WHITEPAPER

Local Oscillator feedthrough suppression using on-chip calibration techniques

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Introduction

The high level of integration allowed by a CMOS RF SoC allows digitally assisted analog circuitry to achieve improved performance through tightly coupled calibration loops. This white paper serves as a case study of one such calibration loop as used on an RFIC developed by Adesto's ASIC & IP division. This RFIC is a highly integrated solution for Mobile Satellite Service (MSS) which allows data connectivity globally in an increased number of applications and enables remote devices and sensors to be connected via the Internet of Things (IoT).

Feed Through Contributors

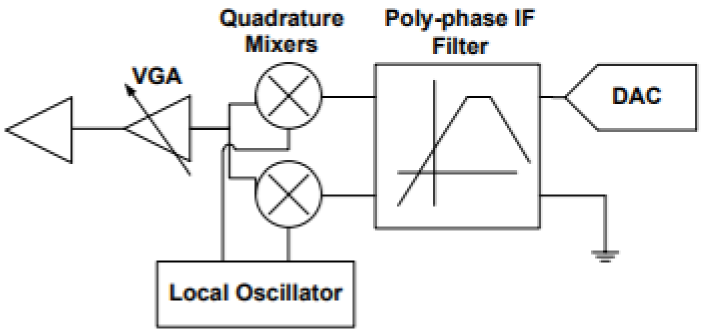
In wireless systems, feed-through from the Transmitter (TX) Local Oscillator (LO) is an important specification. In direct up-conversion transmitters, the feed-through can weaken modulation quality (EVM). For single side-band intermediate frequency (IF) up-converters where the IF is too low to allow practical RF filtering, the feed-through will result in a failure to meet the transmitted spectral mask specifications. In this case feed-through acts as a blocker for channels adjacent to the intentional transmission. These strict specifications often introduce the need for a calibration scheme to improve on the native performance that is achievable.

Current available solutions involve large device sizes to minimize offset contributors, careful symmetric layout and finally calibration schemes that may require RF feedback with an envelope detector or full loop back of the transmit signal through a receive path. The calibration scheme implemented in this paper only requires base-band measurements.

LO feed-through consists of many components. Electromagnetically radiated LO feed-through can be mitigated by using an off frequency VCO either oscillating at twice the required LO used in conjunction with a divider, or other 2/3 or 3/2 schemes. Coupling due to parasitic capacitances can be minimized to a certain extent by careful layout. Base-band filter contributors can be minimized by DC offset correction.

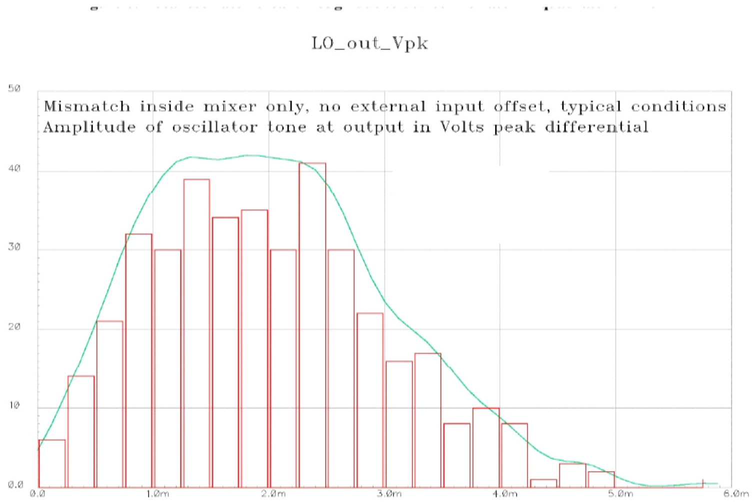
System Overview

Adesto implements a calibration scheme that requires base-band measurements only. The calibration scheme discussed here was implemented on a 0.18um CMOS RFIC. The IC utilized a low IF TX frequency plan with an active RC polyphase filter to serve as a reconstruction filter and to generate quadrature signals for the side-band suppression mixer as shown in the figure below.



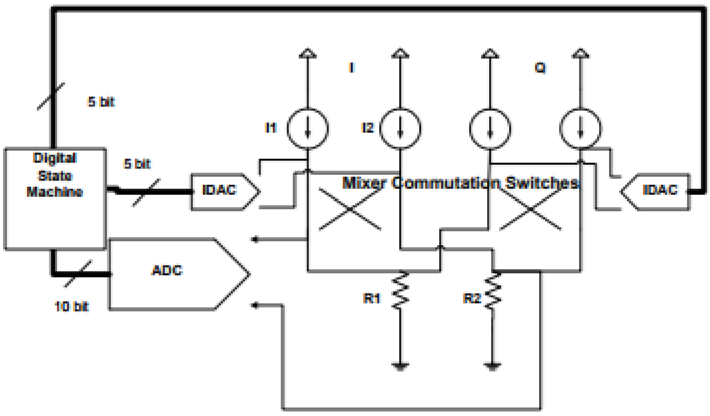
Transmit Architecture

Monte Carlo mismatch simulations showed offsets in the mixer and base-band poly-phase filter, with the mixer dominant and indicated the need for a calibration scheme. The mixer was dominant due to the low gain of the polyphase filter at DC which negated the need for base-band DC offset correction. As the mixer was dominant AC coupling to the mixer would be of marginal benefit to the LO leakage performance. Gaussian distribution of offsets in I and Q mixer branches will add to give a Rayleigh distribution of LO feed-through power as seen at the output of the transmitter as shown in the following figure. The results showed the LO feedthrough passing specification for less than 99.7% of devices even for this mechanism alone mandating a calibration scheme.



Monte-Carlo statistical simulation of mixer LO feedthrough showing Raleigh distribution

Two five-bit current DACs are used to compensate for offsets in the quadrature Gilbert cell mixers. Measurement of the DC offset is made using a 10-bit auxiliary ADC IP block with zero incremental complexity/cost as this is being utilised already on the custom RFIC for TX power control and sensor measurements.



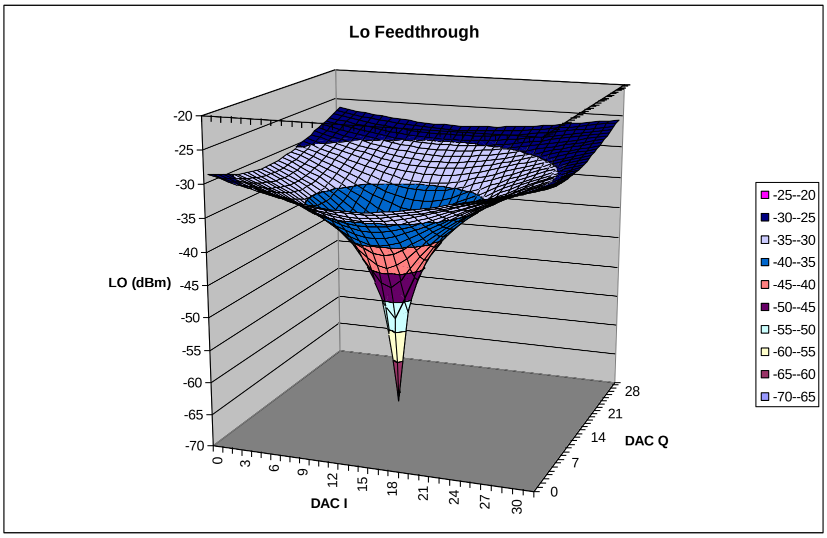
Block Diagram of the Calibration Scheme

ADC offsets and load resistor mismatches, which do not significantly contribute to LO feed-through and would add errors to the calibration, are cancelled by taking two measurements with the mixer switches in either direction. (Double-sampling.) The ADC and resistor components cancel when the measurements are subtracted leaving a measurement of the current mismatch which is the parameter of interest.

Offsets are reduced by minimizing the difference between ADC samples first for the I mixer, then for the Q mixer, through adjustment of the corresponding DAC. While the I mixer is being calibrated the Q mixer commutation switches are turned off to remove any effect from the Q mixer transconductor offsets on the I mixer and vice-versa. The low frequency switching is controlled through set and re-set operation of the RF divider and quadrature generation block needed to divide the X2 VCO. The calibration also compensates for TX base-band filter offsets. A digital state machine could be used to close the loop on chip or alternatively an external microcontroller could be used using the integrated SPI interface. As the ADC and DACs sample at 500kHz, the calibration can be complete using a SAR algorithm in <50us.

Results

The figure below shows the measured LO feedthrough versus DAC codes for sample number #1 where the contours of the feedthrough can be observed, and the optimum code is DAC I:15 DAC Q:13.

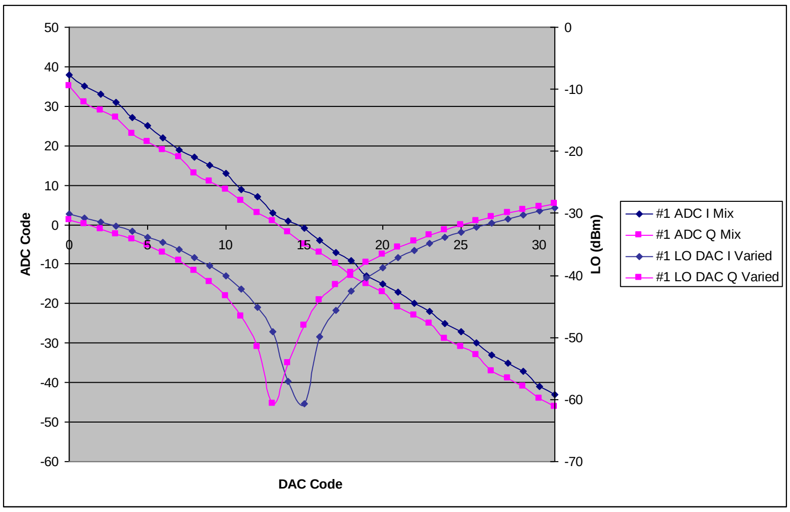


Measurement results from a production sample showing feed-through contours

The effect of the DAC on the feed-through can be clearly seen. The feed-through can be minimized to -65 dBm with the VGA gain set to give an output power of -9dBm giving LO feed-through of -56dBc.

The following figure shows ADC measurements for both I and Q mixers for the same part as for the figure above. A subsequent table shows measurements for 5 samples and compares to the actual LO feedthrough. The ADC measurements are in fact the subtraction of two ADC measurements taken to cancel R and ADC offsets as outlined previously. Over-laid on the plot is measured LO feed-through versus DAC code sweeps corresponding to the I DAC swept with Q DAC at optimum code and Q DAC swept with I DAC at optimum code.

Ideally, we would expect to see the minimum LO feed through at the DAC codes where the ADC measurements approach zero.



Measurement results from a production sample showing ADC measurements & feed-through

The LO feed through plots correspond to two cross sections through the contour plot at the optimum DAC code. A strong correlation between the ADC measurements approaching zero and the corresponding LO feed through plot can be seen. Other parts measured show similar characteristics. In our measurements, for all samples, the ADC measurements serve as a practical predictor for optimum LO feed through DAC code, to within 1 DAC code, as shown in the table. Any errors could be due to second order coupling effects not measured by the base-band calibration, or noise in the ADC measurement which could be mitigated by filtering. These do not significantly degrade the practical performance achieved.

	Predicted optimum based on ADC samples		Actual optimum from LO feed-through measurement	
	DAC I	DAC Q	DAC I	DAC Q
#1	14.5	13	15	13
#2	13	13	13	13
#3	15.5	15	16	15
#4	17	14	17	14
#5	14	12	14	12

Measurement results table

Further details on the results with corresponding graphs can be viewed in the ISSC paper on this subject [1].

Conclusion

The calibration scheme is shown to be effective and a reliable method to reduce LO feed-through due to base-band components. The algorithm is easily implemented in a low-cost fashion using existing circuits and avoids the need for RF feedback.

Appendix

[1] O'Sullivan et al, "Carrier Leak Calibration Scheme on a 0.18μm Transmitter", in ISSC, 2002.