Application Note

Correcting the External and Internal RF Droop for RF Transmitters

TEXAS INSTRUMENTS

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Data Converters and Clocks

ABSTRACT

This application note explains how the AFE8092 function helps in correcting the RF droop caused due to internal and external factors using digital block in transmitter chain. The document explains the method and the feature of RF droop correction macro in the AFE8092.

The application note is structured as follows

- Understand the need for RF droop correction
- Reasons behind RF droop
- Procedure to find the RF droop coefficients
- Deployment of RF droop Macro

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1 Introduction

The AFE8092 is a high performance multi-channel RF trans-receiver. This device consists of 8 transmitters and receiver chains and 2 feedback channels. The transmitters have the capacity for sampling up to 12 GSPS and frequency range of 6 GHz. The RF receivers can sample the data with a rate of 4 GSPS. The focus of this application note is transmitter chain.

2 RF Droop

2.1 Reasons Behind RF Droop

One of the important performance requirements in the RF Transmitter is to provide constant power across frequency in the band being used. Multiple external and internal factors (to the device) cause change in the output power across frequency. This phenomenon is referred to as RF droop in this document. An overview of reasons causing the RF droop is given below

1. **Capacitors or inductors in the path**: The output path of a transmitter contains multiple capacitors and inductors either for some design purpose or can occur as parasitic components. Since the impedance of these components changes with frequency, the output power changes across frequency.
2. **Matching Circuits**: Matching circuits are designed to make the frequency response as flat as possible by matching the device impedance to the characteristic impedance of the transmission system. Still some amount of non-flat frequency response is seen due to the insertion losses and reflected power. Such frequency variation becomes prominent for wide band applications as designing matching circuits for wide band applications is quite difficult.
3. **Power amplifier**: In general, systems employ a power amplifier at the output of transmitter and before the antenna as shown in Figure 2-1. This power amplifier also gives rise to a particular frequency response according to the parameters.

2.2 Digital Correction of RF Droop

The new AFE8092 RF droop correction block corrects the non-flat frequency response mentioned above using digital correction. The digital correction block implements a second order fit to correct for the RF droop. Therefore, to determine the correction parameters, we need droop measurements taken at 3 frequencies: F_{NCO}, $F_{NCO} + \Delta F$ and $F_{NCO} - \Delta F$, where F_{NCO} is center frequency of the given band. Typically, ΔF is chosen to be close to 0.4 × (Transmit data interface rate). Assume the difference in amplitude at frequencies $F_{NCO} - \Delta F$ and F_{NCO} to be M1 and between the frequencies $F_{NCO} + \Delta F$ and F_{NCO} to be M2.

2.3 Overview of RF Droop Correction Measurements

This section explains how to use and enable the RF droop correction in AFE8092. Figure 2-1 shows a common RF circuit and the tap-off points from where the input measurements can be taken. If *Meas1* tap-off point is chosen, the RF droop introduced until the output of Matching Network is corrected. If *Meas2* tap-off point is chosen, the RF droop introduced until the output of Power Amplifier is corrected.
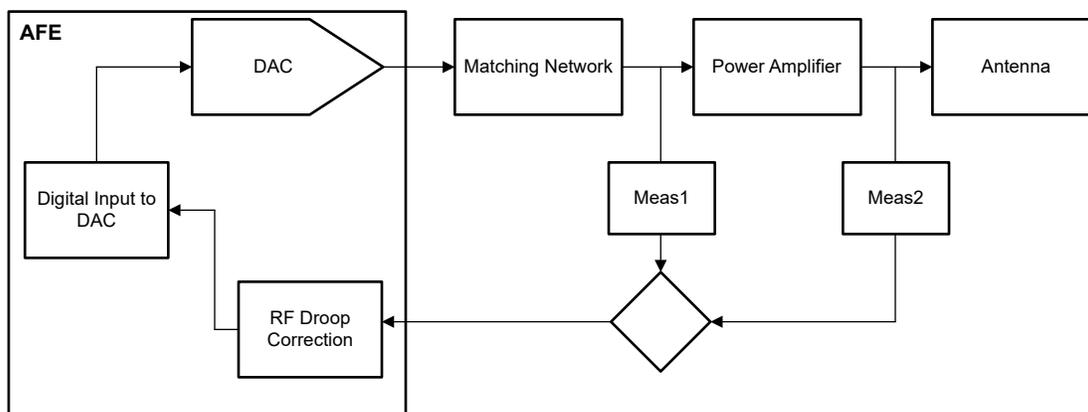

Figure 2-1. RF Circuit

Either the M1 and M2 can be measured at Meas1 or at Meas2.

2.4 Enabling the RF Droop Correction

To enable the RF droop correction following steps are used.

1. Bring-up the device in the desired system configuration. Once the bring-up is done, check if the jesd link of the device is up and FPGA is able to send the data. (AFE80XX configuration guide gives details about this in JESD configuration section.).
2. Transmit tones at F_{NCO}, F_{NCO}- ΔF and F_{NCO}+ ΔF , measure the amplitudes at either Meas1 or Meas2 tap-off point as shown in Figure 2-1.
3. ΔF must always be less than or equal to 0.4 × (Transmit data interface rate). The function will try to flatten the frequency response in band F_{NCO} ±ΔF.
4. The input of tone amplitude to the function is given in terms of LHS and RHS (both in logarithmic scale). LHS and RHS are amplitudes of tones with respect to the tone at Fc. Ie. LHS = Amplitude(dBm) of tone at Fc - Amplitude(dBm) of tone at Fc - ΔF.
5. After M1 and M2 are determined, the correction can be applied using CAFÉ function *configureTxRfDroop*.

See Table 2-1 to understand how to input the measurements and enable the RF droop correction block through a micro. Once the micro is enabled the input values can be used across bring-ups.

Table 2-1. Functions and Variables to Enable RF Droop Correction

Functions and Variables	Remark
configureTxRfDroop(afeInst,*txChSel*, *bandNo*, *ncoNo*, *deltaFreq*, amp1, amp2)	CAFE function to enable the RF droop correction[NP1]
afeInst	AFE Instance
txChSel	Select the TX Channel 0 for TXA 1 for TXB 2 for TXC 3 for TXD 4 for TXE 5 for TXF 6 for TXG 7 for TXH
bandNo	Select the TX Band. 0-Band0, 1-Band1
ncoNo	Select the NCO 0 for nco1 1 for nco2 2 for nco3 3 for nco4
deltaFreq	ΔF ×2^{16}/ Fdata , where ±ΔF + F_{NCO} is the frequency where amp1 and amp2 measured and Fdata is the transmit data interface rate
amp1	int(10**(RHS/20)*2**15)
amp2	int(10**(LHS/20)*2**15)

2.5 Example for Using the RF Droop Correction

Using the following steps RF droop correction macro can be deployed.

1. Bring-up the device in the configuration as per requirement.
2. Send tones and measure the amplitude at the edge of the band (±ΔF + FNCO) and at the center of the band (FNCO).
3. Figure 2-2 demonstrates a plot of amplitude Vs frequency of a channel A transmitter (TXA) which is configures with NCO frequency (FNCO) at 2 GHz and transmitter data rate (Fdata) of 983 MHz.
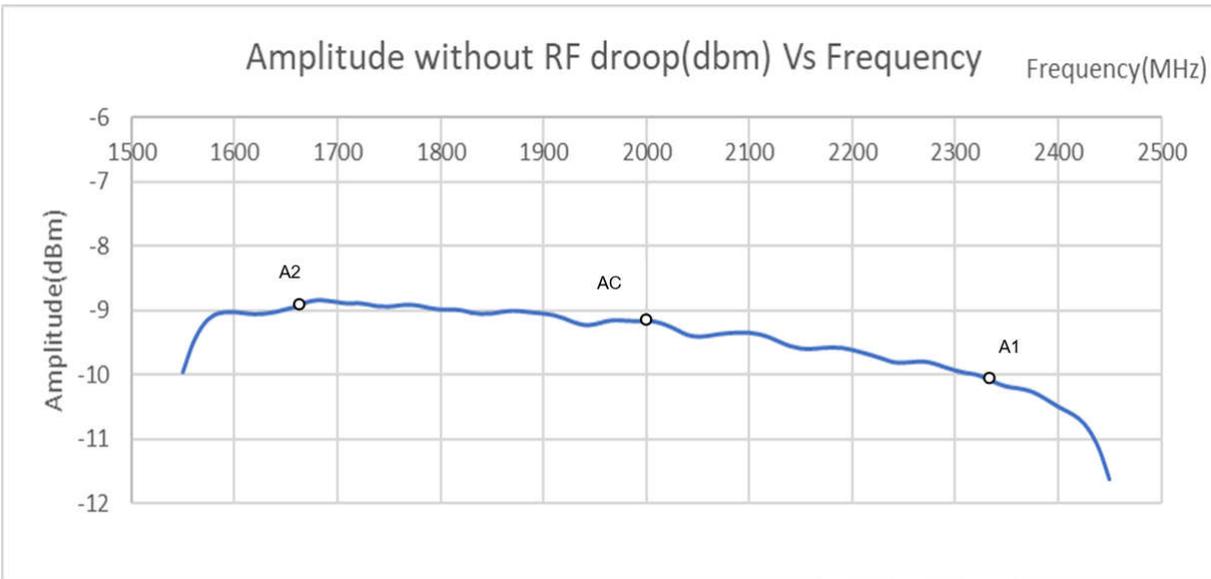
Figure 2-2. Amplitude without RF Droop vs Frequency

4. As mentioned before we need three measurements for amplitude at FNCO and $\pm\Delta F$ + FNCO. Let us take $\Delta F=$ Fdata × 0.35 ≈ 340 MHz, hence the values use for function call are determined as follows.

Variable	Value obseved	Calculation	Final value for C-AFE function call.
afeInst	Single device	0	0
txChSel	TXA	0 for TXA	0
bandNo	Band0	0-Band0	0x0
ncoNo	NCO1	0 for NCO1	0
deltaFreq	340 MHz	$\Delta F \times 2^{16}$/Fdata	Int(22667)
Amplitude(A_c) at FNCO =2000MHz	-9.51 dBm	NA	NA
Amplitude(A_1) at FNCO + ΔF =2340 MHz	-10.122 dBm	NA	NA
Amplitude(A_2) at FNCO -ΔF =1660 MHz	-8.933 dbm	NA	NA
RHS	0.61 dbm	$A_c - A_1$	NA
LHS	-0.577 dbm	$A_c - A_2$	NA
amp1	NA	int(10**(RHS/20)*2**15)	Int(35151)
amp2	NA	int(10**(LHS/20)*2**15)	Int(30661)

5. Additionally, the function for the previous example can be called by the following command:

    CAFÉ.configureTxRfDroop(0 ,0 ,0 ,0, int (22667), int (35151), int (30661))
6. The previous procedure must be repeated for every Transmitter channel.

2.6 Frequency Response Before and After Droop Correction and Limitations

The flatness being a key factor in performance of a RF DAC was measured in TI lab. Figure 2-3 shows the actual frequency response of output power with and without RF droop correction on AFE8092. Note that the M1 and M2 measurements were taken after the matching circuit (at Meas1 position) in this case.
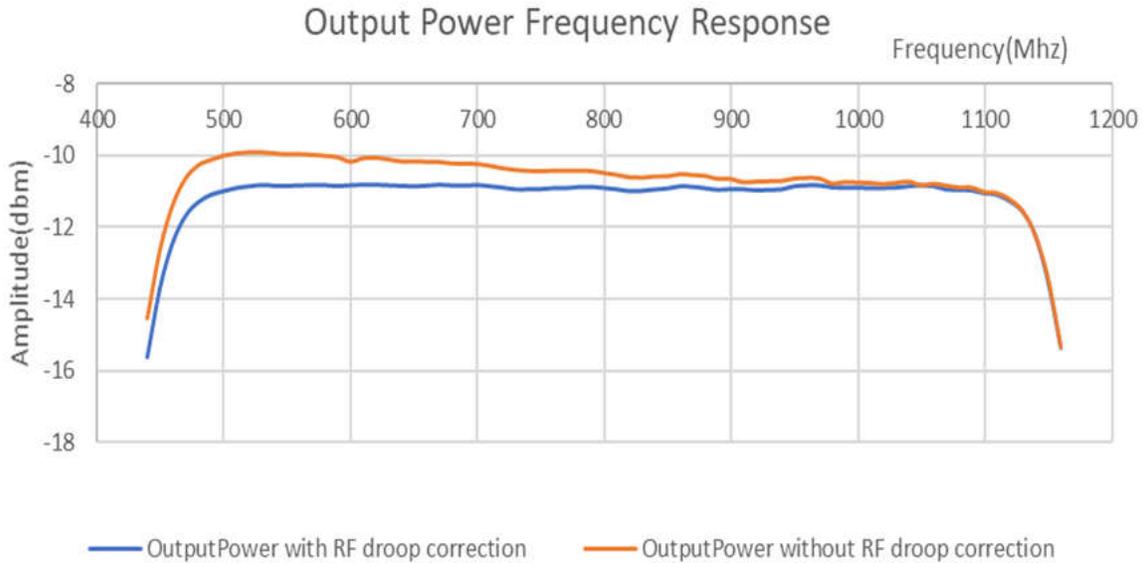

Figure 2-3. Output Power Frequency Response

As Figure 2-3 demonstrates without the RF droop correction, there is a droop of almost 1 dB across the bandwidth, which gets reduced substantially once RF droop correction is enabled. Note that the M1 and M2 measurements were taken at 520 MHz and 1080 MHz respectively.

The amount of Rf droop Max of ($\lvert Ac - A1 \rvert$ and $\lvert Ac - A2 \rvert$) that can be corrected have an upper limit. Following chart mentions the maximum Rf droop that can be corrected with respect to the ratio of ΔF to band width (Fdata).

ΔF/ Fdata	Max of ($\lvert$ Ac - A1 $\rvert$ and $\lvert$ Ac - A2 $\rvert$) dBm
0.1	0.8 dBm
0.2	2.2 dBm
0.3	3.3 dBm
0.4	4.7 dBm

3 Summary

RF droop estimation and applied correction for each band enabled improve the amplitude flatness across the frequency range of interest.

We can summarize from the test data that the profile of amplitude across the frequency up to the second order can be corrected with the aforementioned method to required specifications. The frequency response can be caused due to internal or external factors of the device. With correct inputs to the rf droop macro, the response can be corrected digitally to meet the specifications required, given the error is within the mentioned limit.

4 References

1. The AFE80xx C API (CAFE) library and Latte EVM software are available for approved customers with access to TI's Secure Server access. To access the Secure Server, request access on the AFE8030 and AFE8092 product folder page.
   a. Texas Instruments, *AFE8030 Octal-Channel RF Transceiver with Feedback Paths*, data sheet.
   b. Texas Instruments, *AFE8092 Octal-Channel RF Transceiver with Feedback Paths*, data sheet.
2. Texas Instruments, *AFE80xx RF Sampling Transceiver*, data sheet.

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