Frequency-Selective Joint T x/Rx I/Q Imbalance Estimation Using Golay Complementary Sequences

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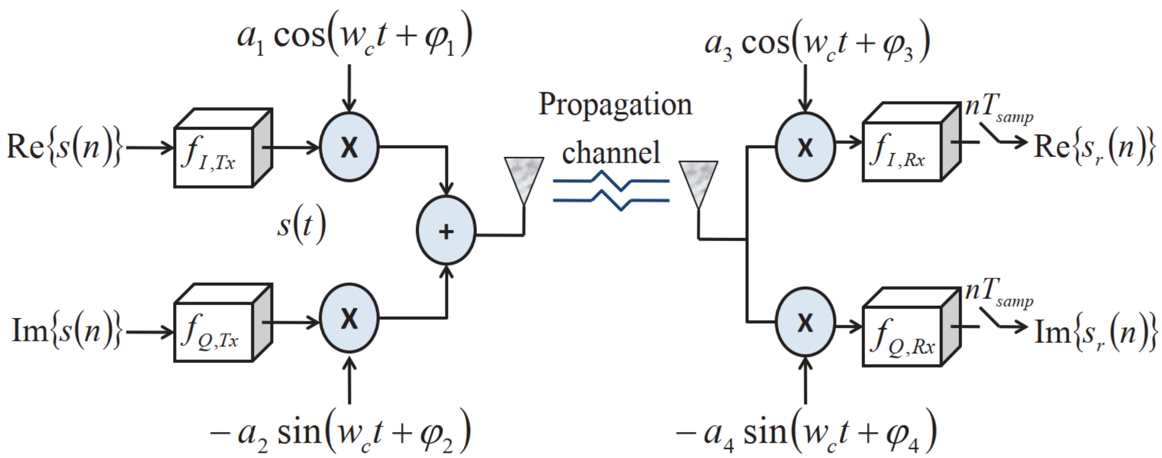
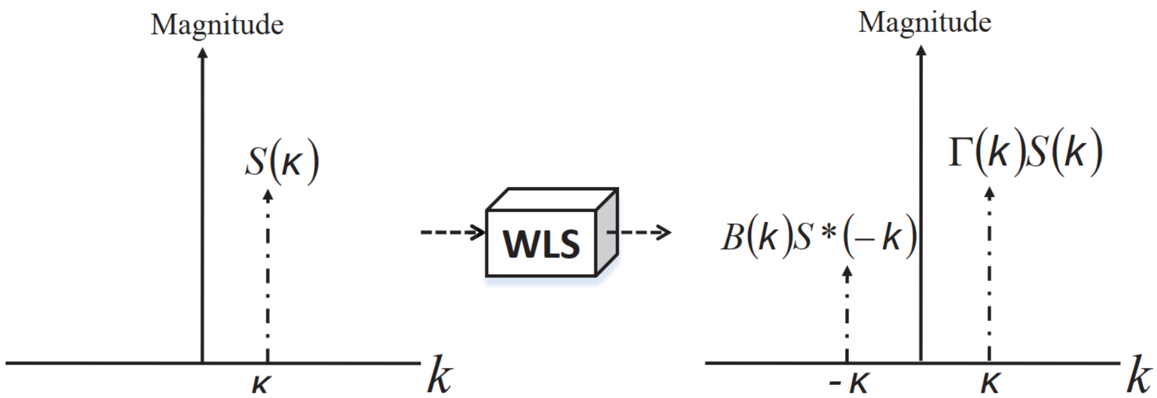
Abstract

- TRX Modeling
  - 

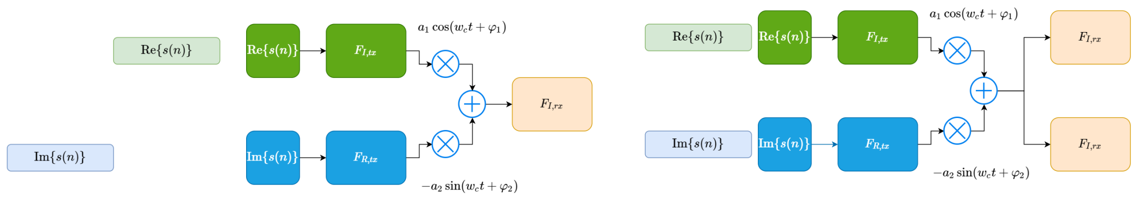
  - $s_r(n) = (\gamma_{Tx}(n) * \gamma_{Rx}(n) * h(n) + \beta^*_{Tx}(n) * \beta_{Rx}(n) * h^*(n)) * s(n) \, (\gamma_{Rx}(n) * \beta_{Tx}(n) * h(n) + \beta_{Rx}(n) * \gamma^*_{Tx}(n) * h^*(n)) * s^*(n) + \gamma_{Rx}(n) * \eta(n) + \beta_{Rx}(n) * \eta^*(n)$
    $$\gamma_{Tx}(n) = \frac{f_{L,Tx}(n) + g_{Tx} e^{j\varphi_{Tx} f_{Q,Tx}(n)}}{2}$$
    $$\beta_{Tx}(n) = \frac{f_{I,Tx}(n) - g_{Tx} e^{j\varphi Tx} f_{Q,Tx}(n)}{2}$$
  - $$\gamma_{Rx}(n) = \frac{f_{I,Rx}(n) + g_{Rx} e^{-j\varphi_{Rx} f_{Q,Rx}(n)}}{2}$$
    $$\beta_{Rx}(n) = \frac{f_{I,Rx}(n) - g_{Rx} e^{j\varphi_{Rx} f_{Q,Rx}(n)}}{2}$$
- Response of The model
  -



- DFT representation:
  - $S_r(k) = \Gamma(k)S(k) + B(k)S^*(-k)$
  - $\Gamma_{Tx}(k) = \frac{F_{I,Tx}(k)+g_{Tx}e^{f\phi Tx}F_{Q,Tx}(k)}{2}$
    $B_{Tx}(k) = \frac{F_{I,Tx}(k)-g_{Tx}e^{j\varphi Tx}F_{Q,Tx}(k)}{2}$
    $\Gamma_{Rx}(k) = \frac{F_{I,Rx}(k)+g_{Rx}e^{-j\varphi_{Rx}}F_{Q,Rx}(k)}{2}$
    $B_{Rx}(k) = \frac{F_{I,Rx}(k)-g_{Rx}e^{j\varphi_{Rx}}F_{Q,Rx}(k)}{2}$

- Estimation and Compensation in Frequency Domain
  - $\begin{bmatrix} S_r(k) \\ S_r^*(-k) \end{bmatrix} = \begin{bmatrix} \Gamma & B \\ B^* & \Gamma^* \end{bmatrix} \begin{bmatrix} S(k) \\ S^*(-k) \end{bmatrix} = \mathbf{D} \begin{bmatrix} S(k) \\ S^*(-k) \end{bmatrix}$
  - $S(k) = F_1 S_r(k) + F_2 S_r^*(-k)$
  - $F_1 = \frac{\Gamma^*}{|\Gamma|^2-|B|^2}, F_2 = \frac{-B}{|\Gamma|^2-|B|^2}$
  - $F_1(k) = \frac{\Gamma^*(-k)}{\Gamma(k)\Gamma^*(-k)-B(k)B^*(-k)}, F_2(k) = \frac{-B(k)}{\Gamma(k)\Gamma^*(-k)-B(k)B^*(-k)}$
- Golay Complementary Sequence
  - $S_{aL}(n) \odot S'_{qL}(n) + S_{bL}(n) \odot S'_{bL}(n) = 0_L$
  - $S_{aL}(n) \odot S'_{bL}(n) + S_{bL}(n) \odot S'_{aL}(n) = 0_L$
  - $S_{aL}(n) \odot S_{aL}(n) + S_{bL}(n) \odot S_{bL}(n) = 2_L$
  - $S'_{qL}(n) = S_{aL}(L-n-1)$
- Receiving Using GCS Training
  - Receiving model:
    - $S_{ra}(k) = \Gamma(k)S_a(k) + B(k)S'_a(k), S_{rb}(k) = \Gamma(k)S_b(k) + B(k)S'_b(k)$
  - Estimation algorithm
    - $\Gamma(k) = \frac{1}{2}\{S_{ra}(k) \odot S_a(k) + S_{rb}(k) \odot S_b(k)\},$
    - $B(k) = \frac{1}{2}\{S_{ra}(k) \odot S'_a(k) + S_{rb}(k) \odot S'_h(k)\}$
  - Derivation:
    - $C_a(k) = S_{ra}(k) \odot S_a(k), C_b(k) = S_{rb}(k) \odot S_b(k)$
    - $C_a(k) + C_b(k) = \Gamma(k)[S_a(k) \odot S_a(k) + S_b(k) \odot S_b(k)] + B(k)[S'_a(k) \odot S_a(k) + S'_b(k) \odot S_b(k)] = 2\Gamma(k)$
    - $D_a(k) = S_{ra}(k) \odot S'_a(k), D_b(k) = S_{rb}(k) \odot S'_b(k)$
    - $D_a(k) + D_b(k) = \Gamma(k)[S_a(k) \odot S'_a(k) + S_b(k) \odot S'_b(k)] + B(k)[S_a(k) \odot S_a(k) + S_b(k) \odot S_b(k)] = 2B(k)$

KC Quick Summary

- Consider jointly Tx-FSIQ, Channel Effect, RX-FSIQ response estimation in frequency domain.
  - Can not decouple TX and RX responses
- Golay Complementary Sequence in frequency domain to reduce the multiplier and matrix inversion requirement.
- Golay Sequence has low PAPR(2dB) effect, PA distortion will not contribute significant interference the estimation process.
- This approach can be treated as enhancement of multiple-tone approach:
  - Less PAPR
  - Simple Estimation.
- Issues:
  - Can not decouple TX and RX mismatches.
  - When consider CFO between TX and RX, it will affect the estimation and compensation model error
- Suitable for closed-loop self-calibration. But need to derive the TX/RX calibration separately.
- Possible approach:
  - TX sends I path and Q path separately in two symbol, using single RX path to eliminate RXIQmismatch, calibrate TX.
  - Do TX pre-distortion (in time domain or frequency domain), compensate TX, and calibrate RX using IQTX signal.
  - Covert calibration results into **time domain** filter model.
  - Equivalence model of time multiplexing calibration
    - 

  - Procedure:
    - TX calibration:
      - decide rx gain
      - tx i path sig and save
      - tx q path sig and save
      - estimate distortion model
    - RX calibration:
      - decide TX gain
      - tx i/q signal with tx compensation
      - receive signal and estimate distortion model
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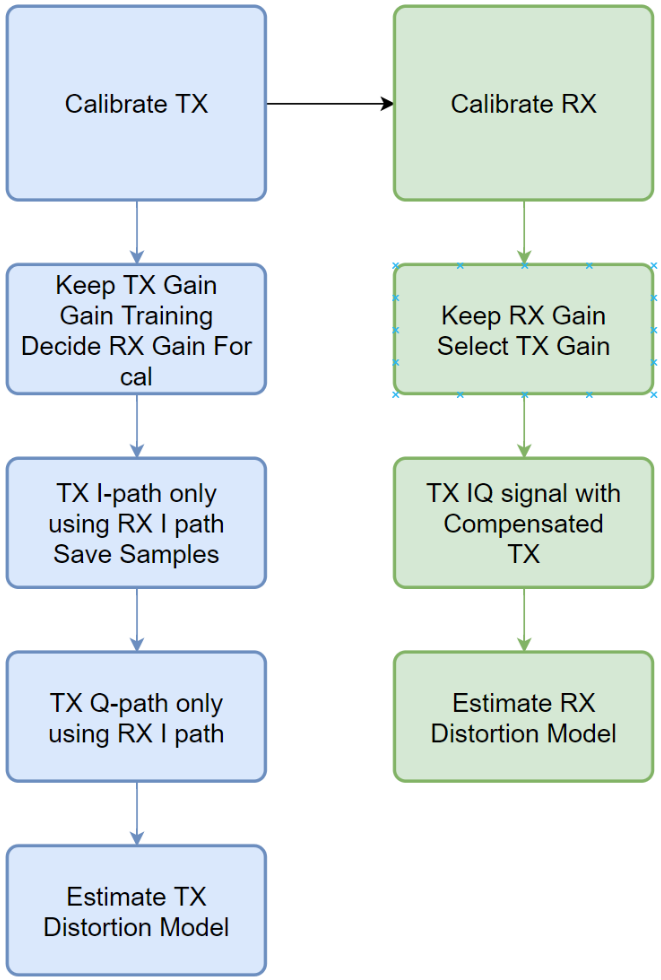

- Also can calibrate RX by single TX path as following: