Digital Cancellation of Nonlinear Self-Interference in Full-Duplex Wireless Transceivers

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***Abstract*—This report presents digital techniques for self-interference signal cancellation in full-duplex wireless transceivers. A new behavioral model using the decomposed vector rotation technique derived from the canonical piecewise-linear functions is employed for building the nonlinear model for RF power amplifiers, and a time-domain representation of band-pass S-parameters with non-uniform components is implemented to construct the channel model, respectively. Computer simulation and experimental test results with related analyses are provided. Results show that very good performance can be achieved by employing the proposed approach in full-duplex operation.**

***Index Terms*—Self-interference cancellation, full-duplex, nonlinear model, channel model**

I. Introduction

WITH the continuous development of information and communications technology, there has been a tremendous growth in the demand for spectrum usage. Full-duplex (FD) technology enables wireless transceivers transmit and receive signal over the same frequency simultaneously. If successfully implemented, it could double spectrum efficiency theoretically. Significant attention, both from industry and academia, has been attracted to this research topic, especially when we are moving towards next generation (5G) communication systems where the spectrum usage will become intensively crowded [1].

An obvious problem owing to simultaneous transmission and reception over the same frequency band is strong self-interference (SI). It contains the signals propagating directly from transmit chain to the receive chain (i.e. direct paths), and the signals reflecting off device-extrinsic scatters (i.e. reflected paths) [2]. In a shared-antenna FD system, as seen in Fig 1, the transmit signal is leaked from Tx to Rx owing to incomplete isolation of circulator while reflected interference is induced by multipath reflection.

Current SI cancellation technologies are operated in three domains: propagation domain, analog domain and digital domain. In digital domain, residual SI after propagation and analog domain cancellation is estimated firstly, and then this reconstructed SI is subtracted from the received signal [2]. Building correct mathematic models that can describe SI is crucial in SI cancellation. In this project we focused on modeling of two vital parts, the nonlinearity of the transmitter power amplifier (PA) and the complex channel model of the circulator between Tx and Rx, and thus to enable effective SI cancellation in digital domain.

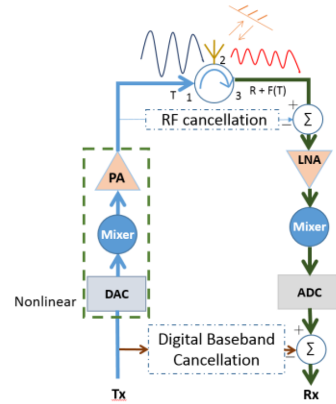

Fig.1 Shared-antenna Full-Duplex System

II. Nonlinear Model

In FD transceivers, PA is the most significant component that induces nonlinear distortion to SI. Correct SI nonlinearity estimation can be achieved by using PA nonlinear model with high accuracy.

There are some nonlinear PA models in FD case being proposed in the literature. These models are more or less based on polynomial or Volterra series. Some inherent limitations, e.g. a large number of variables, and lack of accuracy for strong nonlinear PA, are shown in these models. In this project, we took a completely different approach based on canonical piecewise-linear functions (CPWL) using a decomposed vector rotation (DVR) techniques which was proposed in [3]. This DVR model is built up from the "absolute" operation, which could describe nonlinearity of PA with higher accuracy and fewer parameters. Simulation results are shown in Fig 2, where measured input and output data are from practical class AB PA. The nonlinear behavior of the PA can be accurately characterized by using the DVR model.

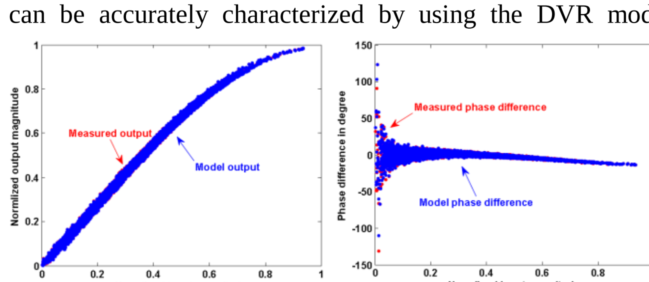

Fig.2 Nonlinear PA model simulation results (AM/AM plot, AM/PM plot)

This work was supported by the MTT-S Undergraduate/Pre-Graduate Scholarships program.
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III. Channel Model

A correct channel model in FD case needs to capture everything between Tx and Rx. It must describe not only direct path through circulator and multipath reflection, but also the propagation and RF analog cancellation. A novel method for time-domain representation of band-pass S-parameters proposed in [4] is operated to model the channel in FD case in this project. This method converts S-parameters into time impulse response containing both uniform and non-uniform components, as shown in Fig 3. Compared with conventional inverse fast Fourier transform (IFFT), it shows much better performance.

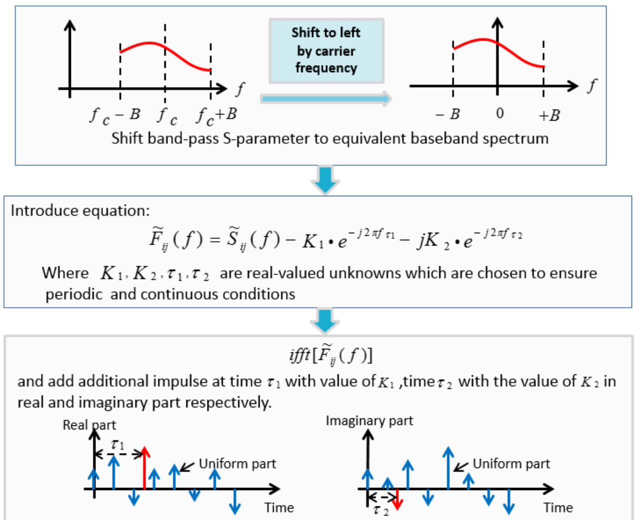

Fig 3. Flowchart for the channel modeling

To verify the performance of this new method and compared with IFFT, measured S-parameters of a simple FD channel, as seen in Fig 4, are converted into time impulse including four uniform and two non-uniform components. Compared with IFFT by using frequency interpolation, time-domain impulse calculated by new method represents S-parameters more accurately, as seen in Fig 5. The RMSE of S-parameters described by uniform and non-uniform time impulse with respect to measured S-parameters is 0.000168, nearly 17 times smaller than RMSE of conventional IFFT, which is 0.0029.

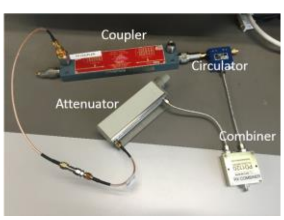

Fig 4. Simplified FD channel test setup

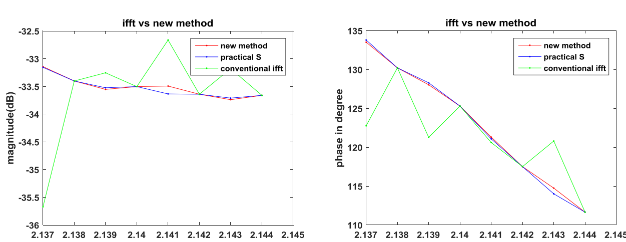

Fig 5. Frequency interpolation results

Further verification is operated by comparing output data of the FD channel with the convolution result of the same practical input data and time impulse converted by the new method. Results show a good agreement between test output and simulation output, as seen in Fig 6. The accuracy of new method is 4 times higher than that using IFFT by calculating RMSE.

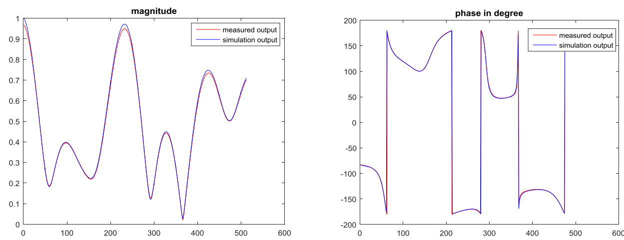

Fig 6. Practical output and simulation results

From above results, we can see that the proposed approach can achieve much better performance than IFFT. To the best of author's knowledge, using uniform and non-uniform time impulse to describe S-parameters is operated first time to model channel in the FD case.

IV. Conclusion

Full-duplex, as a key technology of 5G, attracts increasing attention. SI signal cancellation is the most important topic in the FD field. In this project, we implemented a PA model to describe nonlinearity and used a non-uniform time-domain impulse to describe the channel in FD system. Both models showed high accuracy. Work into model parameter extraction and update will be further conducted in the author's research master project.

Impact of the MTT-S scholarship and future career plan:

MTT-S undergraduate/pre-graduate scholarships gave me the strong sense of achievement and motivated me to put more efforts in my study and research. Attending IMS 2015 was an amazing experience for me. I started to discover more interesting research topics in microwave field. I also had an opportunity to talk with senior PhD students and obtained many useful advices for further study and research.

I am currently studying towards my master degree in microwave field. After completing my master study, I plan to continue my study and research as a PhD student in microwave field.

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