Analog Crosstalk Cancellation for High Data Rate Communication Links

1st Frida Strömbeck
Microwave Electronics Laboratory
Chalmers University of Technology
Gothenburg, Sweden
0000-0001-8109-7219

2nd Herbert Zirath
Microwave Electronics Laboratory
Chalmers University of Technology
Gothenburg, Sweden
0000-0002-5721-4793

***Abstract*—In this work, a design of an analog I/Q crosstalk compensation circuit in 130 nm SiGe BiCMOS is proposed. The circuit consists of four baseband variable gain amplifiers based on Gilbert cells. As a proof of concept, a 20 Gbps QPSK input signal with high bidirectional crosstalk (20% and 30 %), equal to an error vector magnitude (EVM) of 25. 1 % and signal-to-noise ratio (SNR) of 12.0 dB, was improved to EVM=16.1 % and SNR= 15.9 dB at the output. Unidirectional cross-talk up to 50%, was investigated, and at 50 % the EVM improved from 25. 9 % to 18. 6 %, and the SNR from 11.7 to 14.6 dB.**

***Index Terms*—Cancellation, Compensation, Crosstalk, High data rate, I/Q, SiGe, VGA**

I. Introduction

The fast development of new commercial semiconductor processes with high frequency properties [1], has led to a high interest in the research of applications at millimeter wave frequencies. Examples include wireless back-haul [2] [3], wireless access [4], radar and radiometer sensors, wireless energy distribution and harvesting etc. Most of these applications require data throughput well above 10 Gbps, even up to 100 Gbps. For these high data rate links, digital signal processing can be cumbersome and power hungry. Impairments like I/Q imbalance is one of the issues that wireless and wireline communication links battle.

In previous work [5], data rates above 100 Gbps were achieved using a low modulation order and a wide bandwidth. In order to further increase the data rate, a higher modulation order would be preferred, thus a larger signal-to-noise (SNR) is required. In this case, it was found that the distortion from the I/Q imbalance was the limiting factor.

The I / Q imbalance is the result of either an amplitude difference between I and Q and / or a phase difference that is deviating from the ideal 90 degrees. The result is a distortion of the signal and can be measured in a signal-to-distortion ratio (SDR), which is given by;

$$\text{SDR} = 10\log\left(\frac{1+\epsilon_R^2+\epsilon_R^2\tan^2(\Delta\phi_R)}{\epsilon_R^2+\tan^2(\Delta\phi_R)}\right) \quad (1)$$

where ϵ_R is the amplitude error and $\Delta\phi_R$ is the phase error. The distortion can be dealt with, but it is challenging to implement for high data rates and in real-time communication systems. The amplitude imbalance is usually dealt with using amplifiers/attenuators.

A baseband signal that is affected by crosstalk will contain a part of the other channel's input.

$$\begin{aligned} \text{I}_{\text{x-talk}} &= \text{I} + x\text{Q} \\ \text{Q}_{\text{x-talk}} &= \text{Q} + y\text{I} \end{aligned} \quad (2)$$

In paper [6], I/Q correction capabilities is demonstrated for baseband signals up to 8 GHz, and quadrature errors up to 20 degrees.

This paper presents an energy-efficient analog solution that can be integrated with the receiver. By extracting a small portion of each channel (I+ I- Q+ Q-), corresponding to the crosstalk (x and y), the opposite pair is added with the signal, canceling the crosstalk.

$$\begin{aligned} \text{I} + x\text{Q} - x(\text{Q} + y\text{I}) = \text{I} - xy\text{I} \approx \text{I} \\ \text{Q} + y\text{I} - y(\text{I} + x\text{Q}) = \text{Q} - xy\text{Q} \approx \text{Q} \end{aligned} \quad (3)$$

As can be seen in Eq. 3, to cancel the cross-talk (i. e. distortion), the negative effect on the SNR is small for unidirectional and limited cross-talk ($x * y$). Bidirectional cross-talk with 30 % in one direction and 20 % in the other has been investigated, as well as unidirectional cross-talk up to 50 %, with improved data transfer. Quadrature errors up to 25.1 degrees were reduced to less than 1 degree.

II. Circuit Design

The cross-talk compensator is designed and realized using Infineon technologies' 130 nm SiGe BiCMOS process (B11HFC). The process features high-speed npn heterojunction bipolar transistors (HBT) with a maximum f_t/f_{max} of 250 GHz/370 GHz [7]. The process features six metal layers for signal and DC bias routing.

The topology for the cross-talk compensator is based on four differential variable gain amplifiers (VGAs). The input distribution network is implemented using transmission lines and resistors. Two 5 Ω resistors are used for the two main channels that feed into two different VGAs configured to provide amplification. These VGAs can be used to adjust for the I/Q amplitude imbalance. For the cancellation channels, a 100 Ω resistor is used, so a small part of the I and Q channel gets coupled out. The amplitudes are equalized by the VGAs,

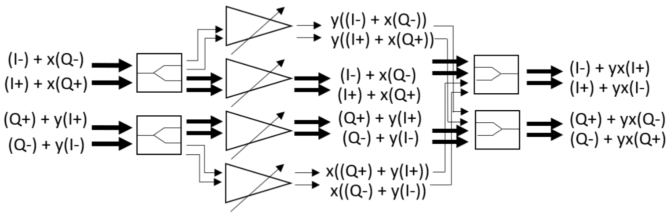

Fig. 1. Block diagram of the crosstalk compensator. The largest part of the signal is coupled to the main VGAs, where any amplitude imbalance can be adjusted. A small part of the signal is used to compensate for any cross-talk between the I and Q channel.

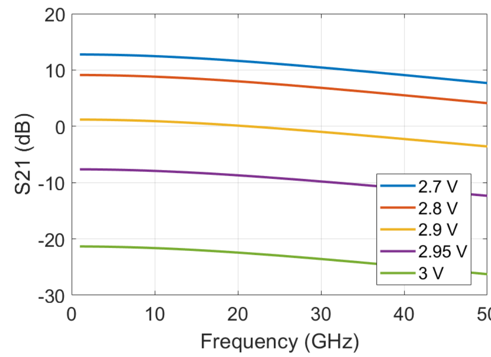

Fig. 3. Simulated conversion gain for the baseband VGA cell.

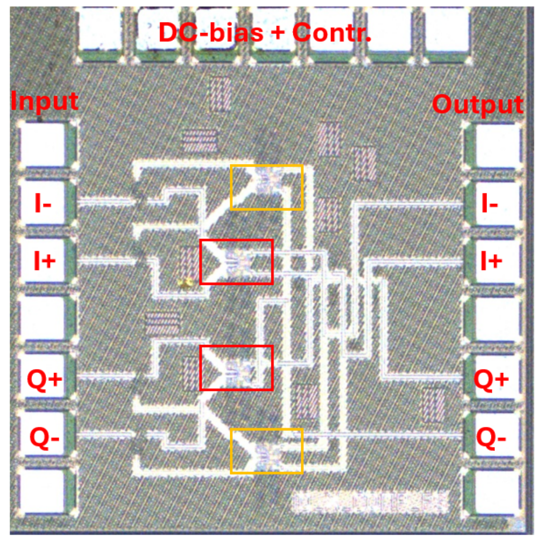

Fig. 4. The layout of the circuit, the differential input is on the left, while the output is on the right. The bias of the circuit is on the top of the circuit, including the controls for the cross-talk cancellation. The red squares indicate the two main VGAs, and the orange once are the compensation cells.

then a combiner is used to subtract the unwanted signal from the two main channels. A block diagram is shown in Fig. 1.

Each VGA cell is based on Gilbert cells. The schematic for the VGA cells can be seen in Fig. 2. Transistor Q1-Q6 has an emitter length of 6 μm, and Q7 has an emitter length of 10 μm. Vcc is 3.5 V, and V_cm is 2.5 V.

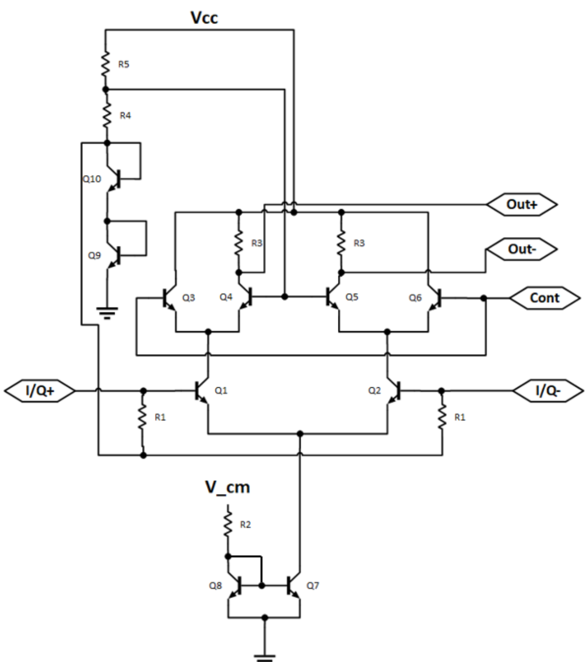

Fig. 2. The schematic for the VGA cells.

In Fig. 3, the simulated conversion gain for each baseband VGA cell can be seen. The control voltage was varied between 2.7 V and 3 V, and the baseband VGA has a dynamic range $>$ 30 dB. The maximum gain is 13 dB and the 3-dB bandwidth is $\approx$ 35 GHz.

The integrated cross-talk compensator with the four VGAs and splitter/combiner network is shown in Fig. 4. The size of the circuit including the pads is 870 μm $\times$ 880 μm, mainly due to the pads.

III. Measurement Results

The circuit was evaluated using a probe station (Cascade MPS150), and the data input was generated by a Keysight M8195A arbitrary waveform generator (AWG). The signal was captured by a Keysight UXR1104A Infiniium UXR Real-Time Oscilloscope. In Fig. 5, a photo of the on-wafer measurement can be seen.

The circuit was initially evaluated using continuous wave (CW) signals. The I channel was injected with two sinusoidal signals (simulated crosstalk), one at 10 GHz and one at 12 GHz. The Q channel was injected with one tone at 12 GHz. The signals can be seen in Fig. 6.

Using the Q-to-I cancellation function of the circuit, the 12 GHz tone was reduced from -18 dBm to -36 dBm. The compensated signal can be seen in Fig. 7.

Mixed crosstalk was tested as well, using 30 % of the Q signal on the I signal, and 20 % of the I signal on the Q signal. The constellation and eye diagram of the un-compensated signal can be seen in Fig. 8, where the the symbol rate is 10

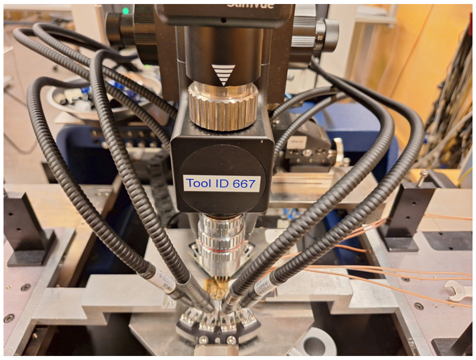

Fig. 5. The on-wafer measurement setup, using a probe station (Cascade MPS150).

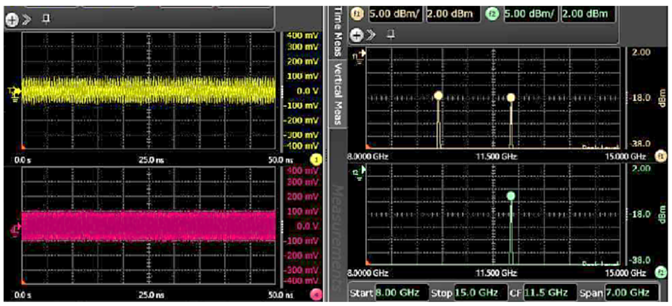

Fig. 6. The I signal is displayed in time domain and in frequency domain on the top, while the Q signal is in the bottom. The signal is not cross-talk compensated by the circuit.

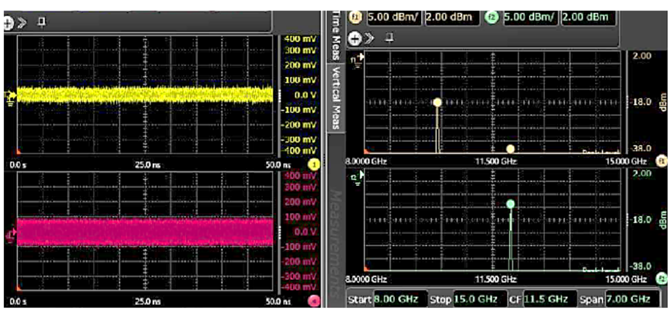

Fig. 7. The I signal is displayed in time domain and in frequency domain on the top, while the Q signal is in the bottom. The circuit is tuned to cancel out the unwanted tone in the I channel.

GBd, resulting in an error vector magnitude (EVM) of 25.1 % and SNR = 12.0 dB. The quadrature error is 24.2 degree.

Using the cancellation circuit, the EVM was reduced to 16.1% and the SNR increased to 15.9 dB (Fig. 9). The quadrature error is reduced to less than 1 degree.

A severe cross-talk of 50% of the I signal on the Q channel was also investigated. Time domain measurements using a 10 GBd QPSK signal can be seen in Fig. 10, including both the uncompensated and compensated signals for comparison.

Without cancellation the EVM was measured to 25.9 % and SNR was 11.7 dB. The quadrature error was 22.6 degrees. Using the cancellation feature, the EVM improved to 18.6 % and 14.6 dB SNR. The quadrature error was improved to 11.0

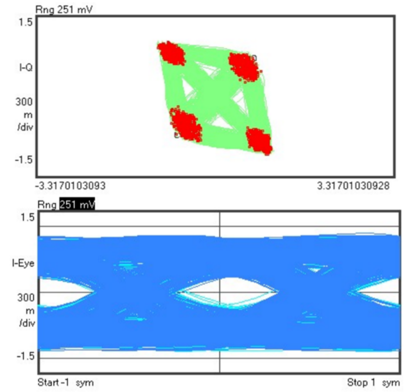

Fig. 8. The uncompensated output signal, with 30 % cross-talk on the I channel and 20 % on the Q channel. A 10 GBd QPSK signal was used.

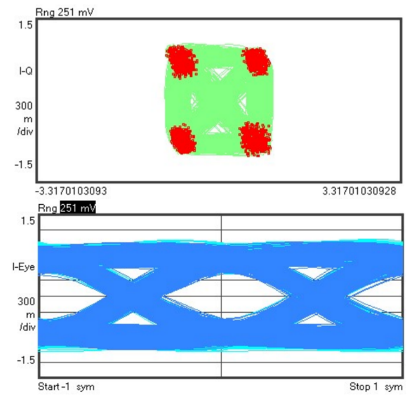

Fig. 9. The output signal, applying the cross-talk cancellation feature, with 30 % cross-talk on the I channel and 20 % on the Q channel. Symbol rate is 10 GBd QPSK.

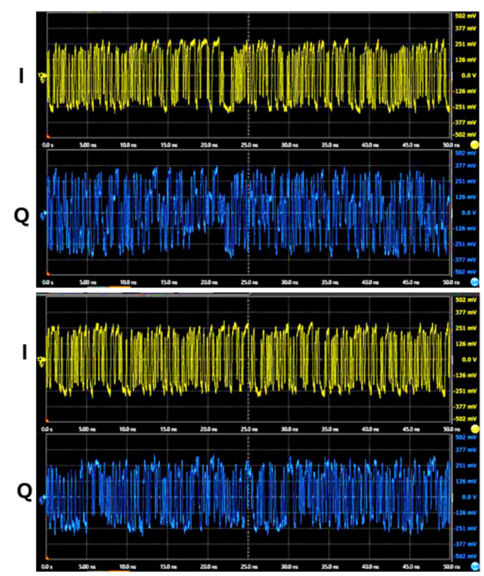

Fig. 10. Time domain measurement of the output (10 GBd QPSK), with 50% cross-talk from I to Q channel. No cancellation is applied on the top, but it is on the bottom.

degrees. Both measurements are shown in Fig. 11.

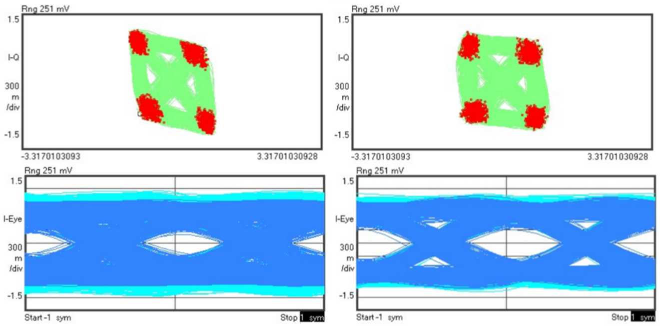

Fig. 11. Constellation diagram and eye diagram of the output (10 GBd QPSK), with 50% cross-talk from I to Q channel. No cancellation is applied on the left, but it is on the right.

The DC power for the circuit was measured to be 0.2 W.

IV. Conclusion

An analog I/Q cross-talk compensation circuit in a commercial SiGe BiCMOS is proposed. It consists of four variable gain amplifiers based on Gilbert cells. A 20 Gbps QPSK input signal with high bidirectional crosstalk (20% and 30 %), equal to an error vector magnitude (EVM) of 25.1 % and signal to noise ratio (SNR) of 12.0 dB, was improved to EVM=16.1 % and SNR= 15.9 dB at output. Unidirectional cross-talk up to 50 %, was investigated and at 50 % EVM improved from 25.9% to 18.6%, and SNR from 11.7 dB to 14.6 dB. The proposed circuit is suitable for energy efficient high data rate communication.

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