# Frequency-Agile Full-Duplex Digital Self-Interference Cancellation Method Postprint

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**Date:** 2019-01-03T00:00:00+00:00

## Abstract

To address the impact of strong interference on full-duplex system performance in extreme spectral environments, a digital self-interference cancellation method applicable to frequency agility is proposed. An error compensation model within the operating frequency band is obtained through offline computation, and this model is leveraged to generate self-interference channel parameters for frequency-hopping points in real time, thereby reconstructing the self-interference signal and achieving digital cancellation. Numerical simulation results indicate that the proposed method can suppress self-interference below the noise floor across the system' s operating frequency band, while demonstrating high consistency and good convergence characteristics throughout the entire band.

## Full Text

## Preamble

### Digital Self-Interference Cancellation Method for Frequency Agility Full-Duplex System

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**Abstract:** To overcome the effects of intense jamming on full-duplex (FD) systems in extreme spectrum environments, this paper proposes a novel digital self-interference cancellation (DSIC) method adapted for frequency-agile full-duplex systems. The error compensation model for the entire working band is calculated offline and can generate self-interference (SI) channel coefficients in real time to reconstruct the SI signal and accomplish DSIC. Numerical simulation results indicate that the level of the residual SI signal after DSIC remains below the noise floor across the full band, demonstrating the consistency and convergence of the proposed method at different frequency points.

**Keywords:** digital self-interference cancellation (DSIC); frequency agility; full duplex (FD)

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## 0 Introduction

The rapid development of wireless communications has led to increasingly demanding spectrum requirements and intensifying spectrum competition, while traditional communication systems generally suffer from low spectral efficiency. In recent years, co-time co-frequency full-duplex technology has gradually attracted attention and achieved significant progress. This technology enables simultaneous transmission and reception on the same frequency, thereby doubling spectral efficiency [1]. This advantage has made co-time co-frequency full-duplex a focal point for research in both academia and industry.

The core challenge in co-time co-frequency full-duplex systems is self-interference cancellation, which is addressed across three domains: spatial [2], RF [3,4], and digital [5], with these three domains working collaboratively to suppress self-interference [6]. However, existing literature primarily focuses on scenarios with fixed frequency points, fixed bandwidth, and relatively low external interference. In extreme spectrum conditions—such as natural environments or adversarial settings with 突发性 (burst) and random strong in-band interference—these disturbances can severely degrade system performance to the point where fixed-frequency, fixed-bandwidth full-duplex systems cannot operate effectively. Frequency-agile co-time co-frequency full-duplex systems offer a viable countermeasure, enabling the system to flexibly adjust its operating frequency within a certain bandwidth to avoid strong interference bands when such problems arise.

Nevertheless, in this operating mode, changes in the working subband alter the in-band channel characteristics, consequently modifying the self-interference signal. Current mainstream digital self-interference cancellation techniques, such as self-interference signal estimation and reconstruction [7,8], adaptive filtering [9], and auxiliary-receiver-chain-based digital self-interference cancellation [5,10], require re-estimation of the self-interference signal and thus struggle to meet the effectiveness and real-time requirements for self-interference cancellation in dynamic frequency-agile full-duplex scenarios.

To address these challenges, this paper proposes a frequency-agile digital self-interference cancellation (DSIC) method that offline constructs a self-interference channel response model across the agile operating band. By obtaining channel response parameters at discrete frequency points, the method derives a response compensation model for the entire passband. This approach completes the estimation of full-band channel characteristics offline, then provides real-time channel characteristic information corresponding to frequency agility during online operation, enabling self-interference cancellation at any frequency point within the passband to meet the requirements of co-time co-frequency full-duplex systems under frequency agility.

## 1 System Model

The system model is illustrated in [Figure 1: see original paper]. In Figure 1(a), the baseband generates a transmitted signal that undergoes processing by the transmit chain to produce an RF signal. After passing through the circulator, this signal is transmitted by the antenna. The signal received by the receive chain contains both the desired signal from the remote end and the self-interference signal leaked from the circulator. Following RF self-interference suppression, the resulting signal is processed by the digital self-interference cancellation module, which jointly uses this signal and the transmit chain baseband signal to generate an estimated signal for cancellation, yielding the final output signal.

Figure 1(b) depicts the agility model. When the signal traverses the RF chain, switching frequency points causes the channel response to change, meaning the corresponding channel parameters vary. This paper aims to obtain prior information about the entire passband' s channel response characteristics before the co-time co-frequency full-duplex system begins operation, thereby establishing an error compensation model. When frequency agility is required, the system can promptly extract channel response estimation parameters for the new frequency point through this model, ensuring effective and real-time self-interference cancellation.

Any fixed-frequency channel response estimation algorithm can be selected for establishing the model at each discrete frequency point in the frequency-agile dynamic scenario. Let the frequency agility range be $[f_1, f_N]$, and let the baseband signal after transmission and reception be defined as $y[n]$. In offline operation (i.e., with no received desired signal), the system uses an estimation algorithm (such as LS) to obtain a channel response estimation parameter sequence for frequency point $f_i$:

$$\mathbf{h}^{(i)} = \left[h_0^{(i)}, h_1^{(i)}, \dots, h_{M-1}^{(i)}\right]^T$$

where $M$ is the estimation length. With a subband spacing of $\Delta f$, generating $N$ uniformly distributed frequency points, the above process is repeated for each frequency point to obtain channel response estimation parameters for different frequencies:

$$\mathbf{H} = \left[\mathbf{h}^{(1)}, \mathbf{h}^{(2)}, \dots, \mathbf{h}^{(N)}\right] \in \mathbb{C}^{M\times N}$$

Normalizing the $N$ frequency points to the interval $[-0.5, 0.5]$ and taking the $m$-th column of $\mathbf{H}$, polynomial fitting yields the polynomial fitting curve for the

$m$-th order channel response estimation parameter across different frequency points:

$$G_m(k_f) = \sum_{p=0}^{P} a_{m,p} \cdot k_f^p$$

where $k_f \in [-0.5, 0.5]$ is the normalized frequency, $P$ is the polynomial fitting order, and $a_{m,p}$ are the polynomial coefficients. This enables rapid calculation of channel response estimation values for any frequency point within the agile frequency range.

Self-interference in co-time co-frequency full-duplex systems originates primarily from the RF channel. For systems with shared transmit/receive antennas, the main self-interference sources include circulator leakage and antenna reflection [11]. Therefore, offline modeling of the wired channel response characteristics across the agile passband can fully characterize self-interference information, and the corresponding compensation model ensures the system meets self-interference suppression requirements.

Consider a linear system where the self-interference signal is modeled using a memory polynomial. Let the additive white Gaussian noise (AWGN) in the receive chain be $\mu[n]$, the desired received signal be $r[n]$, and the baseband signal from the receive chain be $y'[n]$. The signal can be expressed as:

$$y'[n] = \sum_{m=0}^{M-1} h_m x[n-m] + r[n] + \mu[n]$$

where $h_m$ represents the channel response parameters. The digital self-interference cancellation module estimates these parameters as $\hat{h}_m$ and reconstructs the self-interference signal:

$$\hat{y}'[n] = \sum_{m=0}^{M-1} \hat{h}_m x[n-m]$$

Subtracting this from $y'[n]$ yields the cancelled signal $z[n]$:

$$z[n] = y'[n] - \hat{y}'[n] = \sum_{m=0}^{M-1} (h_m - \hat{h}_m) x[n-m] + r[n] + \mu[n]$$

The first two terms on the right side represent the residual self-interference (residual SI) after DSIC:

$$r_{\mathrm{SI}}[n]=\sum_{m=0}^{M-1}(h_m-\hat{h}_m)x[n-m]$$

Accurate acquisition of channel response parameter estimates is the core of signal estimation and reconstruction-based digital self-interference cancellation algorithms. For fixed frequency points, numerous algorithms have been studied, including least squares (LS), recursive least squares (RLS), and minimum mean square error (MMSE) criteria. However, for dynamic frequency-agile scenarios, relevant literature and work are scarce. This paper proposes a frequency-agile digital self-interference cancellation method to address the self-interference suppression problem under frequency agility.

## 2 Frequency-Agile Digital Self-Interference Cancellation

The proposed method comprises offline and online processes. The offline process establishes a response compensation model across the entire working band, while the online process utilizes this model to extract compensation parameters in real time for self-interference cancellation.

The algorithm proceeds as follows. First, during the offline initialization, the system configures the working band, subband spacing, and number of subbands, and generates baseband transmitted signals $x[n]$. Second, the offline process selects different subbands as RF transmission bands, obtains the baseband signal $y_i'[n]$ from the receive chain, and uses $x[n]$ and $y_i'[n]$ to estimate the channel response parameter sequence $\mathbf{h}^{(i)}$ for each band. Third, with $N$ subbands and $M$ channel response estimation parameters per subband, the process repeats to acquire all subband channel response estimation parameters $\mathbf{H}$. The parameter sequences are divided into $M$ groups by parameter position, and each group undergoes polynomial fitting to obtain $M$ fitting curves $G_m(k_f)$. Finally, during online operation, the system selects a working frequency $f_k$, uses the parameter curve set obtained in the offline process to calculate the corresponding band' s channel response parameters $\mathbf{h}(f_k)$, estimates the self-interference signal $\hat{y}'[n]$, and completes digital cancellation to obtain the final signal $z[n]$.

## 3 Numerical Simulation and Analysis

Based on the proposed scheme, the LS criterion is selected as the discrete frequency point self-interference estimation algorithm, and numerical simulations are conducted using MATLAB. The main parameters are listed in . Considering the variation in channel response across different frequency points in the circuit and circulator characteristics, a special FIR bandpass filter with poor in-band flatness and a passband of 1-1.5 GHz is generated in the simulation to characterize the channel response across the agile working band. The filter has 49 taps, and its characteristics are shown in [Figure 2: see original paper].

First, digital self-interference cancellation at a specific frequency point within the agile passband is considered. With no desired signal present during the offline process ($r[n] = 0$), the LS criterion estimates a parameter sequence $\mathbf{h}$ of length $M$ and the estimated signal $\hat{y}'[n]$. The cancellation performance is evaluated using the digital cancellation ratio (DCR), defined as the level of digital self-interference suppression in dB:

$$\mathrm{DCR} = \mathrm{Power}_{\mathrm{Before\ DSIC}} - \mathrm{Power}_{\mathrm{After\ DSIC}}$$

[Figure 3: see original paper] shows the relationship between the estimation length $M$ and DCR at different frequency points within the working band. In this simulation, $M$ is selected to achieve approximately 70 dB cancellation at each frequency point.

The offline process obtains channel response parameter sequences for 51 uniformly distributed frequency points across the working band. These sequences are polynomially fitted according to the aforementioned rules to acquire the fitting curve set $G_m(k_f)$. [Figure 4: see original paper] illustrates the relationship between the polynomial fitting order $P$ and DCR, tested at new frequency points 10 MHz away from those in [Figure 3: see original paper]. The results demonstrate that when $P = 21$, the new test frequency points achieve approximately 70 dB self-interference suppression.

During online operation, the desired received signal (Received SoI) is added to the signal. The polynomial-generated estimation parameters from the offline process are used for digital self-interference cancellation. The simulation results are shown in [Figure 5: see original paper], where (a) displays the baseband spectrum at the RF working frequency $f = 1.46$ GHz, achieving approximately 70 dB self-interference suppression with the residual SI below the noise floor, and (b) shows the constellation diagram of the desired signal before and after DSIC, proving the effectiveness of the method.

Full-band simulation results are presented in [Figure 6: see original paper], where the horizontal axis represents normalized frequency and the vertical axes show error vector magnitude (EVM) and DCR, respectively. Figure 6: see original paper shows that the proposed method controls EVM at approximately 8% with about 70 dB self-interference suppression across the entire working band, consistent with the suppression achieved through direct estimation in the offline process. In contrast, DSIC with fixed parameters only performs well at certain points while performing poorly at others. These results demonstrate the consistency and effectiveness of the proposed algorithm across the full working band.

## 4 Conclusion

This paper addresses the performance degradation in digital self-interference cancellation caused by channel response variations in frequency-agile scenarios, which lead to large errors in reconstructed self-interference signals. The proposed method offline constructs a response compensation model across the entire working band and uses this model to extract compensation parameters in real time during frequency agility to reconstruct and cancel the self-interference signal. By completing the response model establishment offline, the method avoids parameter re-estimation during online frequency agility, satisfying the timeliness requirements for self-interference cancellation in dynamic scenarios. Numerical simulation results demonstrate effective suppression at any frequency point within the passband. Future work includes further algorithm optimization and experimental validation on actual systems.

## References

[1] Zhang Zhongshan, Long Keping, Vasilakos A V., et al. Full-duplex wireless communications: challenges, solutions, and future research directions [J]. Proceeding of the IEEE, 2016, 104(7): 1369-1409.

[2] Jasim A A, Younus K M. Ali A, et al. A simple self-interference cancellation technique for full duplex communication [C]//Proc of Internet Technologies and Applications. 2017: 224-229.

[3] Kim J, Choi W, Park H. Beamforming for full-duplex multiuser MIMO systems [J]. IEEE Trans on Vehicular Technology, 2017, 66(3): 2360-2373.

[4] Han Xiuyou, Huo Bofan, Shao Yuchen, et al. RF self-interference cancellation using phase modulation and optical sideband filtering [J]. IEEE Photonics Technology Letters, 2017, 29(11): 917-920.

[5] Li Jiong, Zhang Hang, Fan Menglan. Digital self-interference cancellation based on independent component analysis for co-time co-frequency full-duplex communication systems [J], IEEE Access, 2017, 5: 10222-10231.

[6] Li Chenxing, Zhao Hongzhi, Wu Fei, et al. Digital self-interference cancellation with variable fractional delay FIR filter for full-duplex radios [J]. IEEE Communications Letters, 2018, 22(5): 1082-1085.

[7] Tian Lu, Wang Shuai, Cheng Zhiheng, et al. All-digital self-interference cancellation zero-if full-duplex transceivers [J]. China Communication, 2016, 13(11): 27-34.

[8] Wang Dan, Huang Kaizhi, Li Yunzhou. Digital cancellation algorithms of in-band full duplex [J]. Application Research of Computers, 2016, 33(8): 2241-2245.

[9] Roberto L V, Emilio A R, Carlos M, et al. An adaptive feedback canceller for full-duplex relays based on spectrum shaping [J]. IEEE Journal on Selected Areas in Communications, 2012, 30(8): 1566-1577.

[10] Ahmed E, Eltawil A M. All-digital self-interference cancellation technique for full-duplex systems [J]. IEEE Trans on Wireless Communications. 2015,

14(7): 3519-3532.

[11] Tang Youxi. No division duplex [M]. Beijing: Science Press, 2016: 17.

*Note: Figure translations are in progress. See original paper for figures.*