Low Distortion Sine Wave Generator for Analog IC Testing: Harmonics Cancellation, Digital Predistortion and Analog Filter

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OUTLINE

- Research Background
- Approach
  - Harmonics Cancellation
  - Digital PreDistortion
  - LC Band pass Filter
- Conclusion

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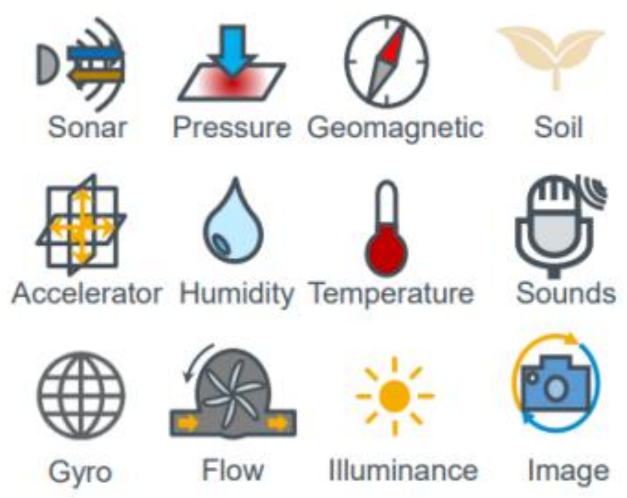
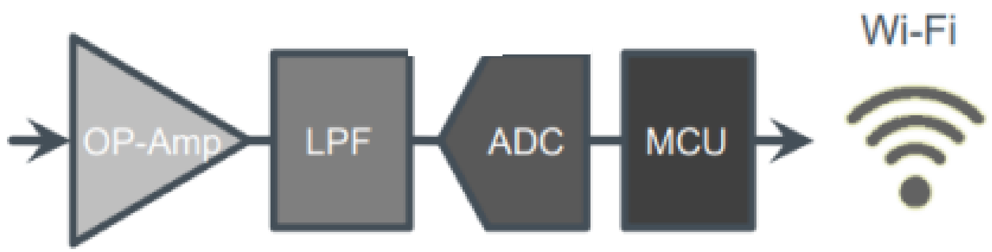
Research Background

IoT sensor network



sensor



IoT : Internet of Things
ADC : Analog Digital Converter

Analog and analog-digital mixed signal (AMS) circuits are key components

Their low-cost testing is important

Research Objective

Development of low-distortion sine wave generator
for mass production test of AMS circuits

Measurement instruments such as
audio analyzers used in bench-top

High cost Long measurement time

Audio Precision APx555B
Audio Analyzer

Unrealistic situation

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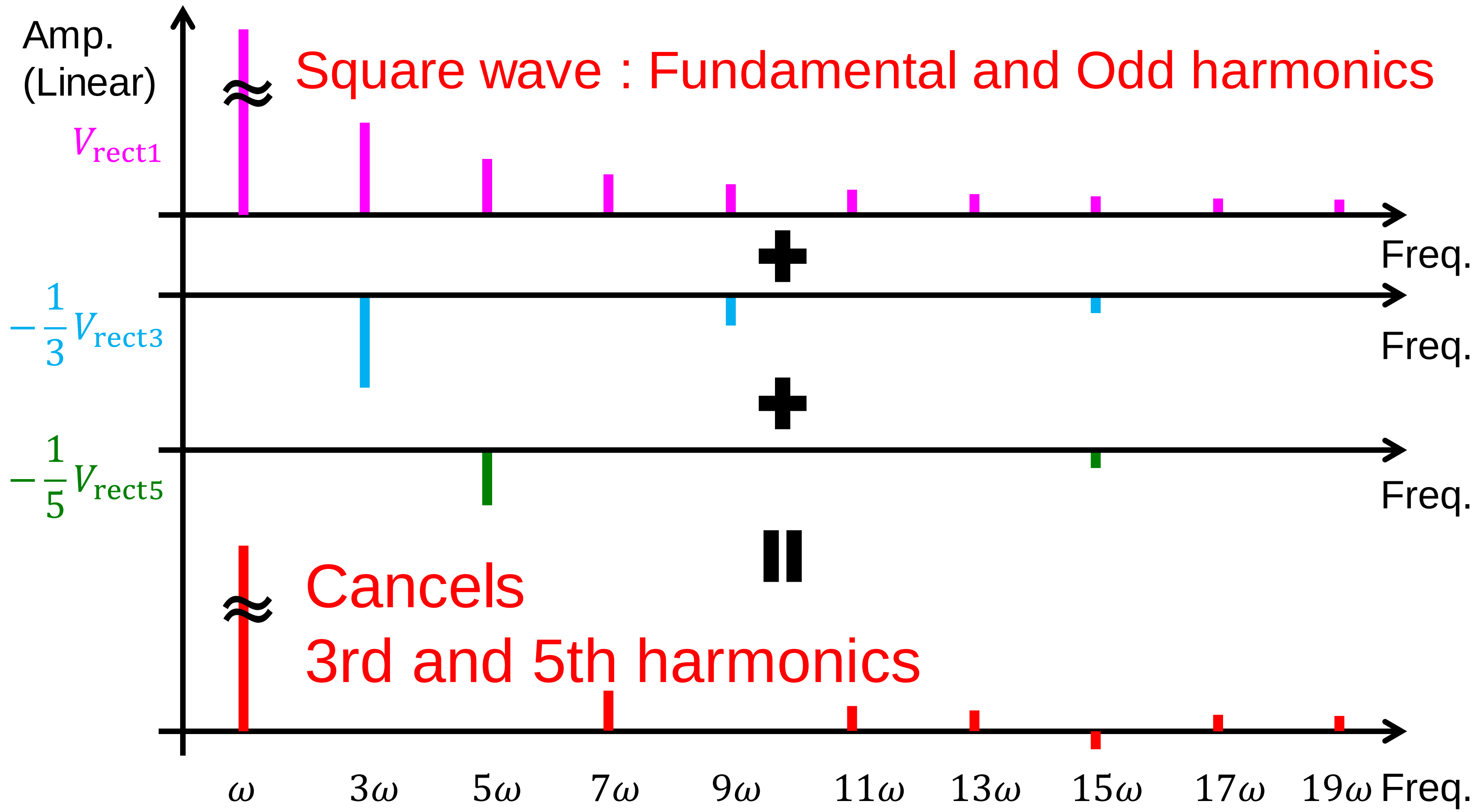
Principle of Low-distortion Sine Wave Generator

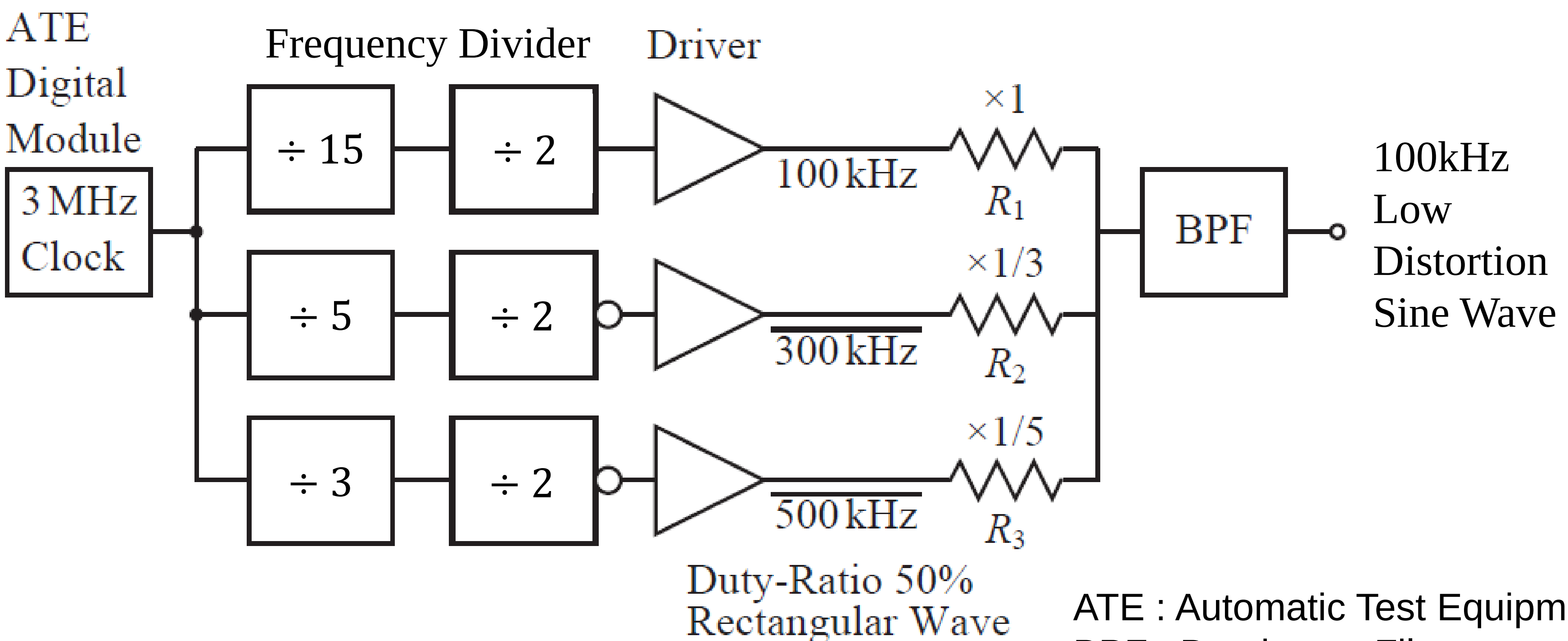
Source of square waves : low-cost generation system

$$V_{rect1},\ -\frac{1}{3}V_{rect3},\ -\frac{1}{5}V_{rect5}$$

(Frequency : ω, 3ω, 5ω)



Low-Distortion Sine Wave Generator



ATE : Automatic Test Equipment
BPF : Band-pass Filter

Signal source :	Digital ATE output
Square waves : with ω, 3ω, 5ω	Divider (Logic circuit)
Signal addition :	Usage of resistors
Analog filter :	Low-order LC BPF

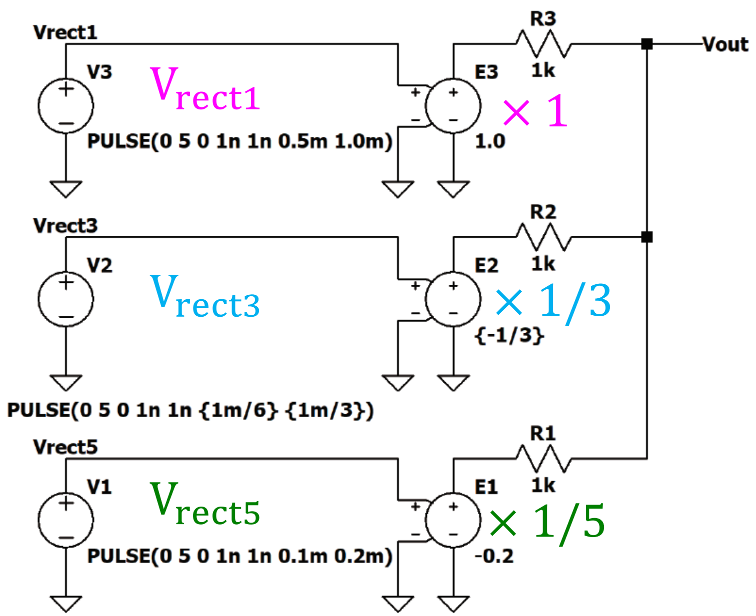
⇒

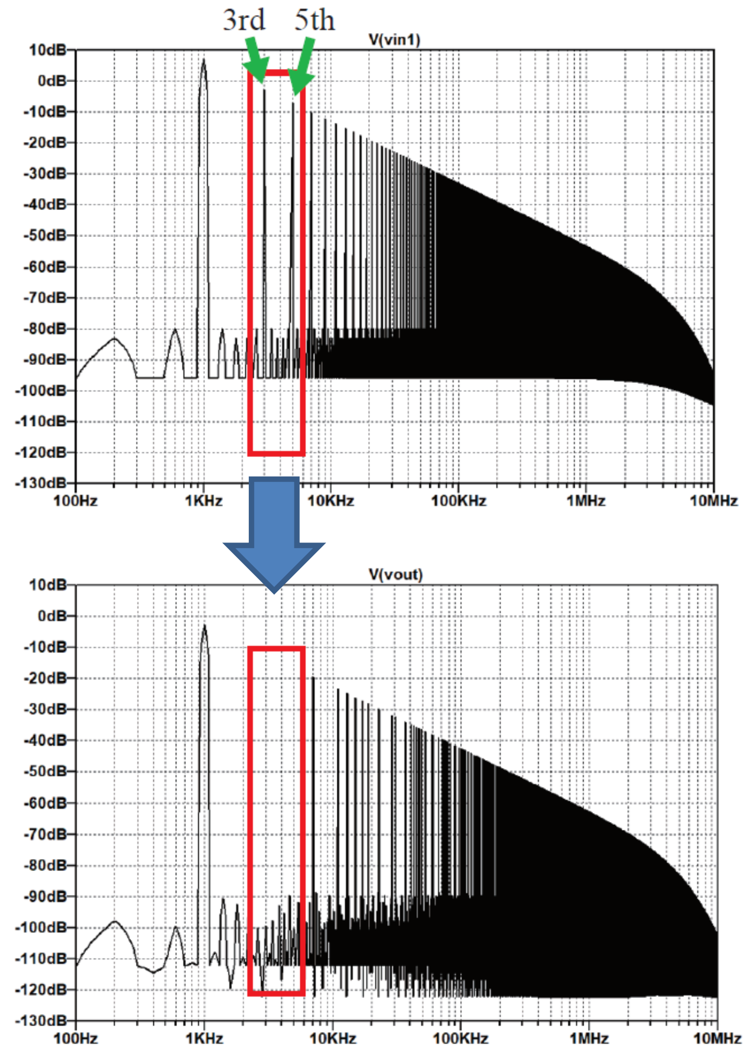
- Simple
- Low-cost

Simulation of Harmonic Cancellation Circuit

Signal source parameters

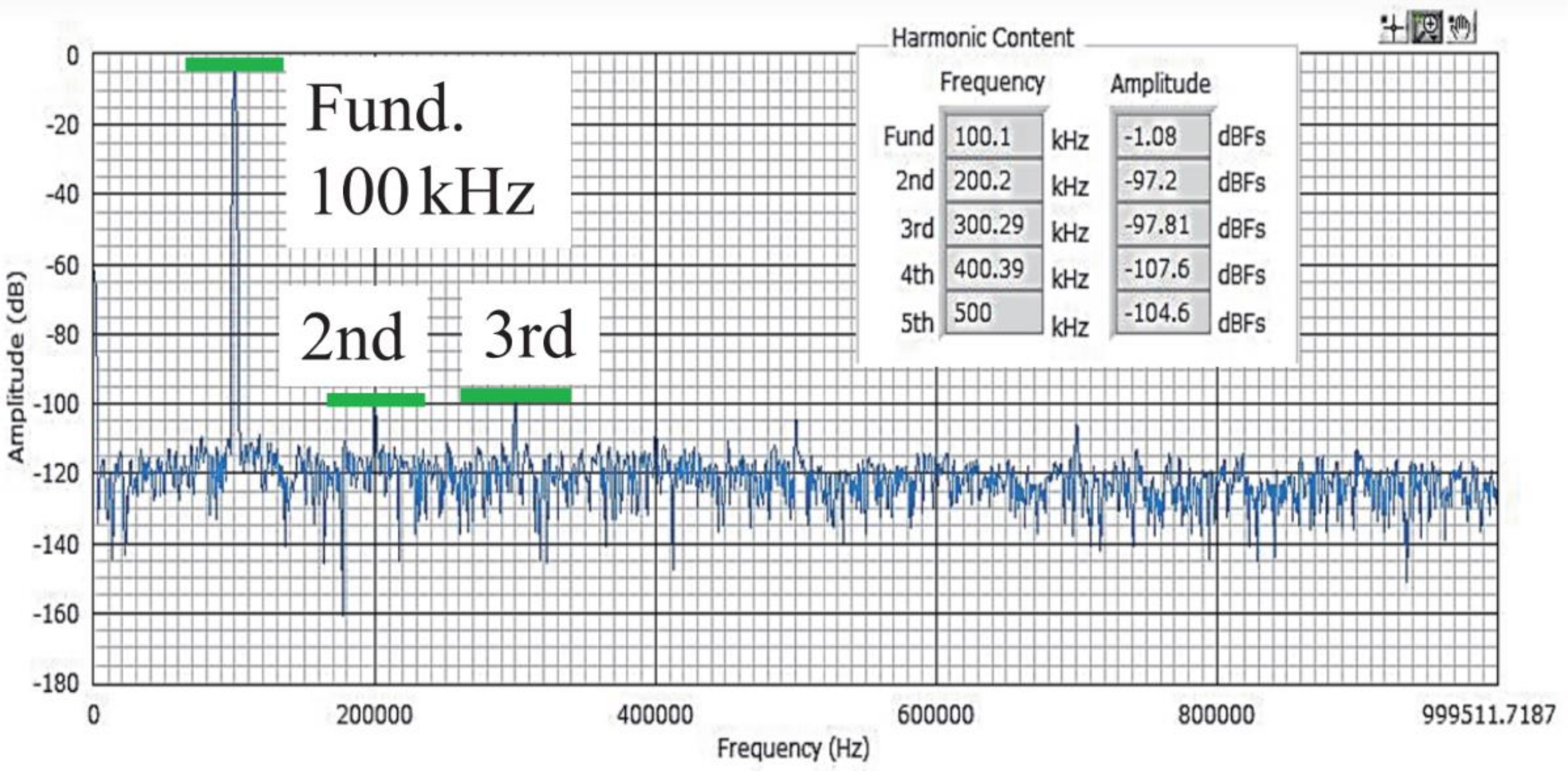
Signal source	Frequency	Amplitude
V_{rect1}	1 kHz	5 V_{0-p}
V_{rect3}	3 kHz	5 V_{0-p}
V_{rect5}	5 kHz	5 V_{0-p}





Removes 3rd and 5th harmonics
by adding rectangular waves with frequencies ω, 3ω, 5ω

Measured Output Power Spectrum



2nd and 3rd harmonic distortion : −96 dBc
4th and higher : −100 dBc or less

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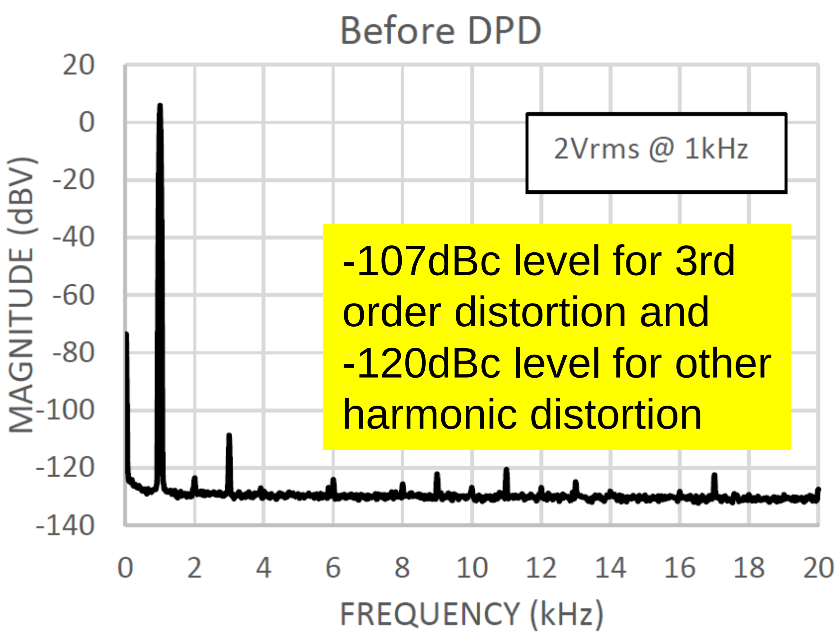
Ultra-low Distortion Signal Source Technology

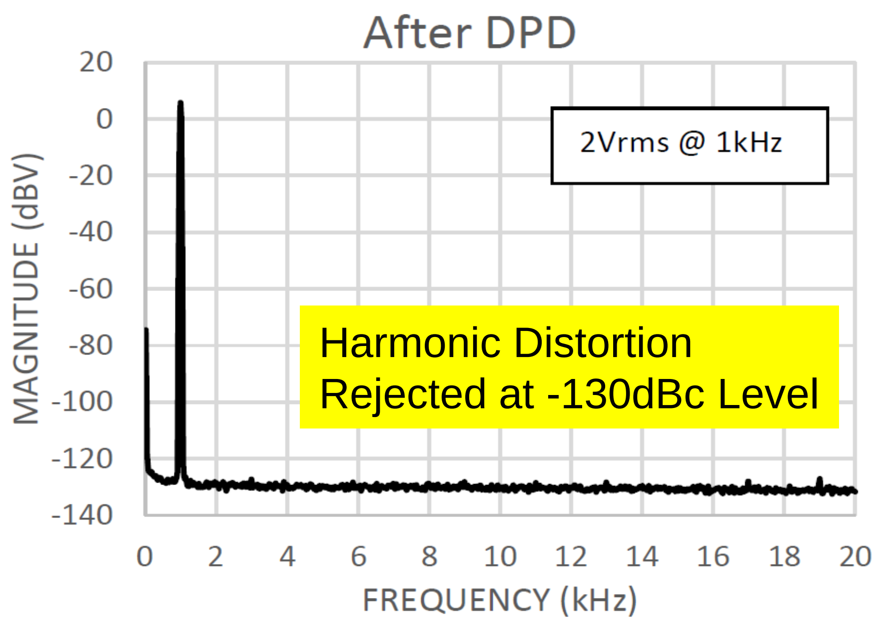
Evaluation of ADMX1002 (ADI):

Ultra-low Distortion and Low Noise Signal Generator

➡ Usage of Digital PreDistortion (DPD) algorithm

Ultra-low distortion signal generation at 1kHz with less than -130dBc spurious.



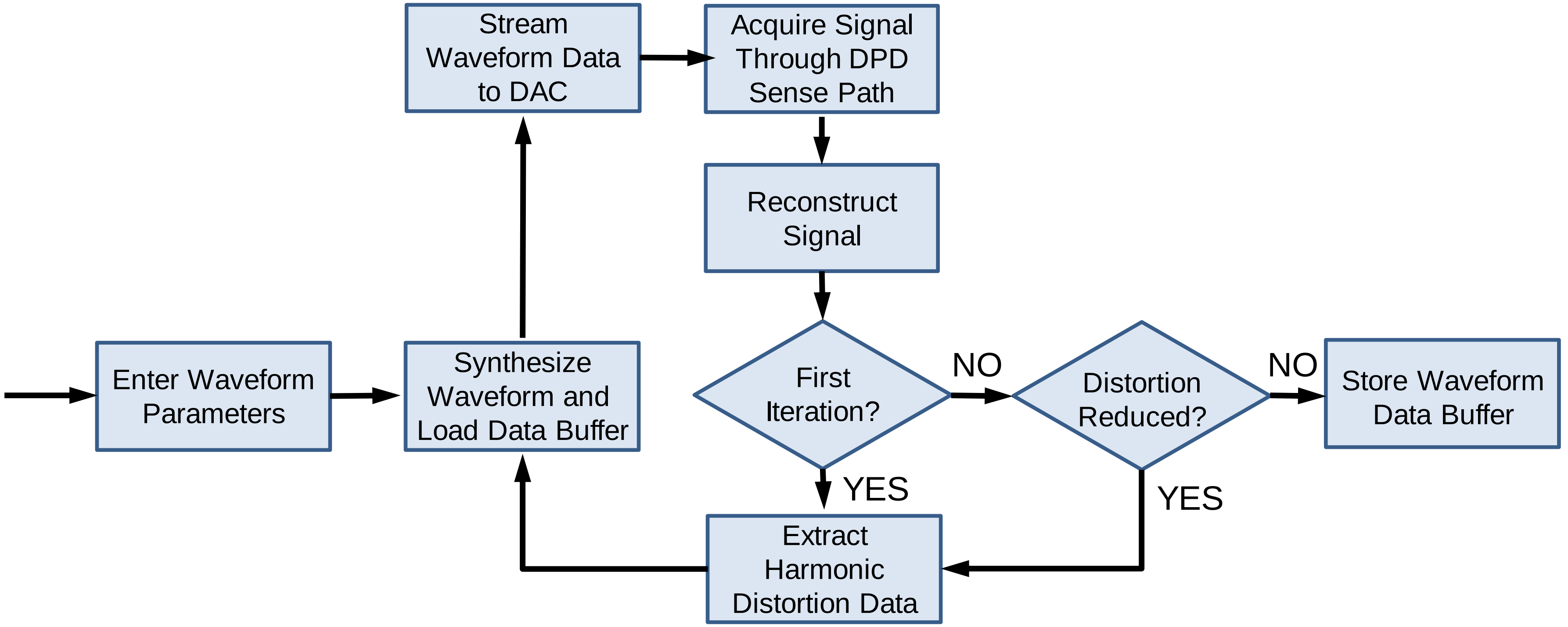


High Performance Source for ADC and Audio Test with Novel Digital Predistortion Technical Article Analog Devices Inc.

DPD Realization Flow

- AD conversion with 20-bit ADC (LTC2378-20)
- Harmonic distortion detection with FFT analysis
- Corrects sine wave digital data to cancel out harmonic distortion (Digital PreDistortion)
- Distortion reduction repeats loop to minimize distortion (-130dBc)

➡ Takes about 2 minutes



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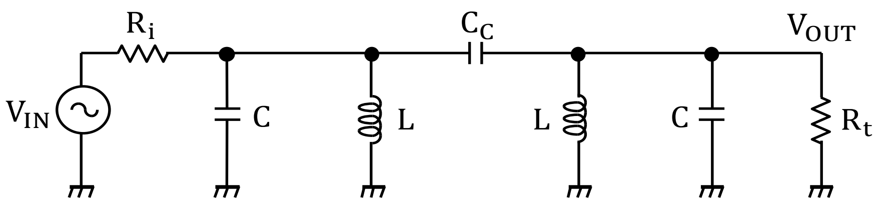
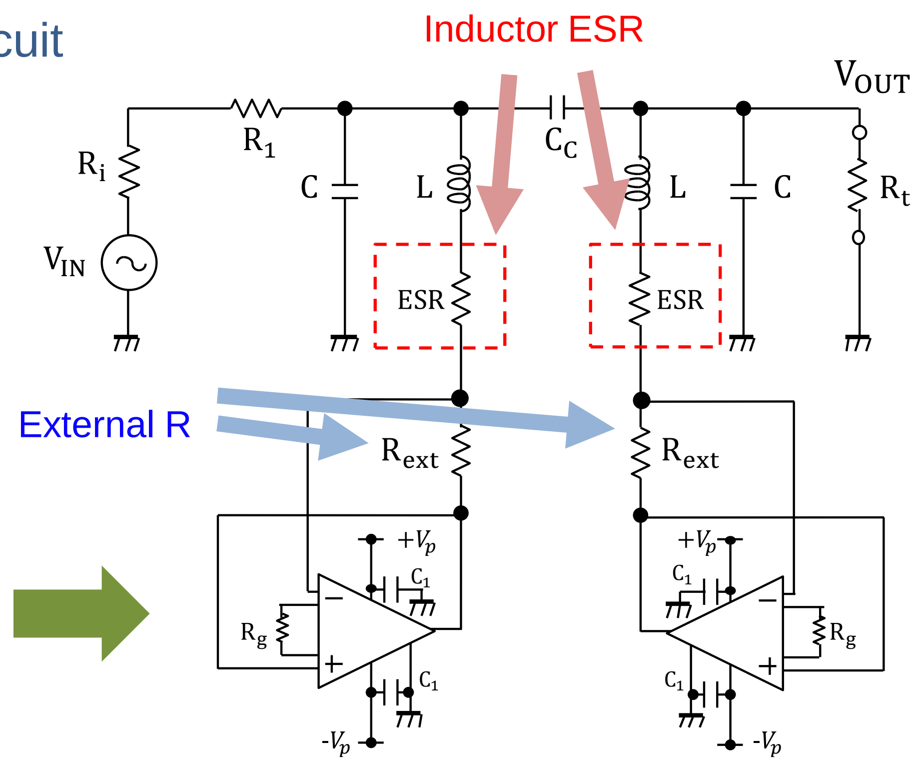
LC Analog Bandpass Filter

Following the harmonics cancellation circuit



Ideal LC BPF

LC analog BPF with proposed inductor ESR compensation

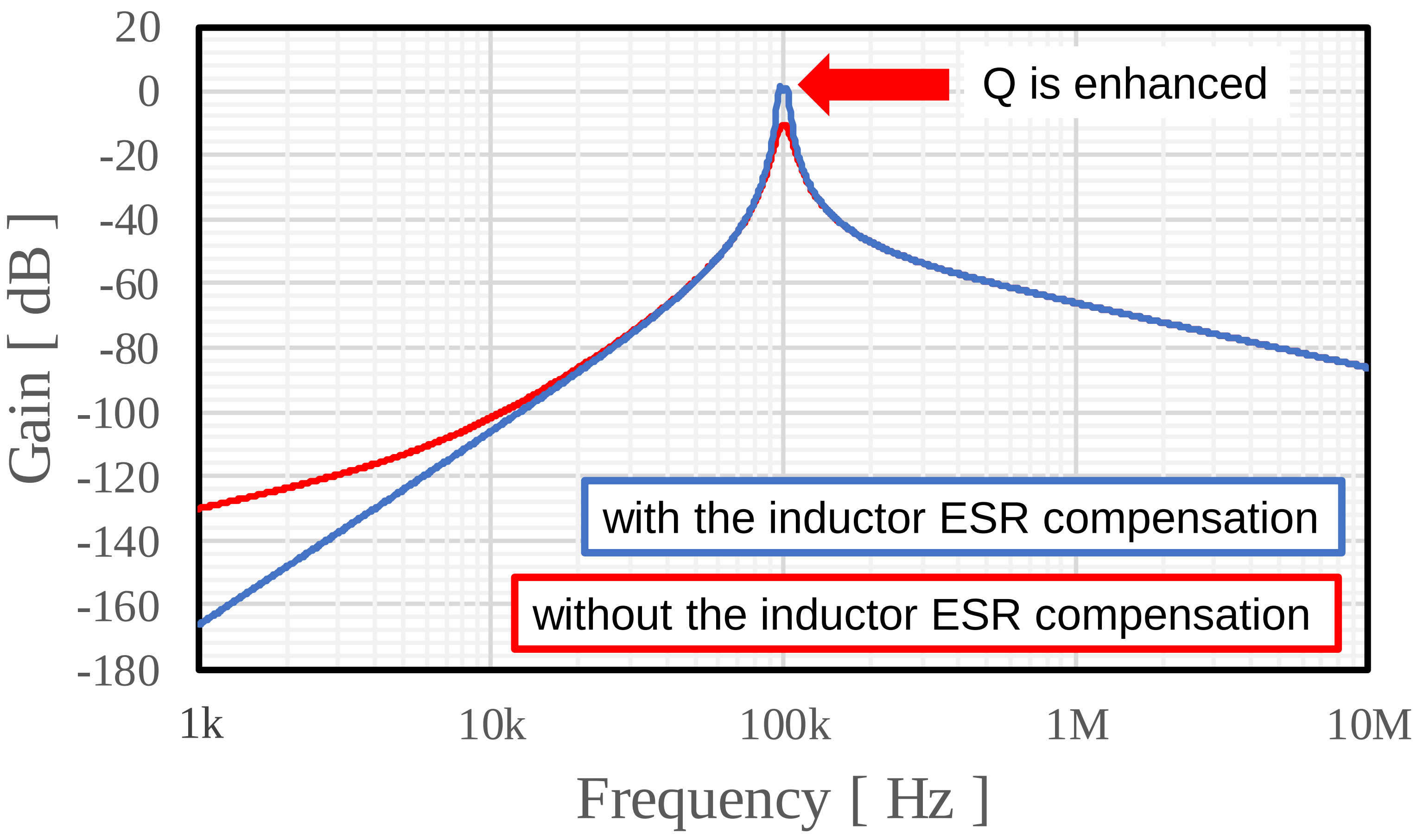


Transfer function of an ideal LC BPF

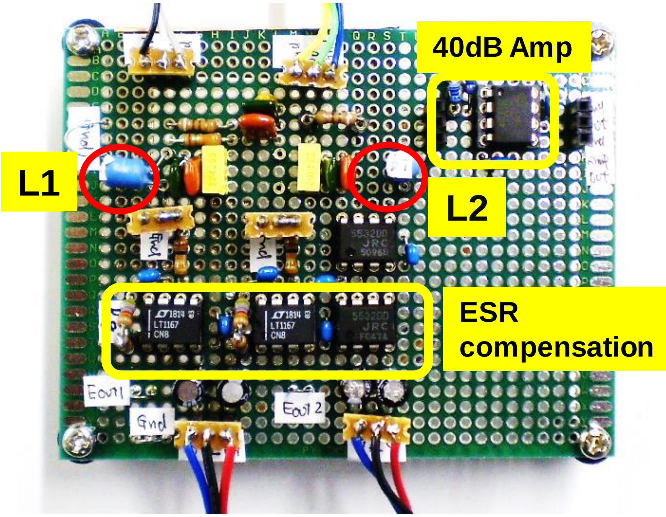
$$G(s) = \frac{s^3 R_t L^2 C_C}{s^4 R_i R_t L^2 C(2C_C + C) + s^3 L^2 (C + C_C)(R_i + R_t) + s^2 L\{2R_i R_t (C_C + C) + L\} + sL(R_i + R_t) + R_i R_t}$$

ESR: Equivalent Series Resistance

Simulation of Gain Characteristics

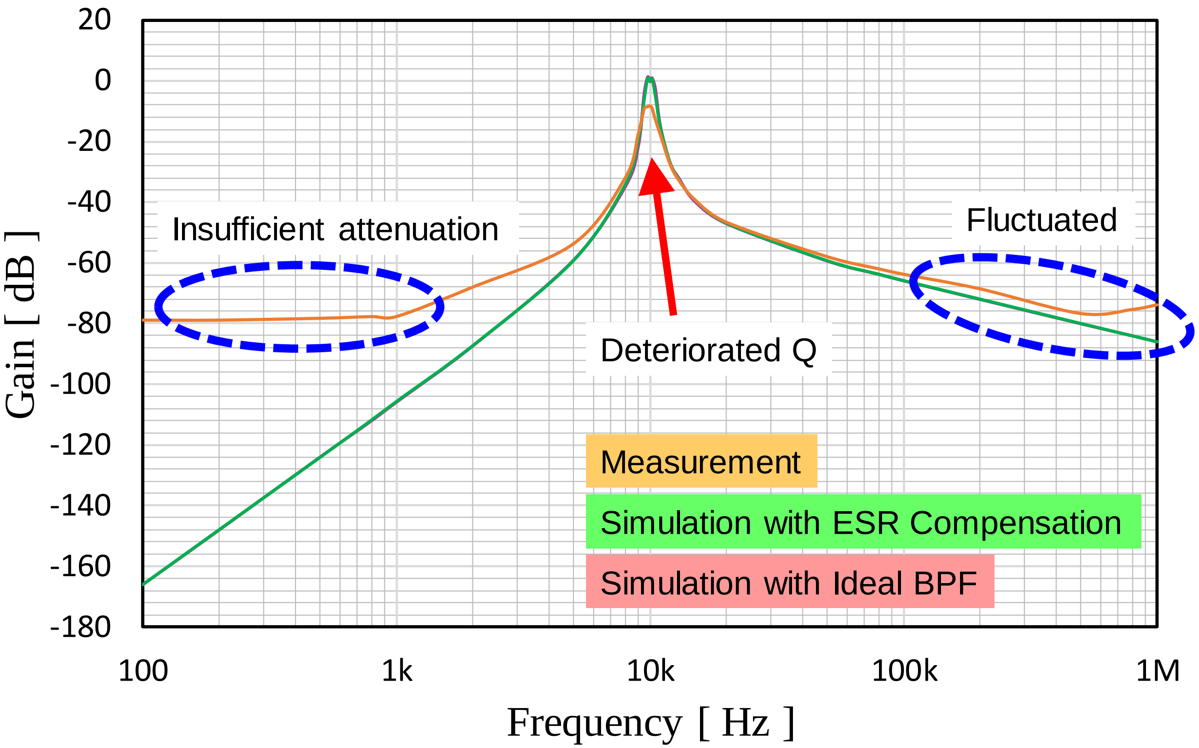


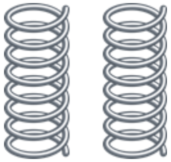
Measurement of BPF Prototype



LC BPF prototype
with ESR compensation

Simulation and measurement result
of BPF with ESR compensation





L_1, L_2 are placed in parallel

↓

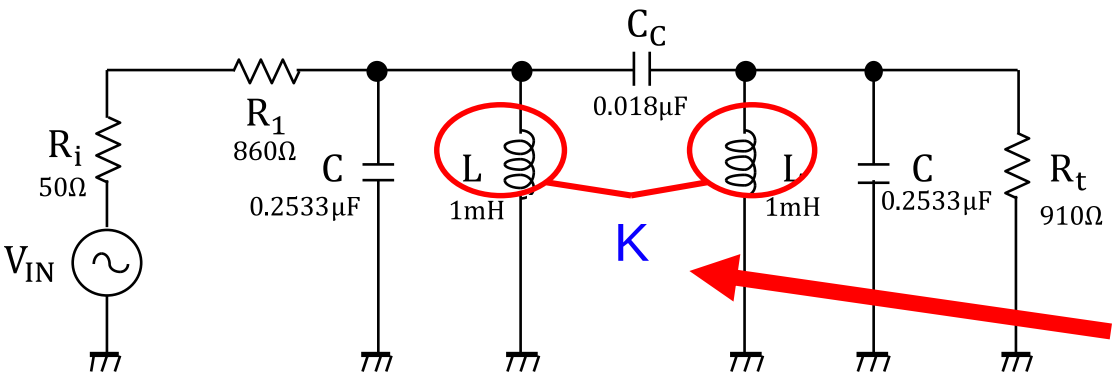
Parasitic mutual conductance

↓

Discrepancies

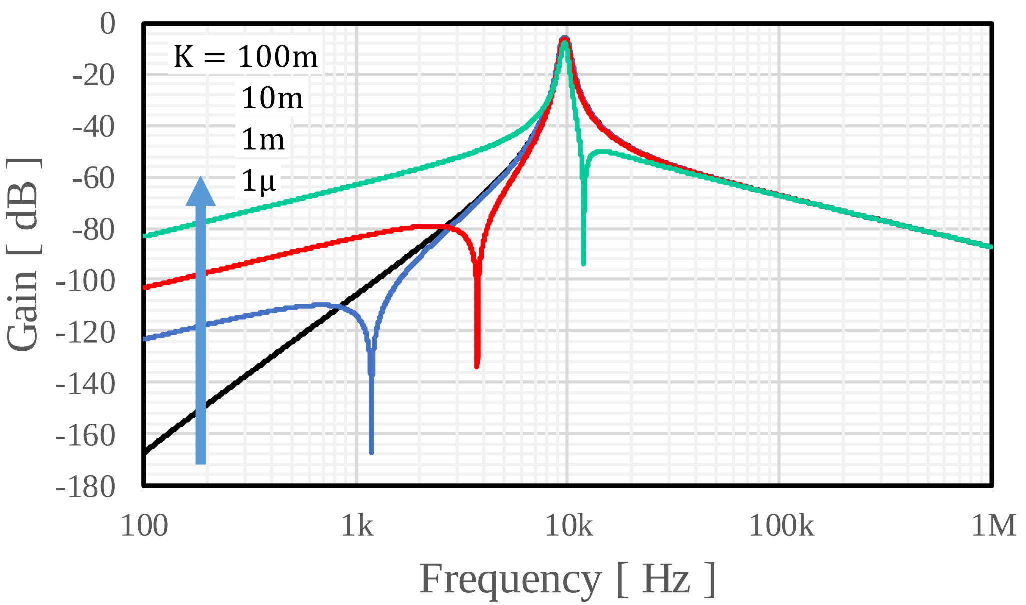
Effect of Coupling Coefficient K

Mutual inductance effect simulation



Coupling coefficient

Circuit

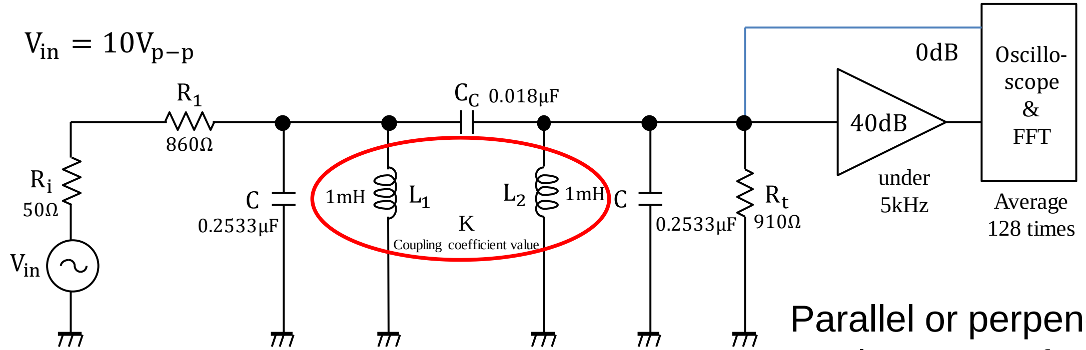


K increases

Stop band attenuation
in low frequency side
→ Worse

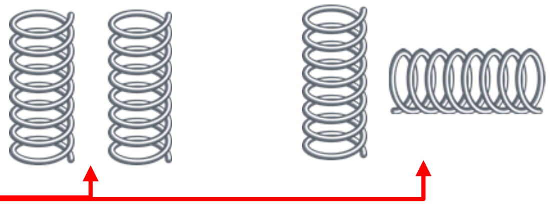
L_1, L_2 Parallel or Perpendicular Placement

BPF measurement result

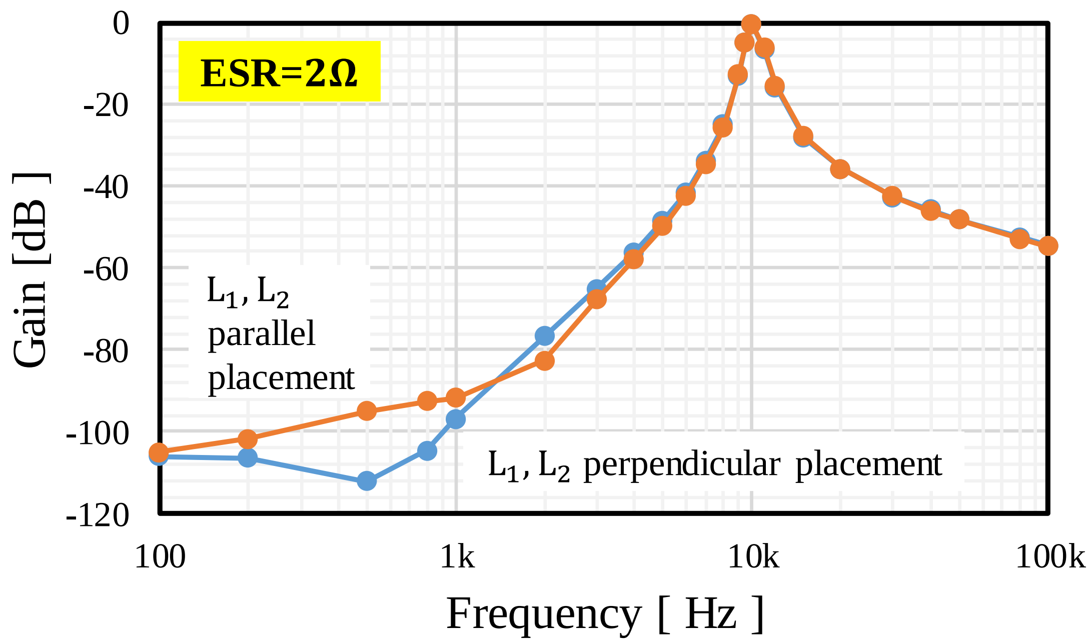


For accurate measurements in stopband,

- Amplifier of 40 dB gain under 5kHz
- 128 times averaging



Parallel or perpendicular placement of L_1, L_2



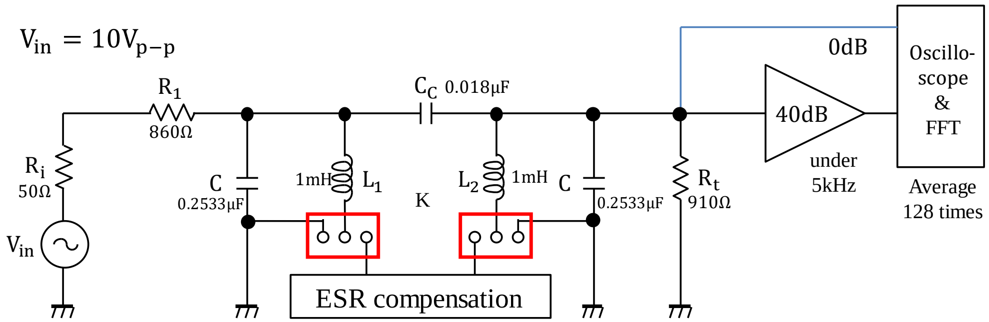
L_1, L_2 are placed in perpendicular

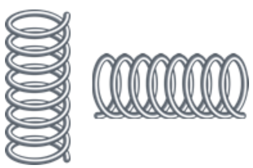
Mutual inductance reduction

Stop band attenuation

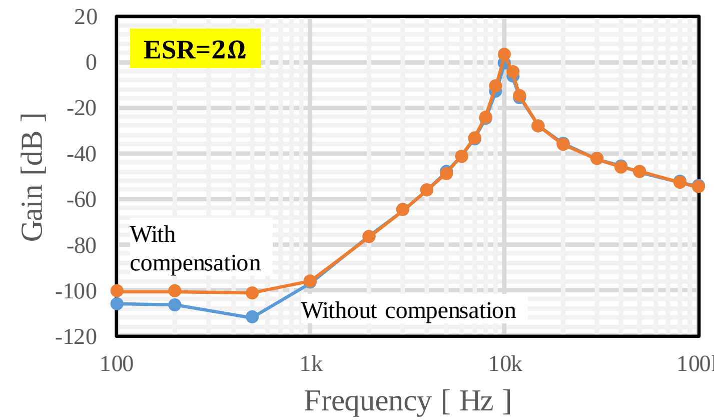
Improved

Measurement of 2nd BPF Prototype

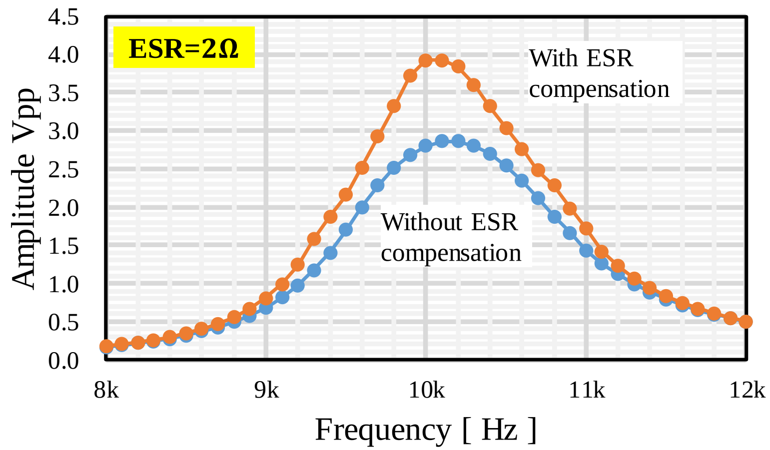




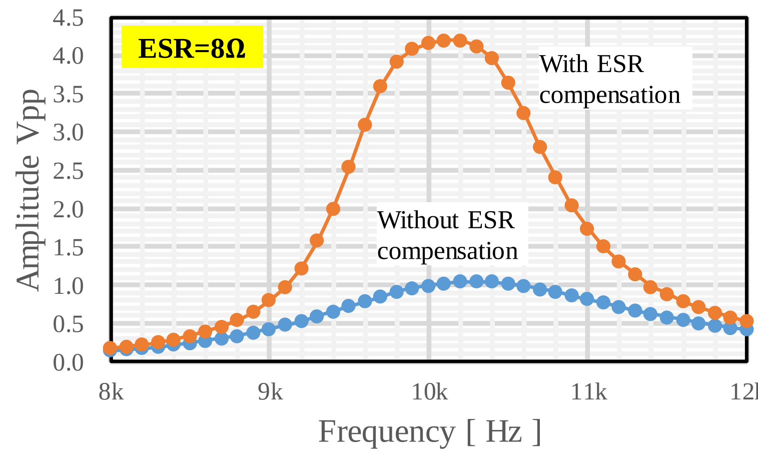
Perpendicular placement of L_1, L_2



Measured result with ESR of 2Ω



Enlarged with ESR of 2Ω



Enlarged with ESR of 8Ω

Q is enhanced

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Conclusion

For low-cost analog/mixed-signal test systems

- Core circuit of low-distortion sine wave generator
  - HD3 and HD5 cancellation
- Evaluation of Digital PreDistortion
- LC BPF
  - Inductor ESR compensation for high Q
  - Parasitic mutual inductance effects
    - ⇒ Placement of inductors
- Verification with circuit simulation and experiments

Thank you for listening !