I,Q Mismatch Analysis and Evaluation Method of Complex Analog Filter

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4B-06

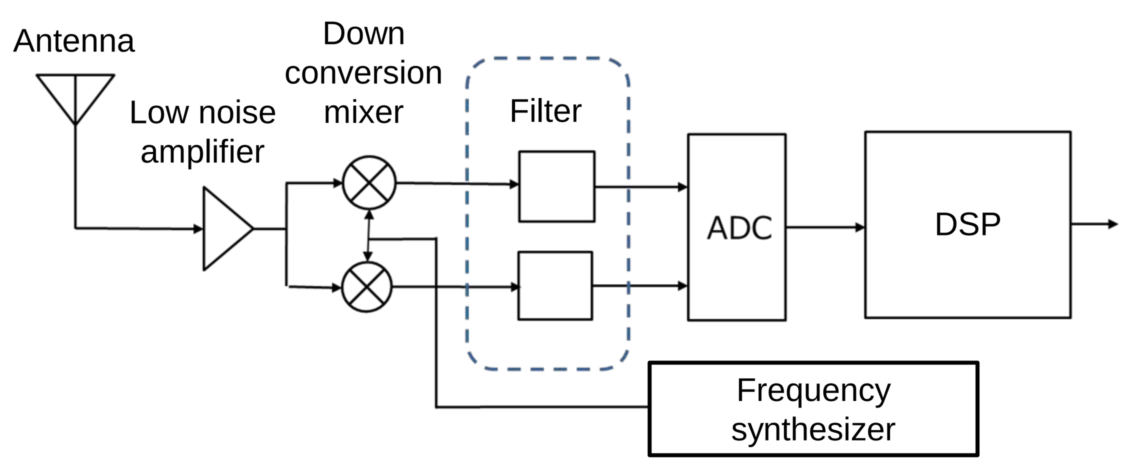
1. Research Objective

Development of I, Q mismatch measurement method for analog complex filter

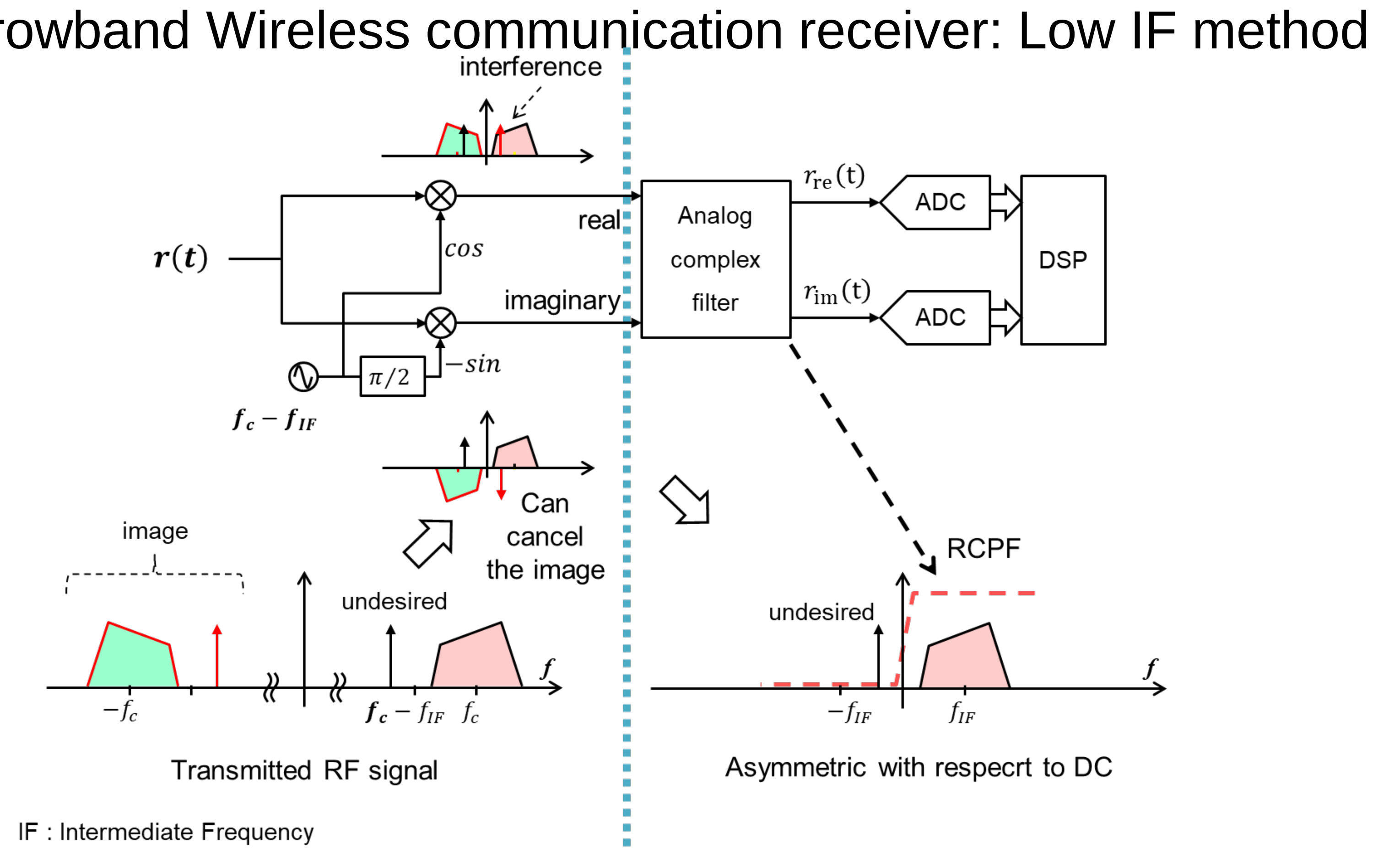
Simple, Accurate

2. Background

Wireless communication area



Narrowband Wireless communication receiver: Low IF method



Problem I,Q complex circuit : RC polyphase filter is composed of only resistors and capacitors

— Element variations

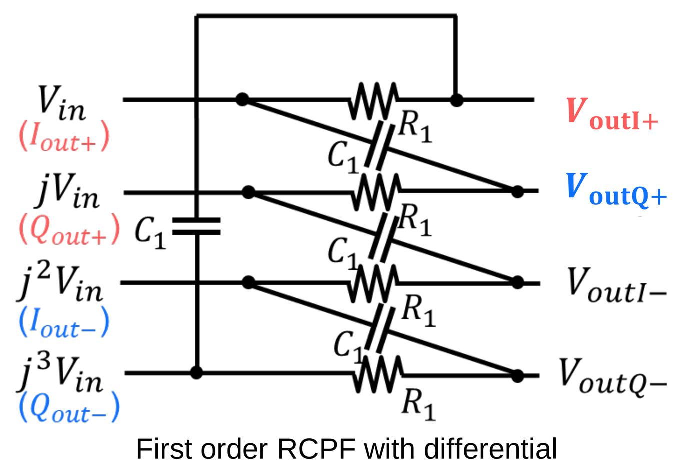
— I, Q signal-path mismatch

Proposal Mismatch measurement

— Using multi-tone signal

— Evaluation algorithm using “division”

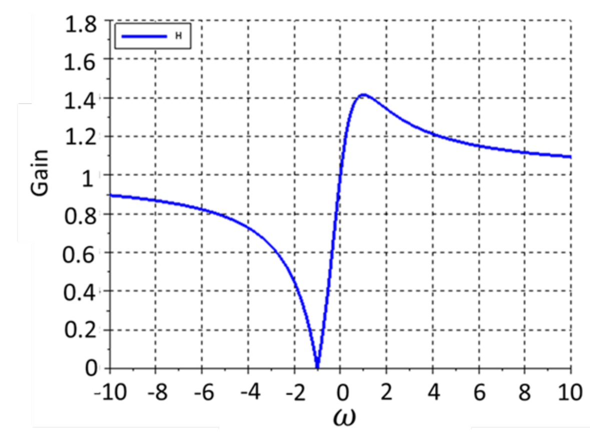
3. RC Polyphase Filter under Test



Analog complex filter
- Image removal
- I, Q signal generation

HPF & LPF overlay circuit
Hilbert filter characteristics

[R, C Element variation]
Notch position → Deviation
Attenuation → Large change



Frequency characteristics of first-order RCPF

$R_1 = 1k\Omega,\ C_1 = 10pF$

Gain, phase quadrature error

$$\frac{V_{outI+}}{V_{outQ+}} \neq -j$$

$$V_{outI+} = \frac{1}{1+j\omega CR}V_{in} + \frac{j\omega CR}{1+j\omega CR}j^3V_{in}$$

$$V_{outQ+} = \frac{1}{1+j\omega CR}jV_{in} + \frac{j\omega CR}{1+j\omega CR}V_{in}$$

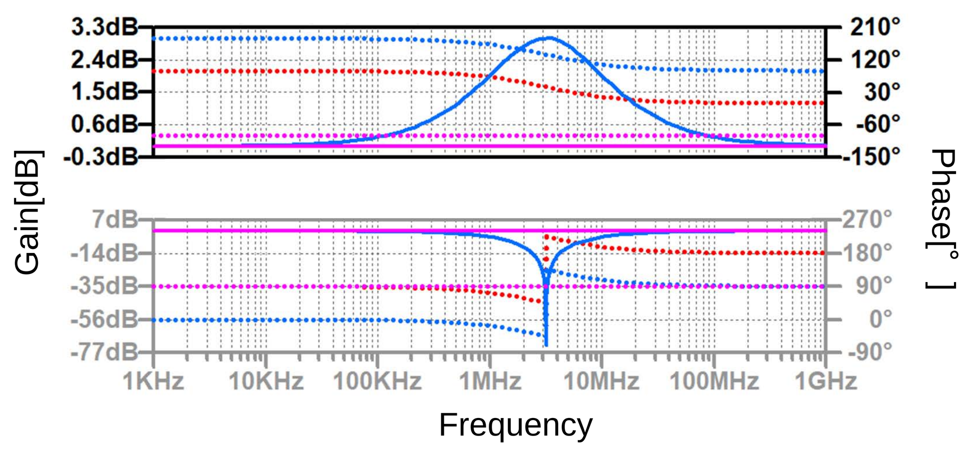
$$V_{outI-} = \frac{1}{1+j\omega CR}j^2V_{in} + \frac{j\omega CR}{1+j\omega CR}jV_{in}$$

$$V_{outQ-} = \frac{1}{1+j\omega CR}j^3V_{in} + \frac{j\omega CR}{1+j\omega CR}j^2V_{in}$$

$$\omega = \frac{1}{RC}$$

$$\frac{V_{outI+}}{V_{outQ+}} = \frac{j^2V_{in} + j\omega CR\cdot jV_{in}}{jV_{in} + j\omega CR\cdot V_{in}} = -j$$

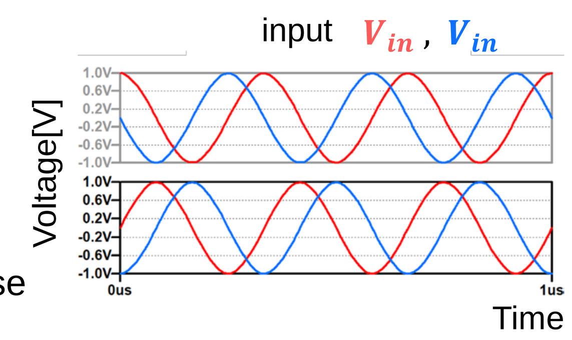
$$\frac{V_{outI-}}{V_{outQ-}} = \frac{V_{in} + j\omega CR\cdot j^3V_{in}}{j^3V_{in} + j\omega CR\cdot j^2V_{in}} = j$$



V_{outI+}, V_{outQ+}, V_{outI+}/V_{outQ+}

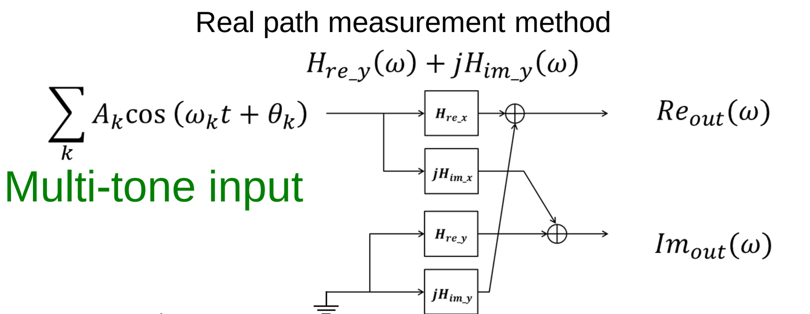
Dotted line: Phase

Practice: Gain



4. Orthogonal Error Measurement Method

Real path measurement method



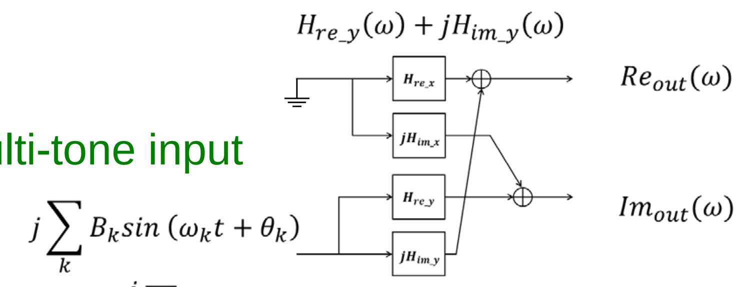
$$ReOut(\omega) = \frac{1}{2}\sum_k A_k\left(H_{re\_x}(\omega_k)e^{j(\omega_k t+\theta_k)} + H_{re\_x}(-\omega_k)e^{-j(\omega_k t+\theta_k)}\right)$$

$$ImOut(\omega) = \frac{j}{2}\sum_k A_k\left(H_{im\_x}(\omega_k)e^{j(\omega_k t+\theta_k)} + H_{im\_x}(-\omega_k)e^{-j(\omega_k t+\theta_k)}\right)$$

$$Imbalance(\omega) = \frac{ImOut(\omega)}{ReOut(\omega)} = \frac{jH_{im\_x}(\omega)}{H_{re\_x}(\omega)} = j$$ (I, Q balanced)

$\neq j$ (I, Q imbalanced)

Imaginary path measurement method



$$ReOut(\omega) = \frac{j}{2}\sum_k B_k\left(H_{im\_y}(\omega_k)e^{j(\omega_k t+\theta_k)} - H_{im\_y}(-\omega_k)e^{-j(\omega_k t+\theta_k)}\right)$$

$$ImOut(\omega) = \frac{1}{2}\sum_k B_k\left(H_{re\_y}(\omega_k)e^{j(\omega_k t+\theta_k)} - H_{re\_y}(-\omega_k)e^{-j(\omega_k t+\theta_k)}\right)$$

$$Imbalance(\omega) = \frac{ReOut(\omega)}{ImOut(\omega)} = \frac{jH_{im\_y}(\omega)}{H_{re\_y}(\omega)} = j$$ (I, Q balanced)

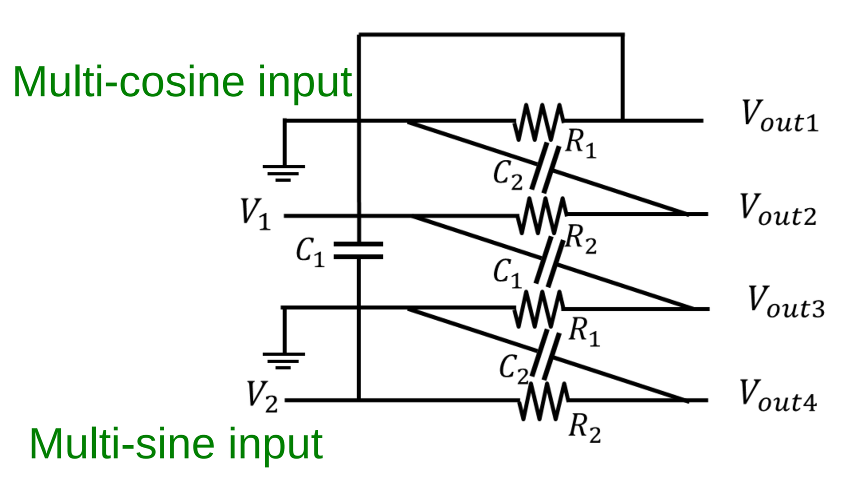
$\neq j$ (I, Q imbalanced)

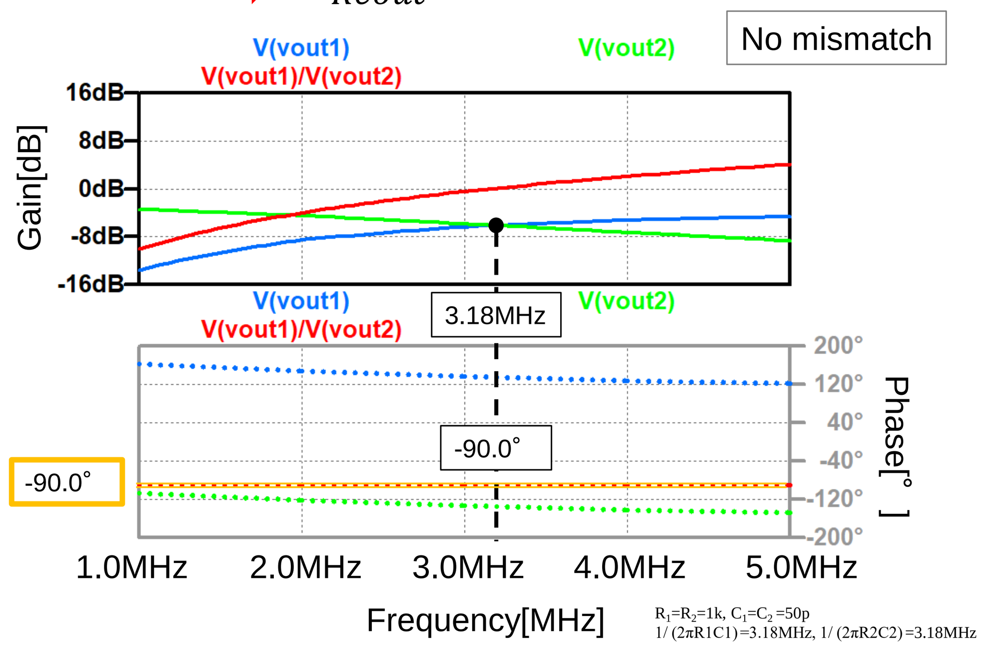
I, Q-path discrepancy → 90˚ relationship collapses

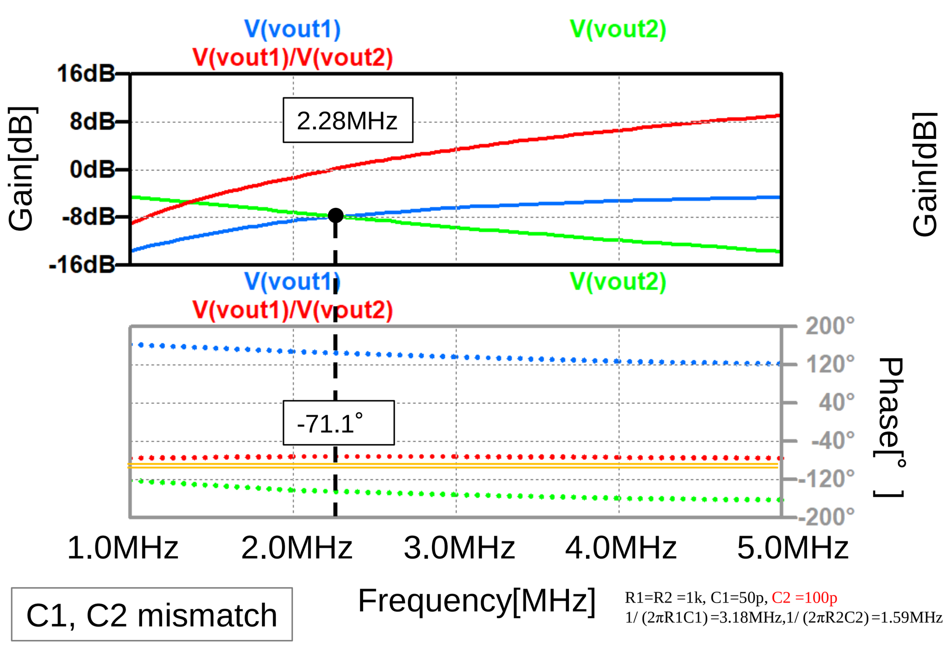
5. Simulation

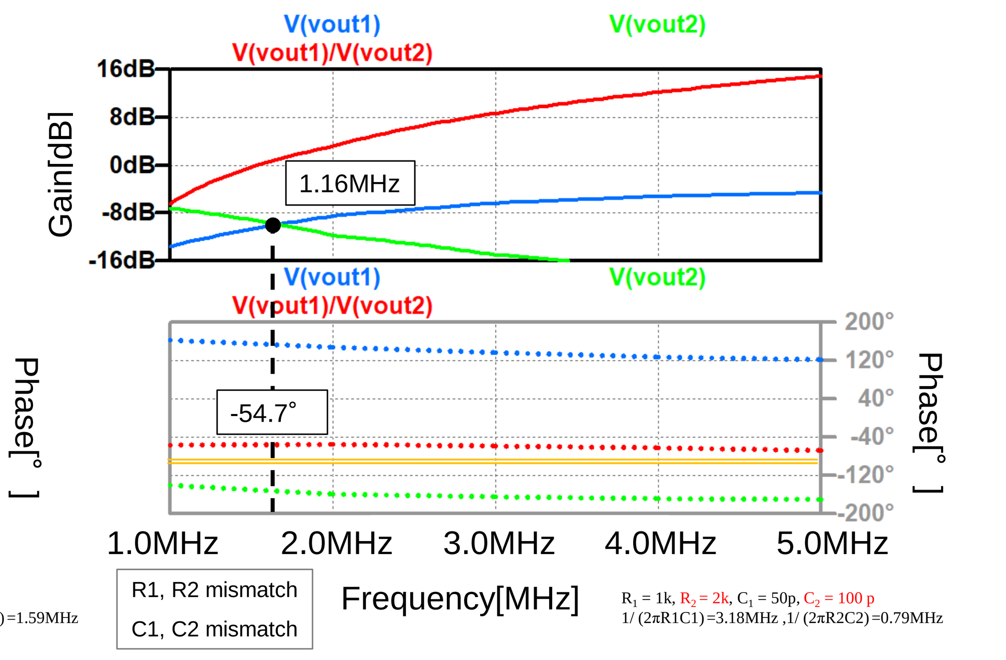
$R_1C_1 \neq R_2C_2$ → $\frac{Imout}{Reout} \neq j$

Simulation circuit









6. Conclusion

● Measurement method of analog complex filter (RCPF)
-Based on the orthogonal error model in RCPF,
Proposal and simulation of orthogonal error evaluation method of I, Q signal-paths using multi-tone input.

●When I, Q signal-paths are orthogonal, phase of I, Q signals is shifted by 90 ˚

●When I, Q signals are NOT orthogonal
- I, Q signal phase relationship corresponding to multitone input is NOT 90 ˚
- The greater the element variation, the larger the IQ signal amplitude difference

References

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[2] T. J. Yamaguchi, M. Soma, M. Ishida, T. Watanabe, T. Ohmi, “Extraction of Instantaneous and RMS Sinusoidal Jitter Using an Analytic Signal Method,” IEEE Trans. Circuits and Systems- II, vol. 50, no.6, pp.228-239 (June 2003).

[3] K. W. Martin, “Complex Signal Processing is NOT Complex”, IEEE Trans. Circuits and Systems I, vol.51, no.9, 1823-1836 (Sept. 2004).

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