. Channel 1 (labeled with “Field”) in yellow shows a gently increase of the waveform measured at the pickup coil of the reference PICC. The green channel 2 shows the corresponding signal measured directly at one of the RFOs. It is not necessary to capture the RFO when making waveform adjustments, but when it is done, the user can directly see the effect of each bit:

- First, the modulation starts for five carrier cycles ramping through the AM regulator with a medium am_filt set to 09h.

- Then, this AM level is held for another three carrier cycles until the clamp between AM and RF is closed and the modulation ramps to its defined RF value.
- The evaluated signal rise time measured from 5 to 60% is approximately 372 ns.

Figure 4. RF field measured at the antenna and RFO signal



The waveform looks good and does not show any overshoots. No specific adjustments are necessary. However, it is possible to adapt the 3 bits to achieve a faster signal rise time. As we have mentioned in section 2, the am_filt needs to be decreased to change the RC time constant and speed up the signal transition. As a general rule of thumb, the 3 bits am_filt, tmods2 and tmodsw2 values should be linked close together. So, when am_filt is set to 04, also tmods2 and tmodsw2 are set around this value.

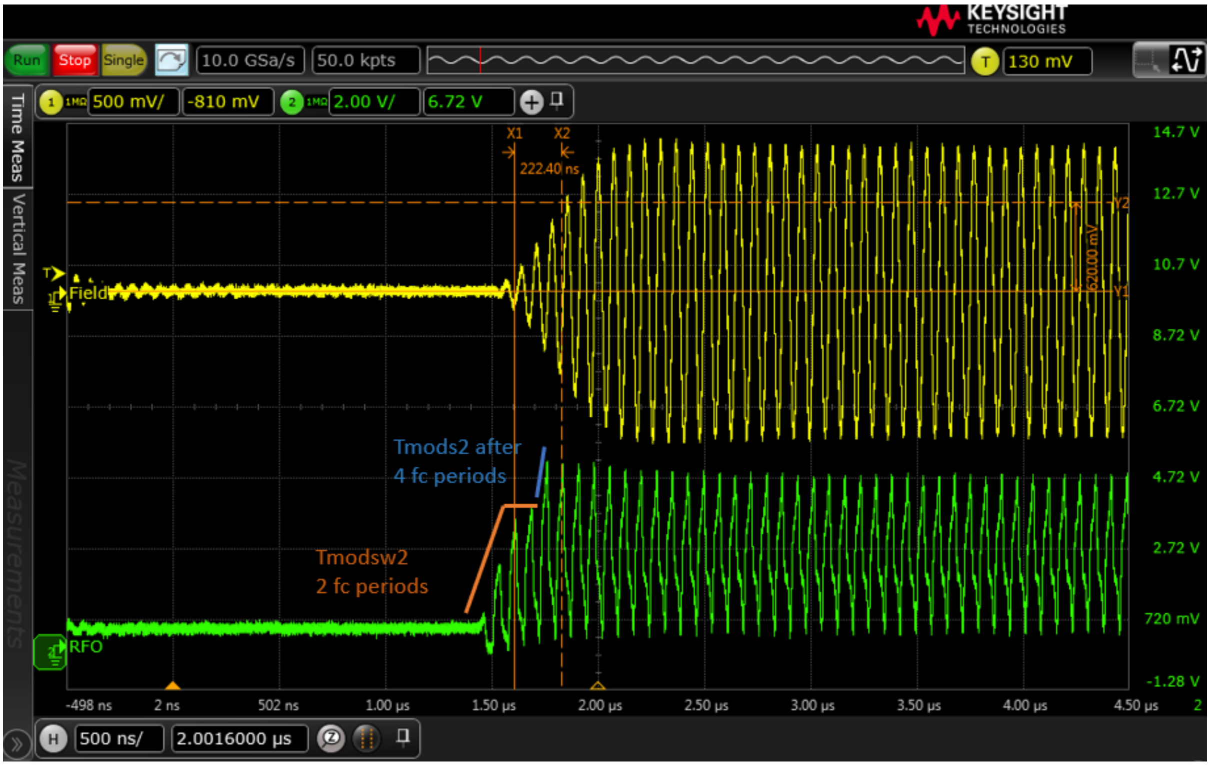
Picture 3 shows the adaptions in am_filt, tmods2 and tmodsw2 to decrease signal rise time.

Figure 5. Improved signal rise time settings.

Transmit AM (tr_am)	OOK	R:0x0003 M:0x04 V:0x00
AM Modulation Index (am_mod)	82%	R:0x0028 M:0xf0 V:0xf0
AWS shaping symmetry (am_sym)	Nonsymerical shape (for OOK)	R:0x006f M:0x20 V:0x00
AWS enable strong sink (en_modsink)	Strong sink	R:0x006f M:0x10 V:0x10
AWS filter speed (am_filt)	0x04	R:0x006f M:0x0f V:0x04
AWS hard switch at rising edge (tmods2)	4 fc periods	R:0x0076 M:0x0f V:0x04
AWS soft switch at rising edge (tmodsw2)	2 fc periods	R:0x0077 M:0x0f V:0x02

The resulting waveform in Figure 5 shows a reduction of the rise time from 372ns to 222ns by keeping the overall beauty of the shape. The RFO signal (channel 2) reveals the filter settings: the modulation is ramping with the AM reference within two carrier cycles, staying there for another two periods until the clamp is again closed between AM and RF to reach the defined RF modulation level.

Figure 6. RF field and RFO signal with reduced filter speed settings

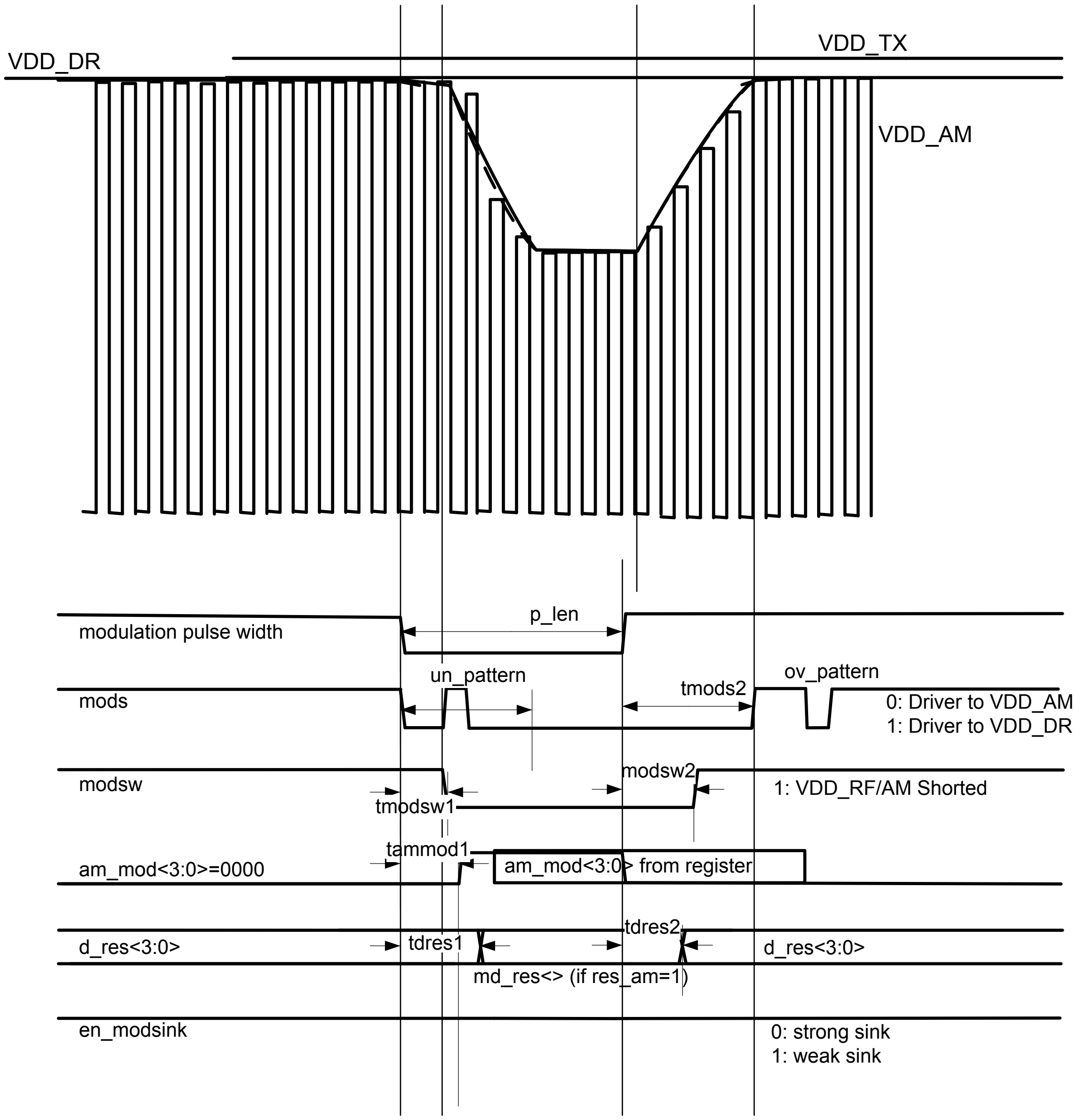


Longer signal rise times could be achieved by changing the am_filt, tmods2 and tmodsw2 to higher values, which are not outlined here.

2.2 Timing related information when using ASK

The following graph represents the interaction of bits and timings during active waveshaping in ASK modulation.

Figure 7. Bit and timing relation for ASK waveform



The interaction of bits for ASK modulation is the same as for OOK modulation except handling of en_modsink and tentx1 bit. As can be seen from Figure 7. Bit and timing relation for ASK waveform, the driver never stops during an NFC-B modulation, but the level of VDD_AM is kept throughout the modulation pause. Furthermore, it is not required to sink a lot of energy during the modulation because we never want to reach a 100% modulation. Thus, the en_modsink bit can be kept at 0 all the time.

2.2.1 Explanation of ASK waveform adaption for the rising edge

Adjusting NFC-B waveform characteristics, for instance, can be done in a very similar way as for NFC-A. However, the bit tentx1 is active and en_modsink set to 0 throughout the complete modulation period. This is due to the reason that the driving field in ASK modulation is not completely stopped. The internal sink thus can be set to weak because the amount of energy can be easily drawn from the antenna tank to achieve good modulation characteristics.

The am_sym bit should be set to symmetrical shape for ASK to maintain good symmetric falling and rising slopes.

The following Figure 8 shows a “strongly” and “artificially” detuned antenna by placing a reference PICC and another reader device directly on the DUT. The settings from Figure 9. Filter setting were used for the analog configuration of the register and filter. The resulting waveform shows over- and undershoot in Type-B modulation, which of course are not desired for typical standard compliance tests at NFC Forum or EMVCo® level. The yellow channel 1 in Figure 8 shows the resulting RF field at the antenna whereas the green channel 2 depicts the measurement on the RFO pin.

Figure 8. NFC-B modulation with over- and undershoots

Figure 9. Filter setting

Transmit AM (tr_am)	AM			R:0x0003 M:0x04 V:0x04
AM Modulation Index (am_mod)	11%			R:0x0028 M:0xf0 V:0x30
AWS shaping symmetry (am_sym)	Symmetrical shape (for ASK)			R:0x006f M:0x20 V:0x20
AWS enable strong sink (en_modsink)	Weak sink			R:0x006f M:0x10 V:0x00
AWS filter speed (am_filt)	0x04			R:0x006f M:0x0f V:0x04
AWS hard switch at rising edge (tmods2)	5 fc periods			R:0x0076 M:0x0f V:0x05
AWS soft switch at rising edge (tmodsw2)	2 fc periods			R:0x0077 M:0x0f V:0x02
User Defined	0074	0f	0f	R:0x0074 M:0x0f V:0x0f
User Defined	0071	ff	00	R:0x0071 M:0xff V:0x00

To resolve the under- and overshoot observations from Figure 8. NFC-B modulation with over- and undershoots, the following considerations should be taken into account: the settings of am_filt, tmods2 and tmods2 made in Figure 9. Filter setting have small values indicating a fast step response with the known drawbacks. A longer filter curve would thus reduce the transients resulting in a slower rising edge but also keeping under- and overshoots better under control. The am_filt is thus adjusted to a value of 0x0C, tmods2 set to 10 fc periods and tmodsw2 set to five fc periods to allow a larger transition time from AM to RF regulator. Additionally, the overshoot pattern has been applied with a value of 09 to smoothen the rising edge even more. The resulting waveform and RFO signals is shown in the figure below.

Figure 10. Waveform adjusted according to settings

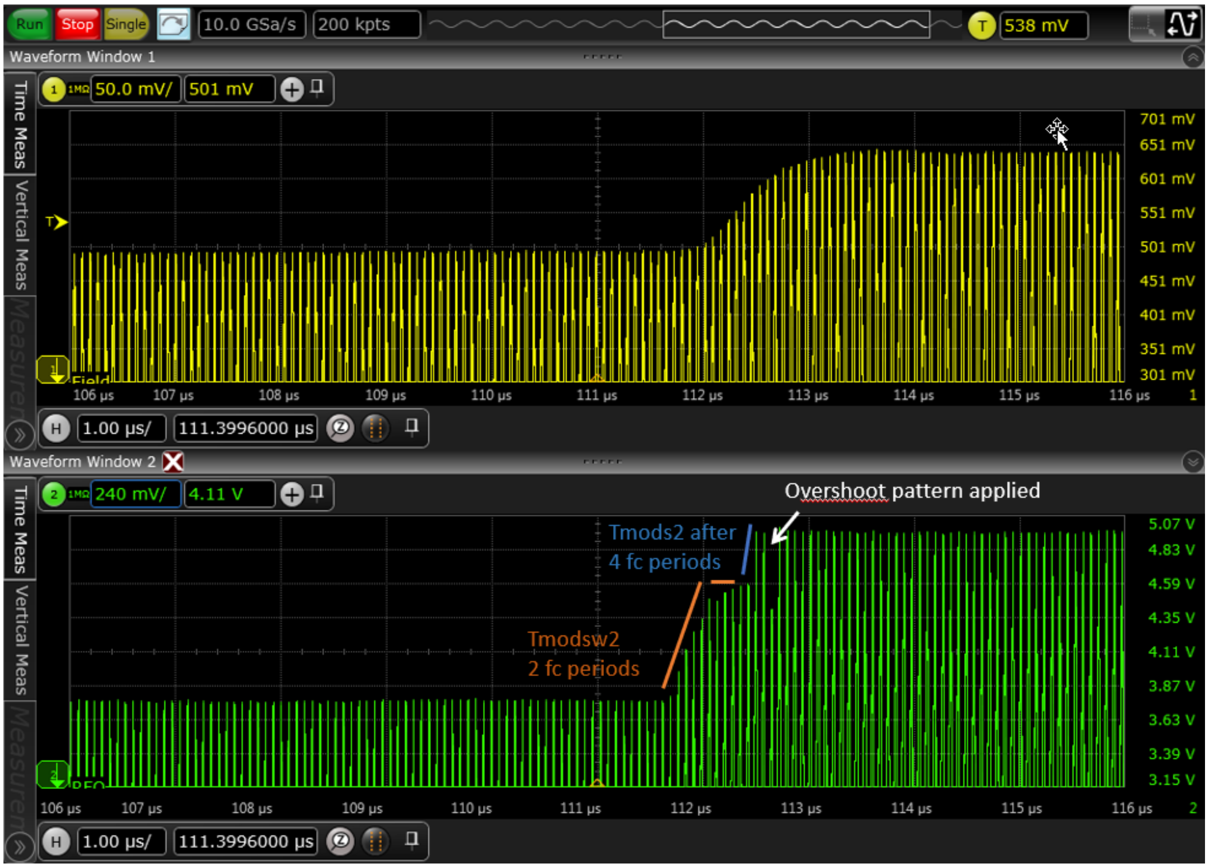


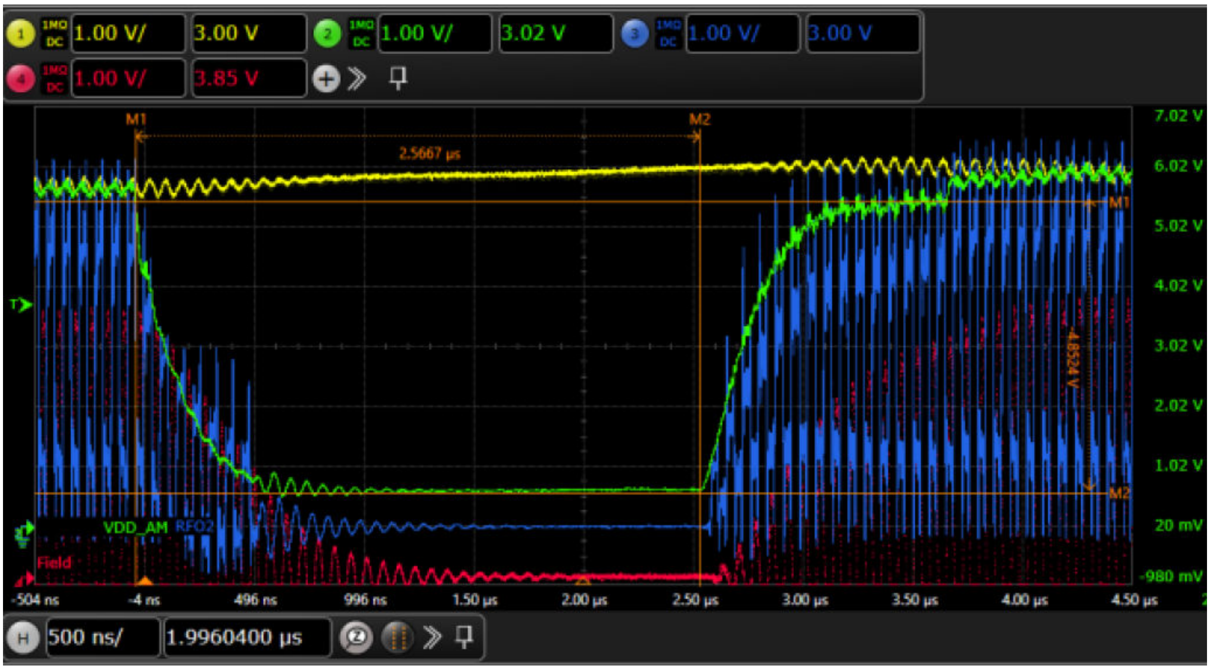
Figure 11. Setting

Transmit AM (tr_am)	AM			R:0x0003 M:0x04 V:0x04
AM Modulation Index (am_mod)	11%			R:0x0028 M:0xf0 V:0x30
AWS shaping symmetry (am_sym)	Symmetrical shape (for ASK)			R:0x006f M:0x20 V:0x20
AWS enable strong sink (en_modsink)	Weak sink			R:0x006f M:0x10 V:0x00
AWS filter speed (am_filt)	0x0C			R:0x006f M:0x0f V:0x0c
AWS hard switch at rising edge (tmods2)	10 fc periods			R:0x0076 M:0x0f V:0x0a
AWS soft switch at rising edge (tmodsw2)	5 fc periods			R:0x0077 M:0x0f V:0x05
User Defined	0074	0f	0f	R:0x0074 M:0x0f V:0x0f
User Defined	0071	ff	09	R:0x0071 M:0xff V:0x09

AWS config one register–bit vddrf_rx_only

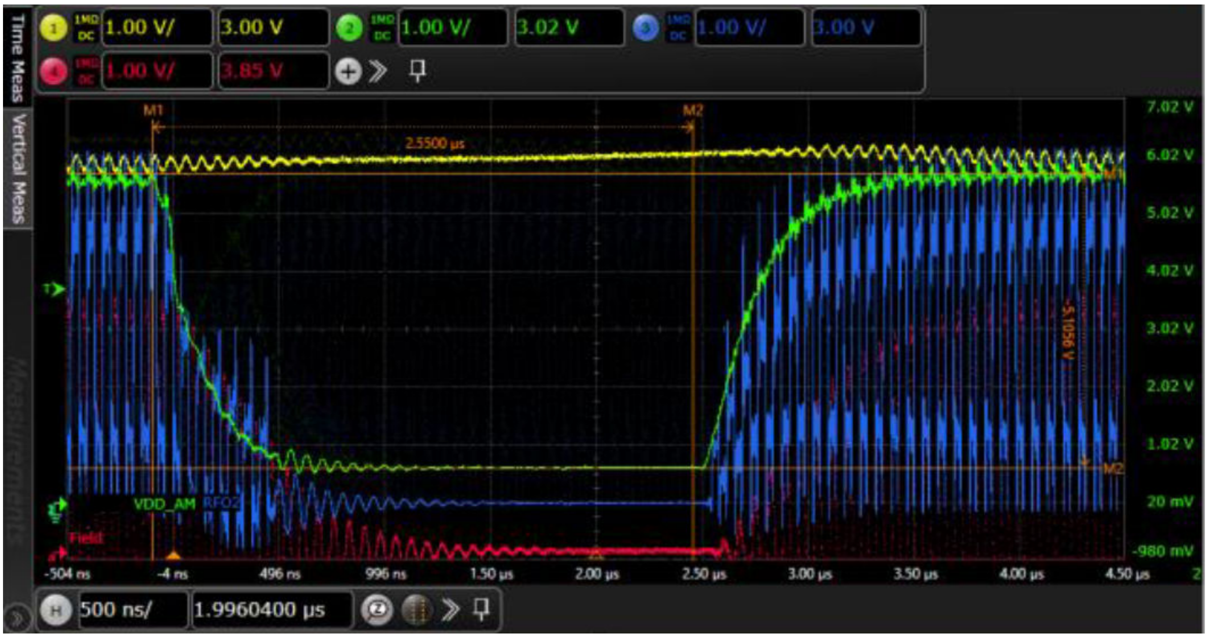
Setting the bit vddrf_rx_only to 1 is only allowed when the internal LDO is bypassed, which is achieved by connecting VDD_RF/VDD_DR to VDD/VDD_TX. At the end of each modulation pause of the OOK and ASK modulation, the driver switches back from VDD_AM to VDD_RF. An additional transient can be caused by this switch, and it is more pronounced at high loads presented to the antenna LC tank.

Figure 12. **Transient at end of modulation pause**



This effect can be prolonged to the receiving period by setting vddrf_rx_only to 1. The driver is kept at VDD_AM level just before the receiving period. Consequently, this additional transient is then seen shortly before the reception but would have been removed during the rising edge of the modulation signal. The same principle can be applied for NFC-B modulation.

Figure 13. **Vddrf_rx_only is set to 1**



3 Conclusion

This application note gives the user the initial guidance to set up the various AWS registers and bits for each application. It is recommended to start with a preset setting for the AWS configuration and then improve these settings step by step. The principles for waveform adjustments for OOK and ASK are similar, but the differences in terms of the internal sink, signal symmetry and modulation index settings are necessary and important. The usual circuit theory on signal response also applies for active waveshape adjustments. Thus, a fast slope transition setting may help on achieving certain standard requirements but is also prone to produce an overshoot to a certain degree. Always watch out for a good compromise between matching circuit components and AWS settings to achieve a good signal response and result in the overall measurement volume.

Revision history

Table 4. **Document revision history**

Date	Version	Changes
19-May-2022	1	Initial release.
02-Aug-2022	2	Updated: • Section 2 AWS mechanism
13-Feb-2023	3	Updated: • Section 2.2 Timing related information when using ASK • Section 2.2.1 Explanation of ASK waveform adaption for the rising edge
22-Jun-2023	4	Added the ST25R3916B device. Updated: • Table 1. Pinout comparison between ST25R3916 and ST25R3916B

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