ACTIVE TRANSMITTER SIGNAL CANCELLATION IN RECEIVE SIGNAL PATH FOR SDR

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ABSTRACT

Elimination of receiver (RX) band-pass filters is actual task for construction of next generation New Radio Wireless Transceivers and other modern equipment (Multiple Input Multiple Output systems, radar applications, etc.) based on software-defined radio. Unfortunately, some new problems with electromagnetic compatibility arise. Main problem start up with Frequency Division Duplex mode, were part of high power transmitter (TX) signal came to high sensitivity RX input through duplexer with limited isolation. In presence of high TX signal RX mixer could come into non-linear working area and RX sensitivity is decreases. This problem may be solved by cancellation of TX signal from RX path. This article provides a preliminary approach to the problem of active TX signal cancellation in RX signal path with cancellation is at least 25 dB, and relatively small additional power consumption and noise. After critical parameters identifying, based on mathematical expressions, the requirements for cancellation blocks parameters are determined. Simplest implementations of the proposed structure are simulated.

KEYWORDS: *Radio transmitters, Receivers, Full-duplex, Self-interference cancellation*.

1 INTRODUCTION

In many wide-bandwidth duplex applications using software defined radio (SDR), the receiver's (RX) bandpass filter is not used. In this case, when using only a duplexer (for example, UE UMTS without RX bandpass filter), the low noise amplifier (LNA) of the receiving path must have higher dynamic range and higher power consumption.

This problem is increasingly being solved using active transmitter signal cancellation in receive signal path [1, 2]. Possibilities for using the cancellation technique are being considered for 5G New Radio Wireless Transceivers [3], for Multiple Input Multiple Output (MIMO) systems [4] and radar applications [5]. There are known solutions for the implementation of individual nodes, such as a delay line [6], filters, etc. Digital applications are being explored [7-9], including in conjunction with analogue [10], for various propagation channels [11] and using neural networks [12].

This article provides a preliminary approach to the problem of active transmitter (TX) signal cancellation in RX signal path with cancellation is at least 25 dB, and relatively small additional power consumption and noise, with integration possibility.

Initial block diagram is shown on Figure 1 and is clear without further description.

The article is organized as follows. In Section 2, preliminary estimation of the main block parameters is carried out under conditions of antenna mismatch. Based on mathematical expressions, the requirements for cancellation blocks parameters are determined. Section 3 develops a usable block diagram of active TX cancellation in RX signal path. In Section 4, the simplest implementations of the proposed structure are simulated. Conclusions on the work are presented in section 5.

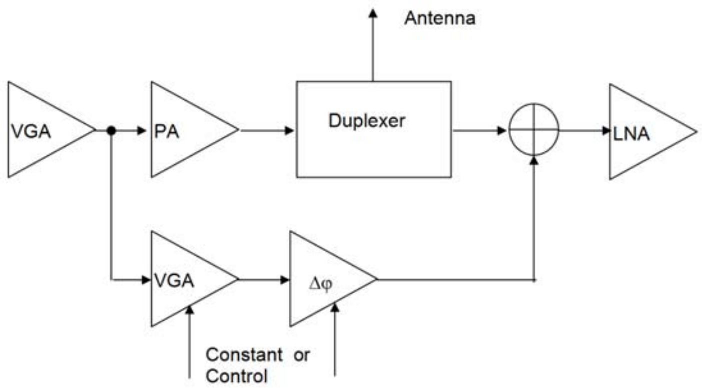

Figure 1. Initial block diagram of active TX cancellation in RX signal path.

2 Preliminary estimation of block parameters

All active block have in-band ripple in amplitude-frequency response and phase response, variable in temperature and supply voltage. Antenna has SWR from 1 to 10, variable in time. Duplexer is most important block for system analysis. We used different models for common parameters study.

2.1 Effect of antenna mismatch

Analysis of antenna mismatch effect was done with Microwave Office (MWO) simulation program. MWO example project “5GHz Diplexer.emp” was used as a duplexer model. An analysis result is shown on Figure 2. TX to RX attenuation is change more than 15 dB at TX frequency band. This large ripple may be compensating only at active and closed cancellation loop. Alternative solution will be offer later at part 3.

2.2 Duplexer simulations

Analysis of duplexer was done with Microwave Office (MWO) simulation program. We used MWO example project “5GHz Diplexer.emp”. Its topology is shown on Figure 3. Analysis results are shown on Figures 4-5.

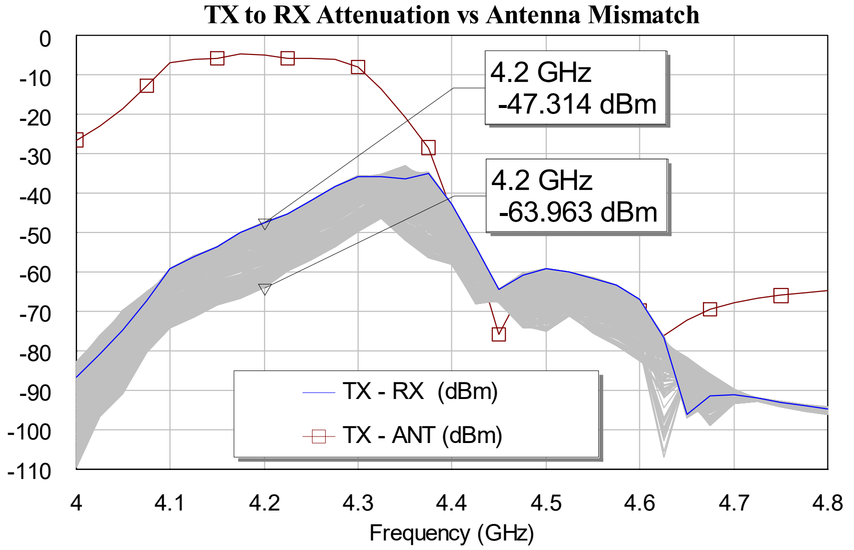

Figure 2. Analysis result of antenna mismatch effect on TX to RX attenuation.

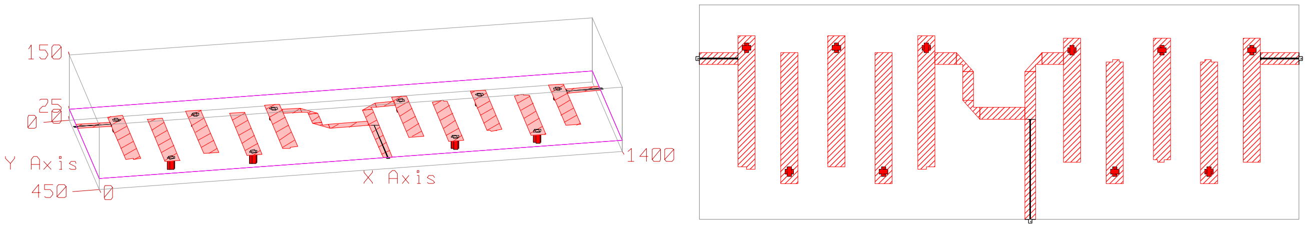

Figure 3. Topology of 5GHz Diplexer.

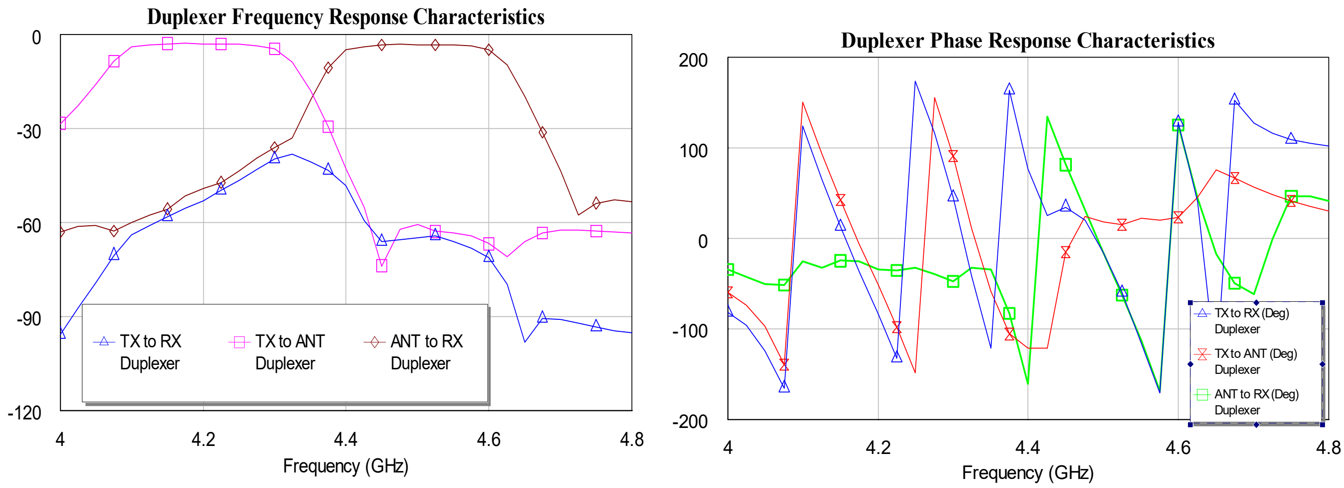

Figure 4. Duplexer frequency and phase response characteristics.

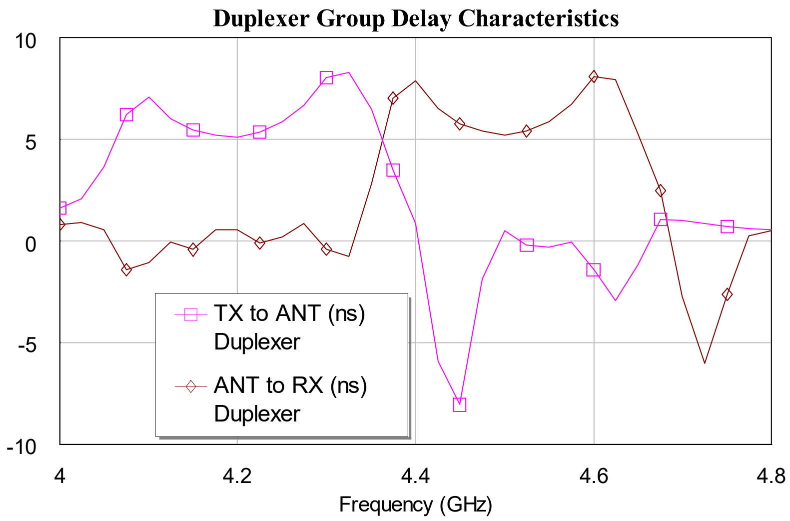

Figure 5. Duplexer group delay characteristics.

Analysis of duplexer model are shown:

- TX to ANT path has big group delay with great ripple in TX frequency band;
- ANT to RX path has small group delay with little ripple in TX frequency band;
- ANT to RX amplitude and frequency response in TX frequency band may be flat with different slope or ripple (depend on filter type - flat or equal ripple characteristic at stop band);
- Selection of duplexer type is possible for simplification of cancellation circuit.

2.3 Cancellation block's requirements

Analysis of duplexers models shown that in addition to amplitude and phase characteristics we mast take into account group delay parameter also. Simplest requirements to cancellation blocks accuracy may be get from trigonometry.

Denote:

C – cancellation, dB, C >0;

φ - phase mismatch, degrees;

ΔG – gain mismatch, dB;

ΔF – frequency offset (half from RF channel bandwidth);

τ - group delay, s;

Δτ-group delay ripple.

Then:

$$C_{(\Delta G)} = -20Log\left|10^{\Delta G/20} - 1\right|;$$

$$C_{(\varphi)} = -20Log\sqrt{2*(1-\cos(2\pi*\varphi/360))};$$

$$C_{(\Delta G,\varphi)} = -20Log\sqrt{(10^{\Delta G/20}-1)^2 + 2*(1-\cos(2\pi*\varphi/360))};$$

$$C_{(\tau)} = -20Log\sqrt{2\cdot(1-\cos(2\pi*\tau*\Delta F))}.$$

For calculation of cancellation depending on group delay ripple we use model, represented on Figure 6.

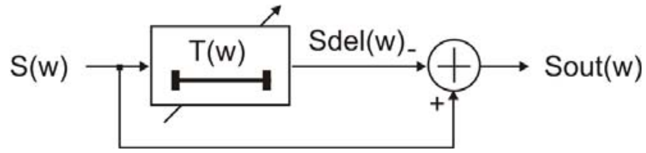

Figure 6. Block diagram of cancellation depending on group delay ripple.

UMTS signal simplified model:

$$S_{(\varpi)} = \sum_{i=-N}^{i=N} (\cos(\omega_i * t) + j\sin(\omega_i * t)) * Shape(\omega_i) \quad ,$$

There: N – number of spectral lines;

$\varpi_i = \varpi_c + \delta\varpi * i$;

ϖ_c - central frequency;

$\delta\varpi = F_{band} * 2 * \pi / (2 * N)$;

F_{band} - UMTS signal band;

$Shape(\varpi_i)$ - UMTS shape filter.

Calculation was executed in case of group delay linear frequency depending (Fig. 7).

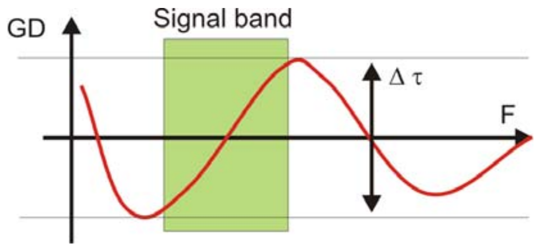

Figure 7. Case of group delay linear frequency depending

$$\tau_{(\varpi)} = \frac{(\varpi_i - \varpi_{\min}) * A}{2 * \pi} - \Delta\tau / 2 ;$$

$$A = \Delta\tau / F_{band} \, .$$

Then delayed signal:

$$Sdel_{(\varpi)} = \sum_{i=-N}^{i=N} (\cos(\omega_i * t + \varphi(\varpi_i)) + j\sin(\omega_i * t)) * Shape(\omega_i + \varphi(\varpi_i)) ;$$

$$\varphi(\varpi_i) = \varpi_i * \tau_{(\varpi)} \, .$$

Cancellation:

$$C_{(\Delta\tau)} = 10 * \log\left(\frac{S^2{}_{(\varpi)}}{(S_{(\varpi)} - Sdel_{(\varpi)})^2}\right) .$$

Graphical dependencies obtained from these equations are shown on Figures 8-12. Analysis shown that for required cancellation (25 dB) we mast have:

Gain mismatch < 0,45 dB;
Phase mismatch < 3 degree;
Delay mismatch <3,5 ns;
Delay ripple <20 ps.
If several factors are affected simultaneously, those requirements must be stronger.

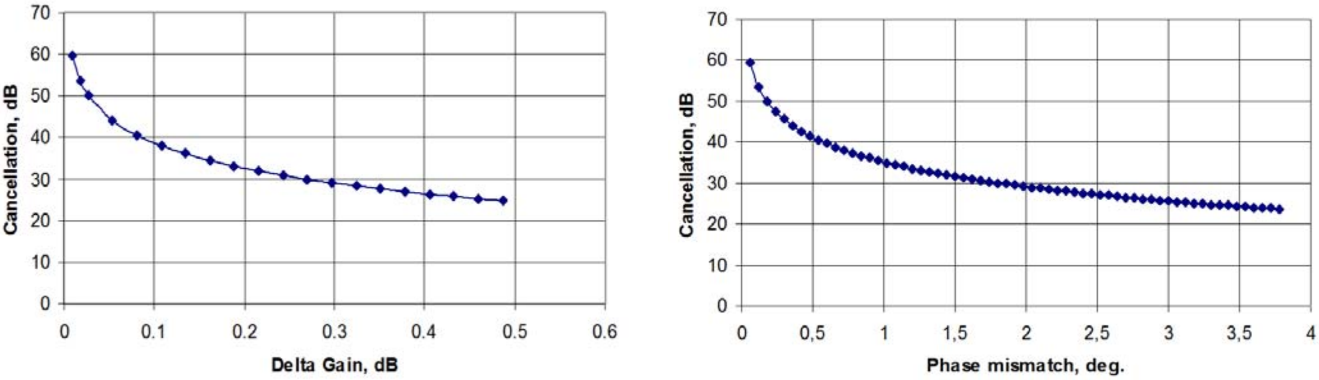

Figure 8. Cancellation vs. Gain and vs. Phase mismatch.

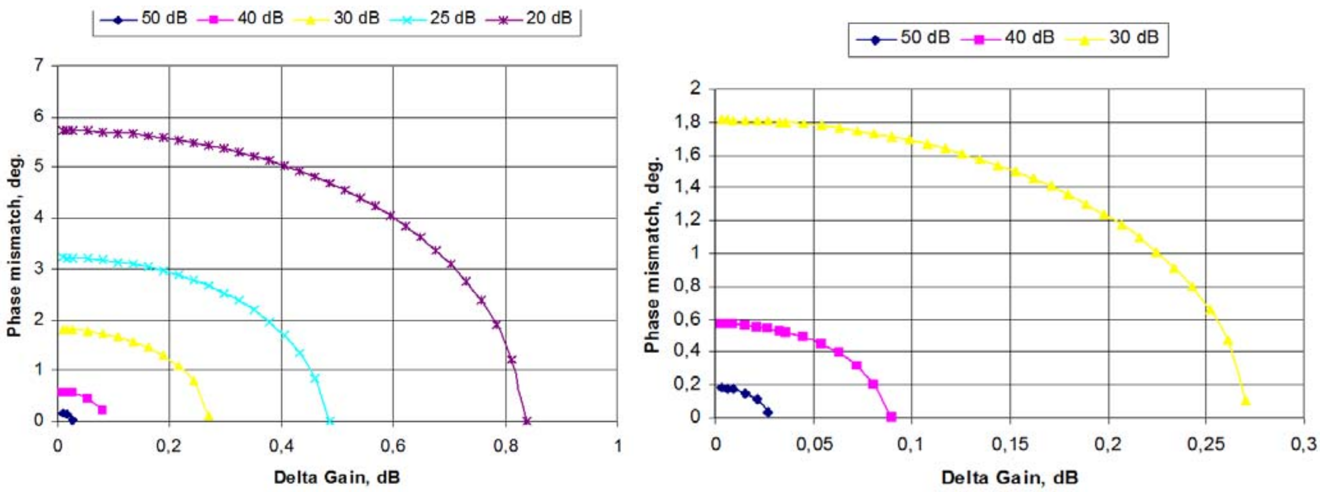

Figure 9. Cancellation vs. Gain and Phase mismatch simultaneously (right graph – enlarged area).

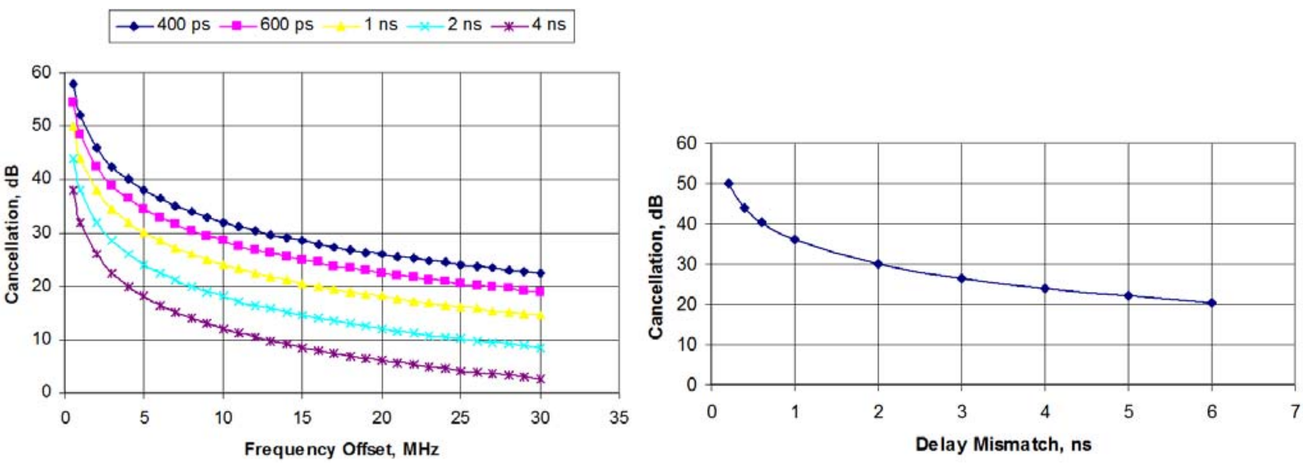

Figure 10. Cancellation vs. Delay mismatch and frequency offset and Cancellation vs. Delay mismatch for UMTS channel.

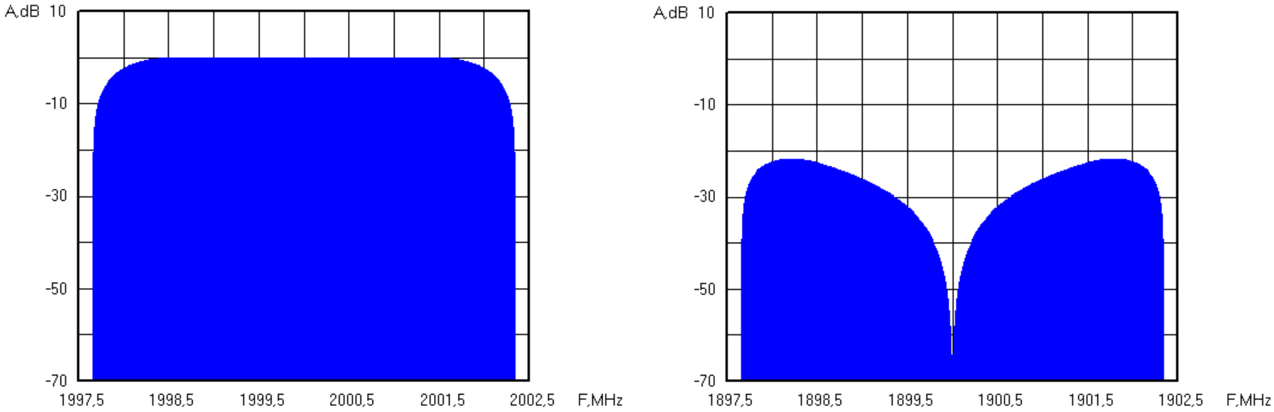

Figure 11. Input and cancelled signals involving group delay ripple (Dt=20ps, C=25dB).

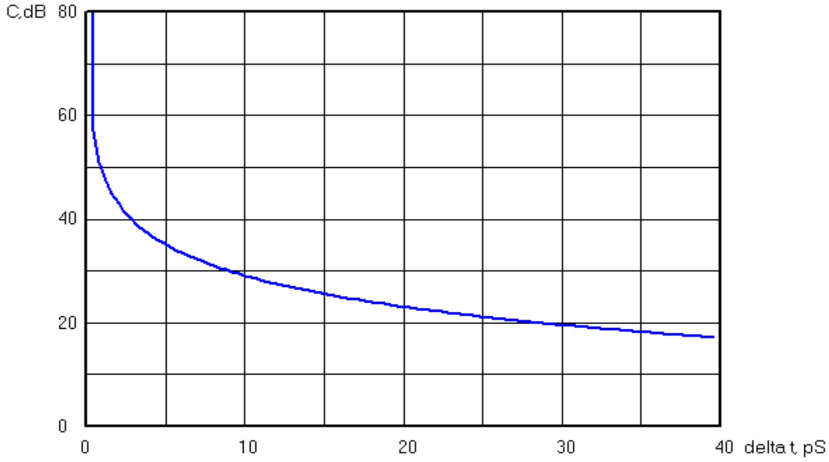

Figure 12. Cancellation vs. group delay ripple for UMTS channel.

3 Block diagram development

According to preliminary estimation of block parameters and cancellation block's requirements, we need add to initial block diagram (Figure 1) variable delay block (Figure 13) with range of delay from 10 to 50 ns. This block diagram is not real practical solution. An alternative solution is proposed in Figure 14.

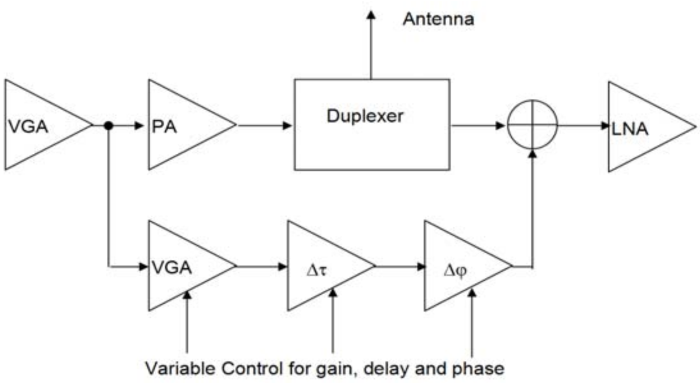

Figure 13. Initial block diagram with additional variable delay block.

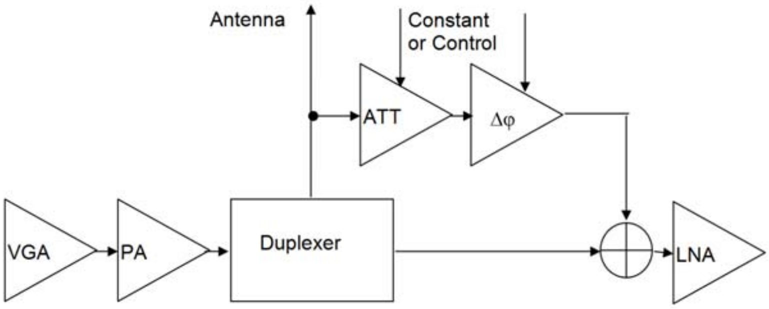

Figure 14. Usable block diagram of active TX cancellation in RX signal path.

Advantages of this block diagram include following:

- Antenna mismatch effect has not effect on cancellation loop therefore closed cancellation loop is not necessary;
- Duplexer group delay on TX frequency in ANT-RX path is small and has little ripple therefore variable delay block is not strongly necessary;
- Cancellation loop may have constant parameters or frequency dependent LUT to control parameters.

Disadvantages:

- Antenna connection needs to be attached.
- Additional input pin in TRX chip.
- End user has to deliver back-signal himself.

If real Duplexer has non-stable and big ripple of attenuation and phase shift on TX frequency in ANT-RX path, closed cancellation loop will be necessary.

4 Cancellation examples

Analysis of cancellation loops with constant parameters was done with Microwave Office (MWO) simulation program. Duplexer model described above were used as an example. A result of simplest RC cancellation example is shown on Figure 15. Results of RLC cancellation example is shown on Figure 16.

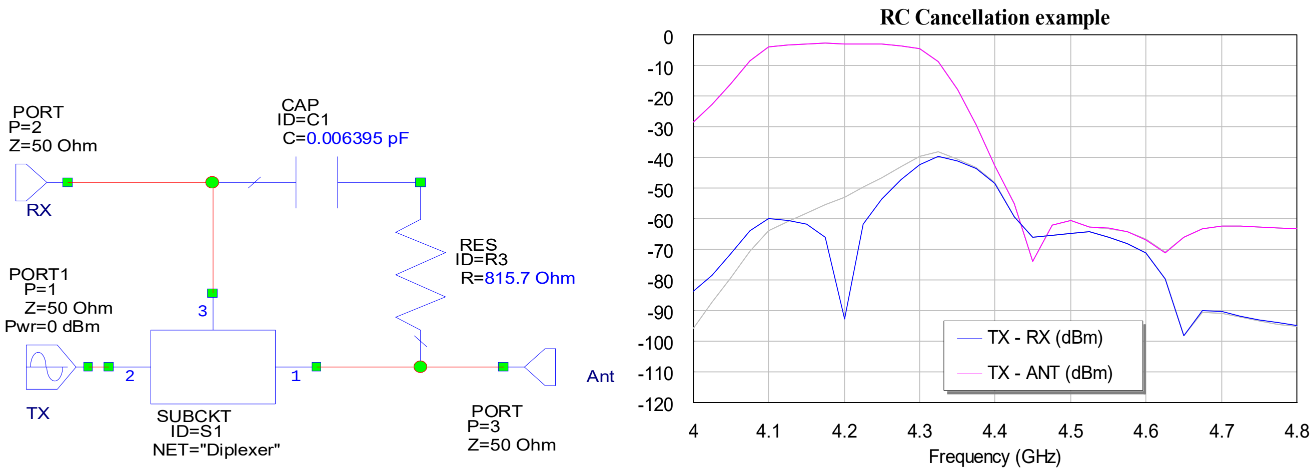

Figure 15. Schematic diagram of RC cancellation and cancellation results of RC example.

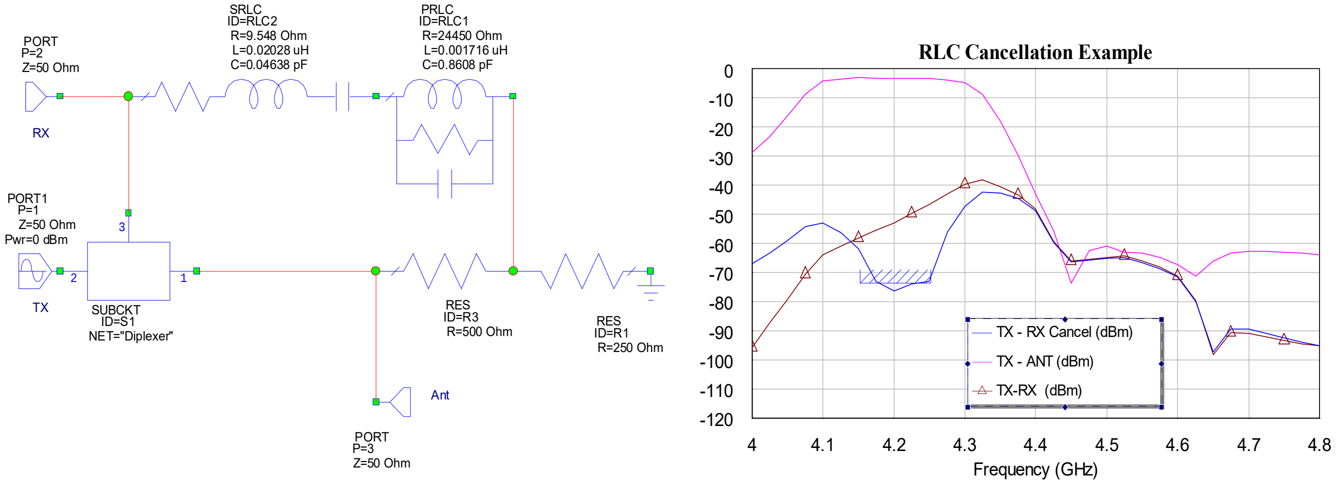

Figure 16. Schematic diagram of RLC cancellation and cancellation results of RLC example.

5 Conclusion

Effect of antenna mismatch was simulated. A duplexer simulation was done. Cancellation block's requirements were elaborated. Analysis shown that for required cancellation (25 dB) following limits are needed:

- Gain error < 0,45 dB;
- Phase mismatch < 3 degree;
- Delay mismatch <3,5 ns;
- Delay ripple <20 ps

Block diagram development was done. The advantages of block proposed diagram are following:

- Antenna mismatch effect has not effect on cancellation loop therefore closed cancellation loop is not necessary;
- Duplexer group delay on TX frequency in ANT-RX path is small and has little ripple therefore variable delay block is not strongly necessary;
- Cancellation loop may have constant parameters or frequency dependent LUT to control its parameters.

A cancellation example was simulated.

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