FMCW Radar Principle

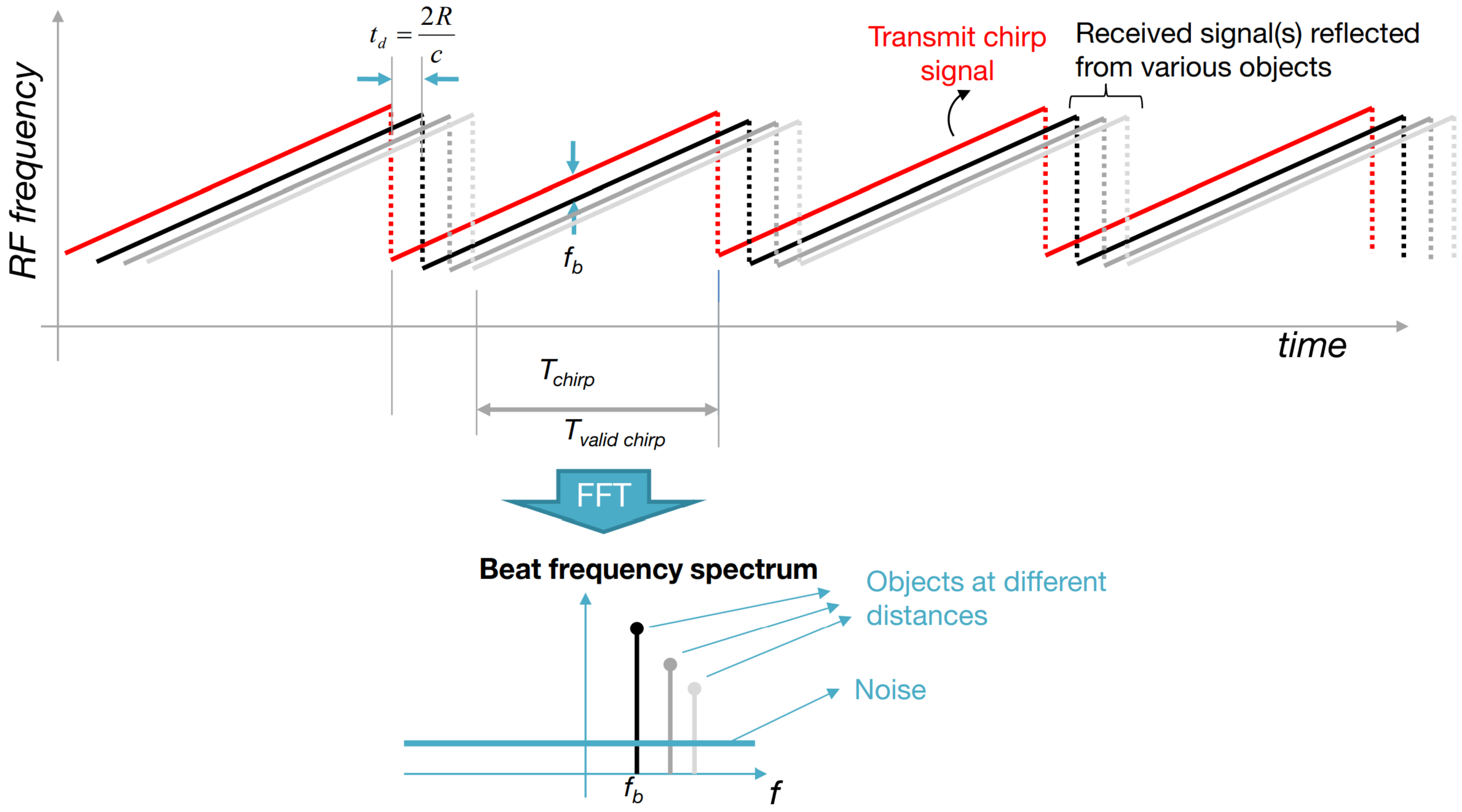


Image took from Complex base band arch. For FMCW radar systems (Auto) - IQ (ti.com)

Range Correlation Effect on the phase noise

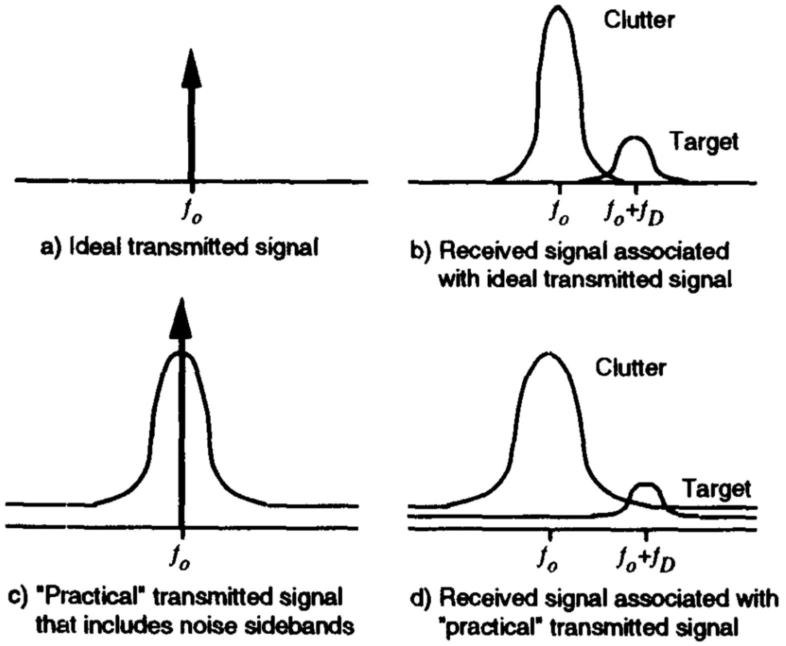


Figure 1 - Transmitted and Received Signal Spectra

$$S_x(f,R) = P_r(R)C(f) + P_r(R)C(f) * S_\phi(f)\left[4\sin^2 2\pi Rf/c\right]$$

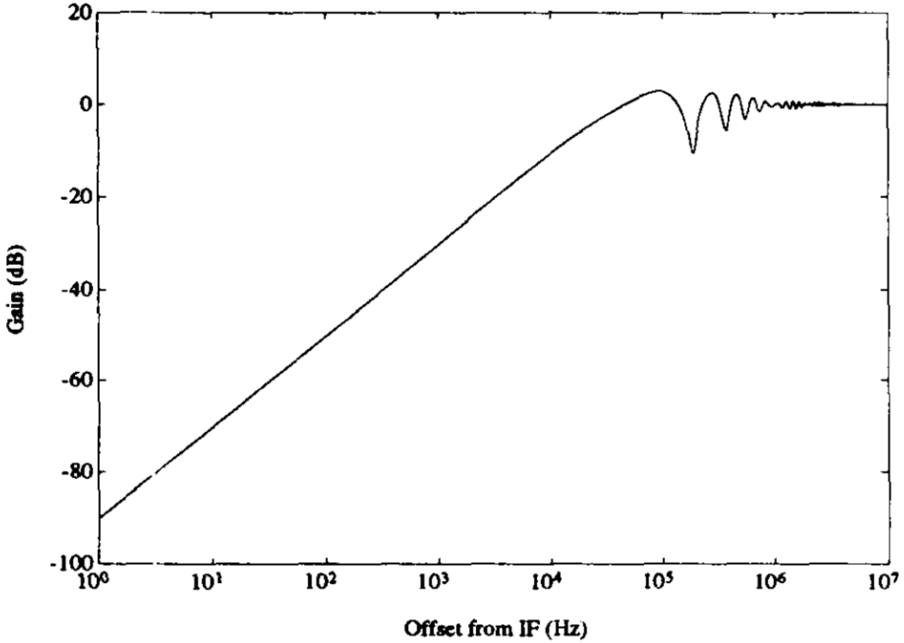


Figure 3 - Range Correlation Filter Effects

M. C. Budge and M. P. Burt, "Range correlation effects in radars," The Record of the 1993 IEEE National Radar Conference, 1993, pp. 212-216, doi: 10.1109/NRC.1993.270463.

Interference Identification for FMCW system

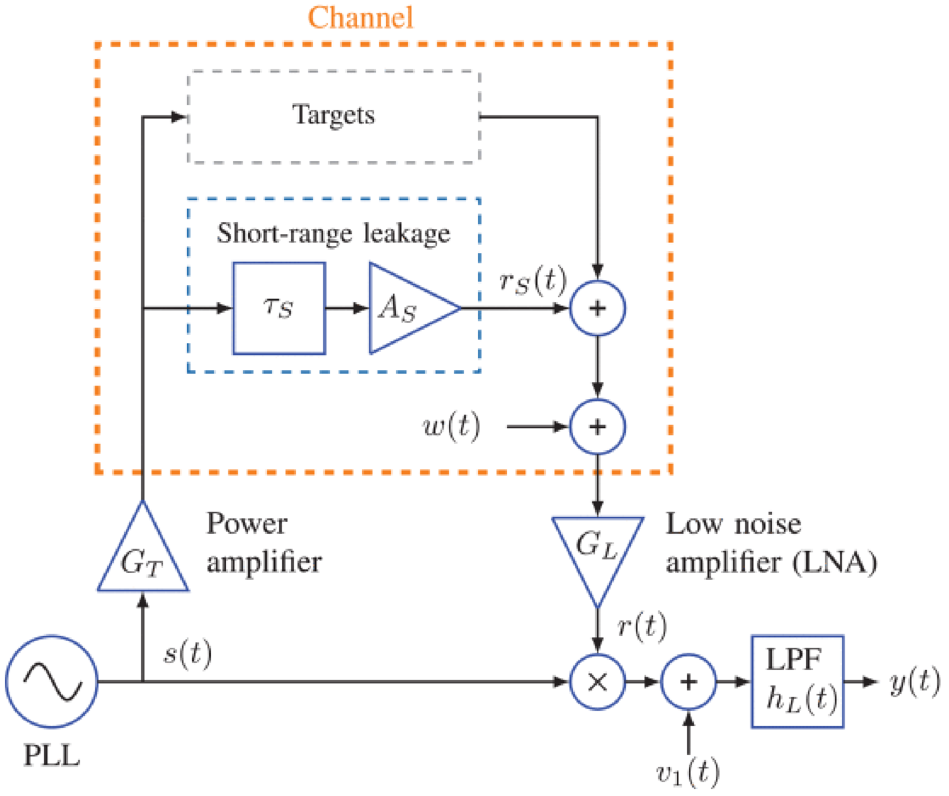
- Deterministic Interferences:

1. Short Range (SR) Reflection from the unwanted nearby reflectors – Digital or mixed-signal cancellation
2. On-chip Leakage from Tx to Rx due to limited isolation – RF or digital cancellation

- Stochastic Interferences:

1. Decorrelated Phase Noise due to PLL of the transmitter itself mixing with the reflected SR signal – Digital or mixed-signal cancellation
2. Decorrelated Phase Noise due to PLL of the transmitter itself mixing with the reflected target signal - Can ignore since its magnitude is too small.

Leakage cancellation scheme – noise model



In this diagram, short-range Leakage is the sum of:

- (unwanted) nearby stationary reflector (signal + phase noise). The phase noise shows up in band after down-conversion.
- On-chip leakage. The worry here is mainly the leaked signal rather than phase noise.

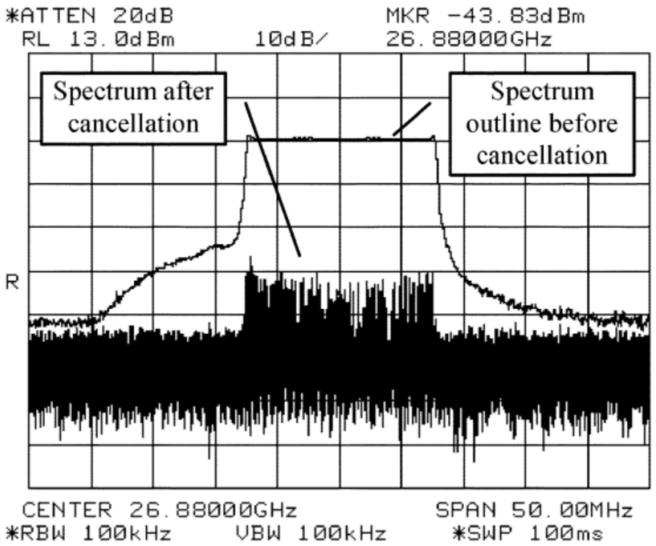
$$
\begin{aligned}
&y(t)\\
&\cong \mathbb{G}\Big[A_S \cos\big(\omega_s t + \Phi_s + \varphi_{PLL}(t) - \varphi_{PLL}(t-\tau_s)\big)\\
&+ A_{onchip} \cos\Big(\omega_{onchip} t + \Phi_{onchip} + \varphi_{PLL}(t) - \varphi_{PLL}\big(t-\tau_{onchip}\big)\Big)\\
&+ \sum(desired\ target\ signals)\Big] + Additive\ Noise
\end{aligned}
$$

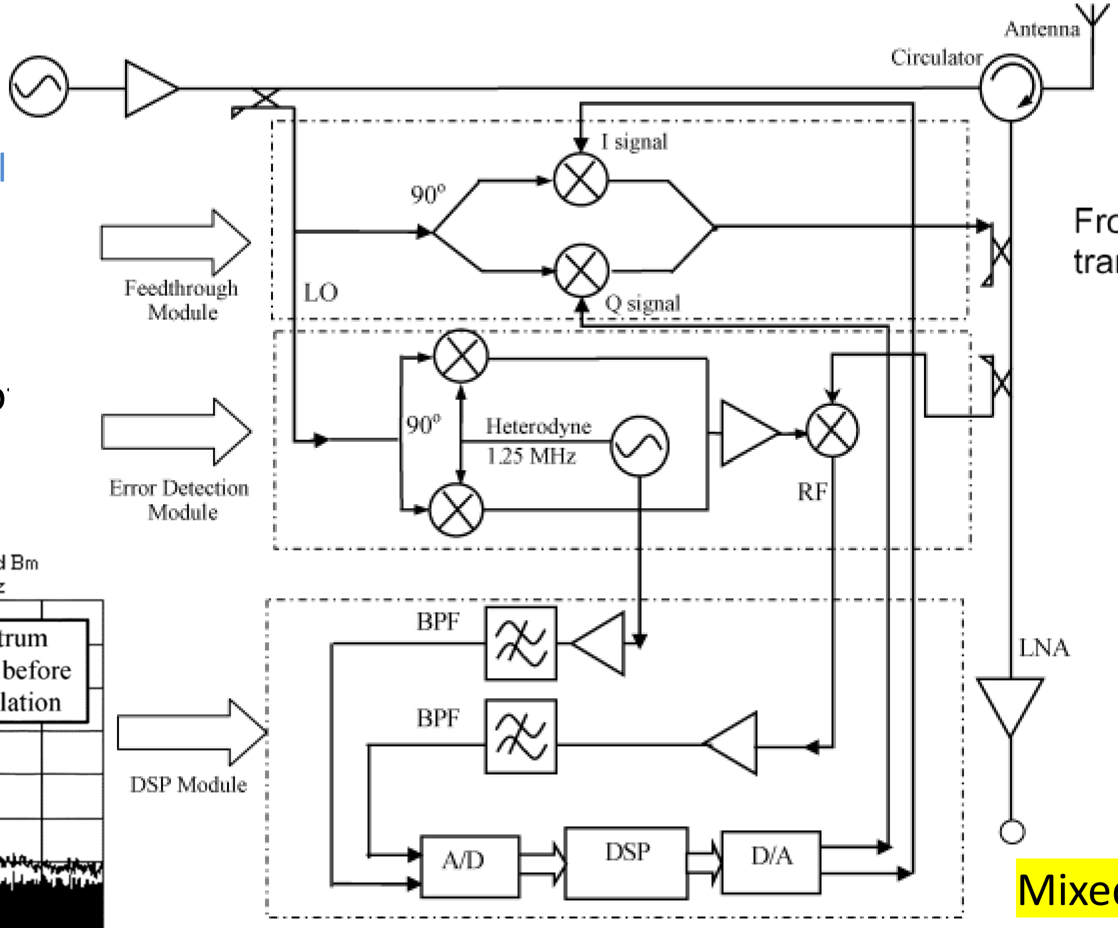
A. Melzer, A. Onic, F. Starzer and M. Huemer, "Short-Range Leakage Cancelation in FMCW Radar Transceivers Using an Artificial On-Chip Target," in IEEE Journal of Selected Topics in Signal Processing, vol. 9, no. 8, pp. 1650-1660, Dec. 2015, doi: 10.1109/JSTSP.2015.2465298.

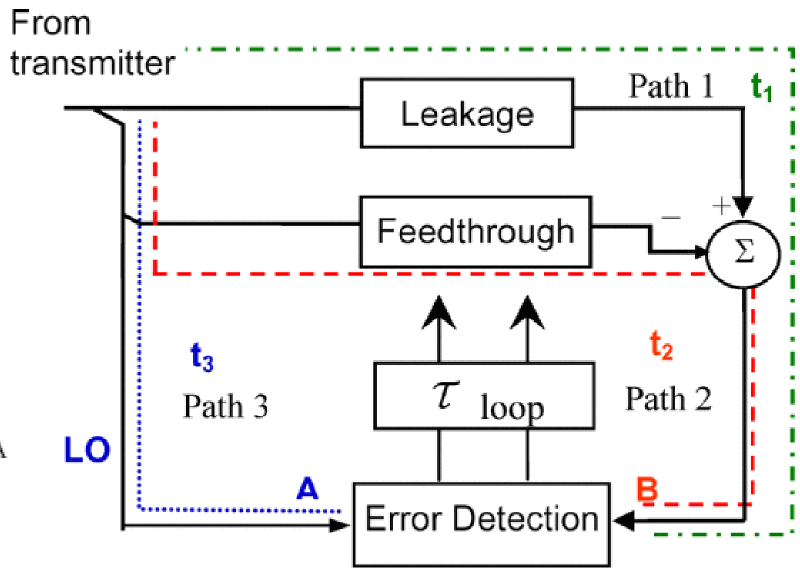
Existing Work on Cancelling On-chip Leakage

Berkeley Wireless Research Center

Idea:
Use
Rx signal – Feedthrough signal
to get an error signal and use this error signal to adjust the on-chip delay until perfect cancellation o leakage.





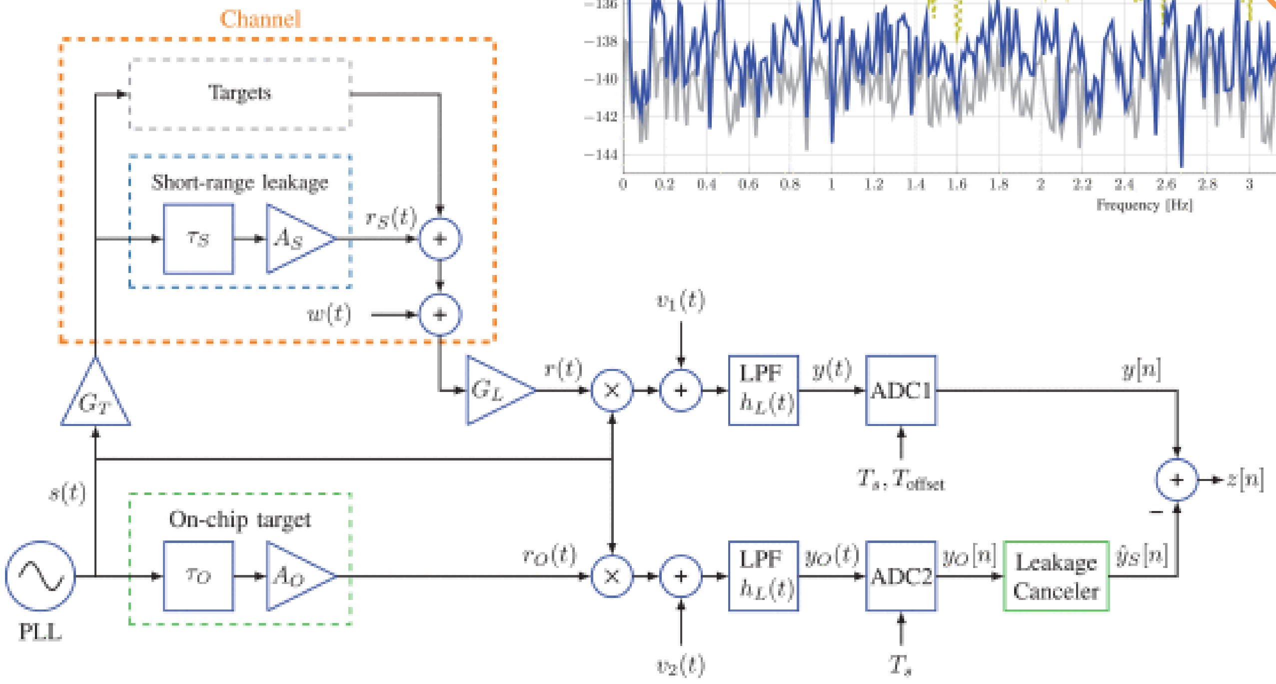


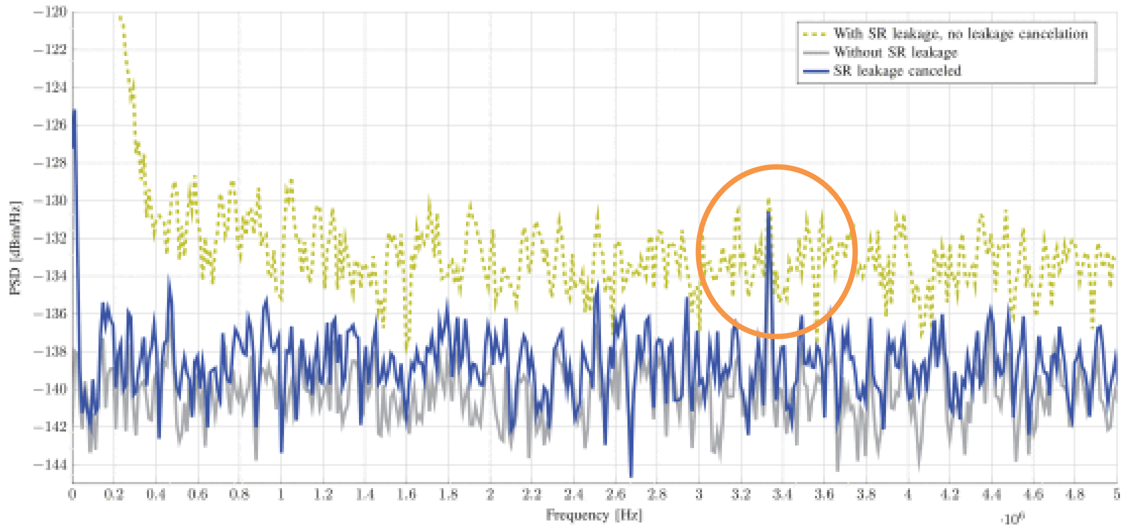
Mixed signal with cancellation in RF domain
But doesn't help SR reflection problem

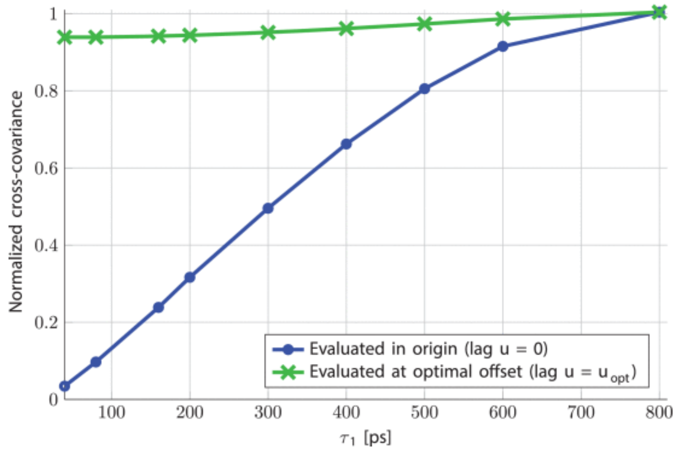
K. Lin, Y. E. Wang, C. -K. Pao and Y. -C. Shih, "A Ka-Band FMCW Radar Front-End With Adaptive Leakage Cancellation," in IEEE Transactions on Microwave Theory and Techniques, vol. 54, no. 12, pp. 4041-4048, Dec. 2006, doi: 10.1109/TMTT.2006.885882. (108 citations)

Berkeley Wireless Research Center

Existing Work on Cancelling DPN in SR Interferences







$$\alpha_L = \frac{\int_{-\infty}^{\infty} S_{\varphi\varphi}(f)\,\kappa_{\tau_O\tau_S}(f)\,|H_L(f)|^2\, e^{j2\pi f T_{\text{offset}}}\,df}{\int_{-\infty}^{\infty} S_{\varphi\varphi}(f)\,\kappa_{\tau_O}(f)\,|H_L(f)|^2\,df}$$

$$\Delta\hat{\varphi}_S(t+T_{\text{offset}}) = \alpha_L\,\Delta\varphi_O(t).$$

$$\hat{y}_S[n] = \frac{A^2\hat{A}_S'}{2}\cos(2\pi\hat{f}_{BS}nT_s + \hat{\Phi}_S + \alpha_L\,\Delta\varphi_O[n])$$

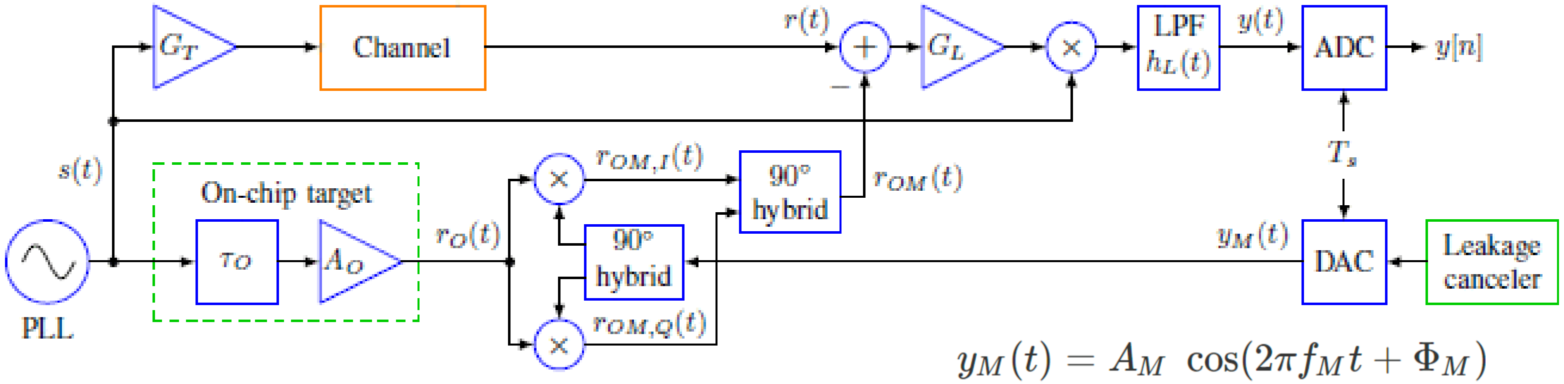
Mixed signal with cancellation in digital domain

Excellent use of MMSE predictor, but assumes perfect front end & limited noise suppresion (~6dB) due to intrinsic noise of on-chip part

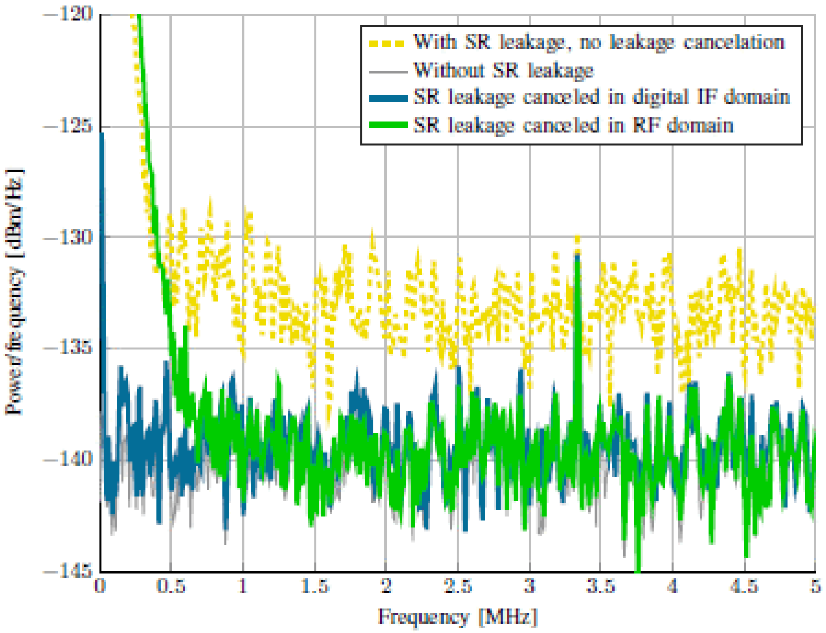
A. Melzer, A. Onic, F. Starzer and M. Huemer, "Short-Range Leakage Cancelation in FMCW Radar Transceivers Using an Artificial On-Chip Target," in IEEE Journal of Selected Topics in Signal Processing, vol. 9, no. 8, pp. 1650-1660, Dec. 2015, doi: 10.1109/JSTSP.2015.2465298.

Berkeley Wireless Research Center

Existing Work on Cancelling SR Interferences + DPN



$$y_M(t) = A_M \cos(2\pi f_M t + \Phi_M)$$



$$\begin{aligned} y(t) &= [(r(t) - r_{OM}(t))G_L s(t)] * h_L(t) \\ &= [G_L r(t)s(t) - G_L r_{OM}(t)s(t)] * h_L(t) \\ &= \underbrace{[G_L r(t)s(t)] * h_L(t)}_{\text{Channel IF signal}} - \underbrace{[G_L r(t)s(t)] * h_L(t)}_{\text{Modulated OCT IF signal } y_{OM}(t)} \end{aligned}$$

$$\begin{aligned} y_{OM}(t) \approx\ & A^2 A_O G_L A_M / 2 \cos(2\pi(k\tau_O + f_M)t + \Phi_O + \Phi_M) \\ & - A^2 A_O G_L A_M / 2 \sin(2\pi(k\tau_O + f_M)t + \Phi_O + \Phi_M) \\ & \cdot \Delta\varphi_{OL}(t), \end{aligned}$$

$$A_M \overset{!}{=} \frac{G_T A_S}{A_O} \alpha_L.$$

$$f_M \overset{!}{=} f_{BS} - k\tau_O = f_{BS} - f_{BO}$$

Mixed signal with cancellation in RF domain

Same math as the previous paper for cancelling DPN except conducted in RF domain. Requires a high-resolution DAC (SQNR better than thermal+phase noise floor) and many additional hardware.

A. Melzer, M. Huemer and A. Onic, "Novel mixed-signal based short-range leakage canceler for FMCW radar transceiver MMICs," 2017 IEEE International Symposium on Circuits and Systems (ISCAS), 2017, pp. 1-4, doi: 10.1109/ISCAS.2017.8050524.

Realization of On-chip Delay Line

- **Passive LC (artificial delay line)**
  - $\tau = \sqrt{LC}, Z_0 = \sqrt{\frac{L}{C}}$. So ~200ps delay can be made with 60 stages of 0.125nH and 50fF stages, center frequency at ~130GHz.

- **On-chip Slow-wave Structure**
  - Various ways to achieve on-chip slow-wave transmission. Metal structure below the T-line creates an artificial dielectric to slow down wave propagation. Traditional T-line takes about 3cm to realize 200ps delay with $\varepsilon_r = 4$. Slow-wave-CPW structure could achieve 2-3 times smaller size. More literature study on this to be done.

A. Melzer, A. Onic, F. Starzer and M. Huemer, "Short-Range Leakage Cancelation in FMCW Radar Transceivers Using an Artificial On-Chip Target," in IEEE Journal of Selected Topics in Signal Processing, vol. 9, no. 8, pp. 1650-1660, Dec. 2015, doi: 10.1109/JSTSP.2015.2465298.