主動式高靈敏度開口環共振腔利用互調現象增強生理訊號

Physiological Signals Enhanced by Using Intermodulation Multiplication of Active High-Sensitivity Split-Ring Resonator

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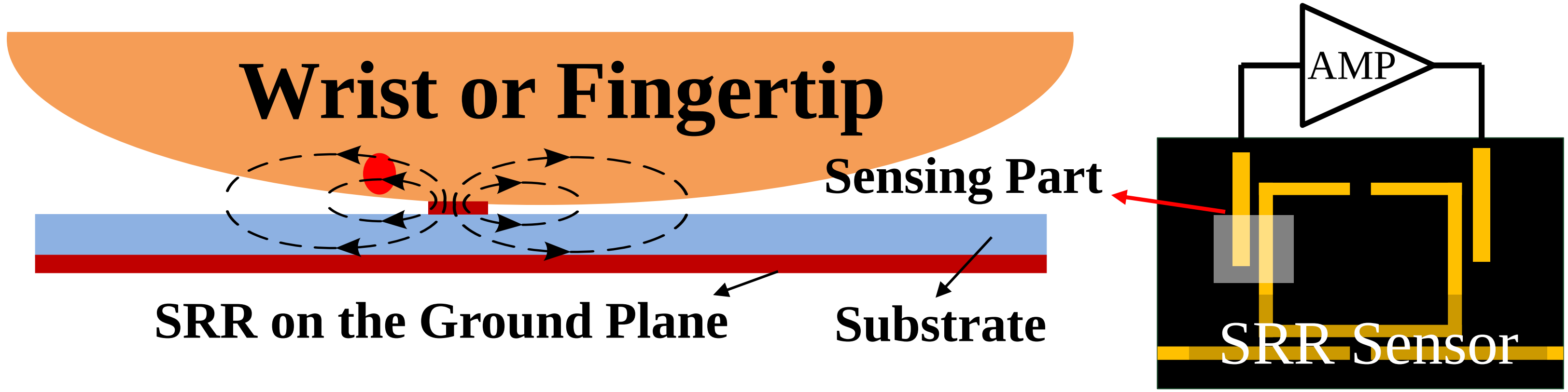
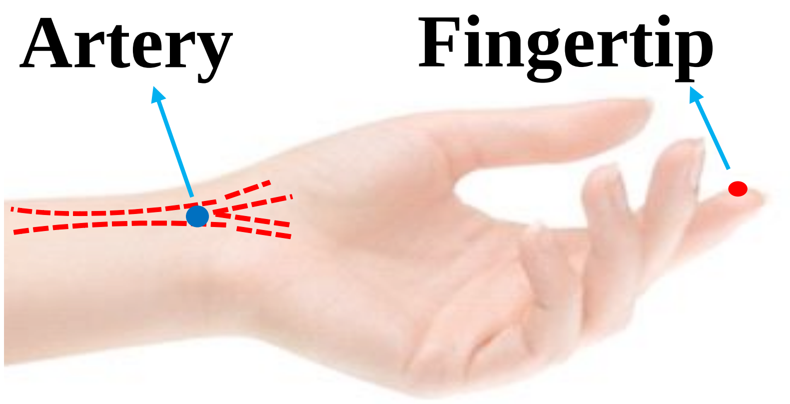
Proposed Method - Active SRR Resonator



- Vital sign detection
  - Active circuit
  - Non-linearity property of AMP
  - Intermodulation (IM) products
  - Enhance the sensitivity of signals



Proposed Method - Intermodulation

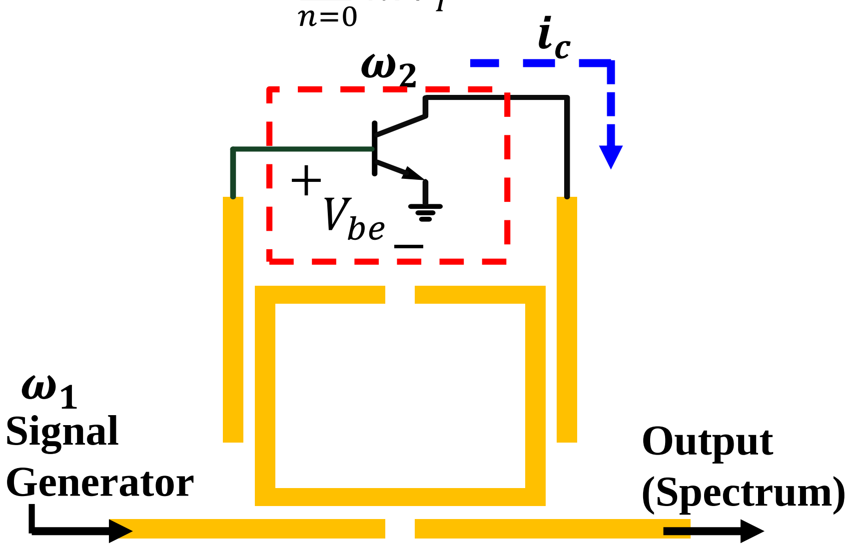
- **Intermodulation (IM)**
  - Output current：i_c

$$V_{be} = A\cos(\omega_1 t) + B\cos(\omega_2 t)$$

$$i_c(AC) = I_s(e^{V_{be}/V_T} - 1)$$

- The transistor's nonlinearity.

$$e^{V_{be}/V_T} = \sum_{n=0}^{\infty} \frac{1}{n!}\frac{1}{V_T^n}(V_{be}^n)$$



ω_1 : Export from Signal generator

ω_2 : Oscillator by SRR

Δf_1 (frequency shift) ⬇ **$\omega_1 \Rightarrow \omega_1 - \Delta\omega_1$**

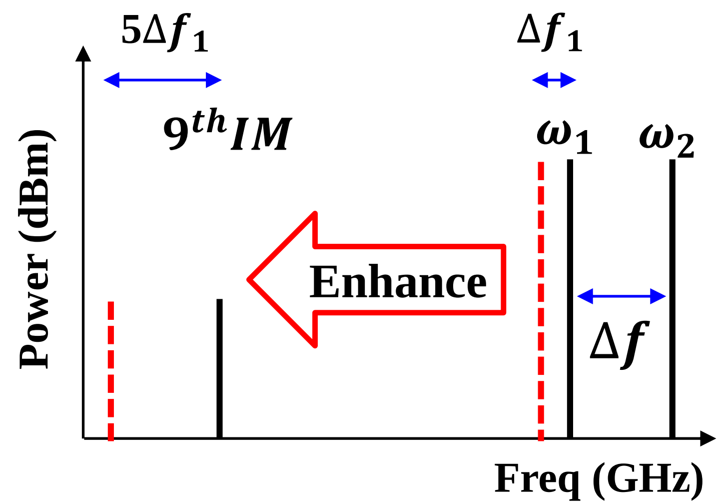
$$n = 1 \Rightarrow \omega_1 - \Delta\omega_1$$

$$n = 3 \Rightarrow \omega_1 \Rightarrow 2\omega_1 - \omega_2 - 2\Delta\omega_1$$

$$n = 5 \Rightarrow \omega_1 \Rightarrow 3\omega_1 - 2\omega_2 - 3\Delta\omega_1$$

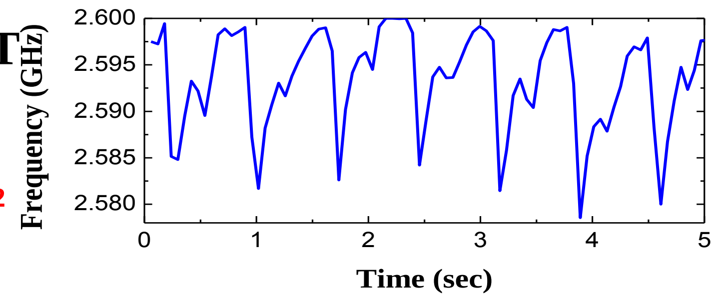
$$n = 7 \Rightarrow \omega_1 \Rightarrow 4\omega_1 - 3\omega_2 - 4\Delta\omega_1$$

$$n = 9 \Rightarrow \omega_1 \Rightarrow 5\omega_1 - 4\omega_2 - 5\Delta\omega_1$$

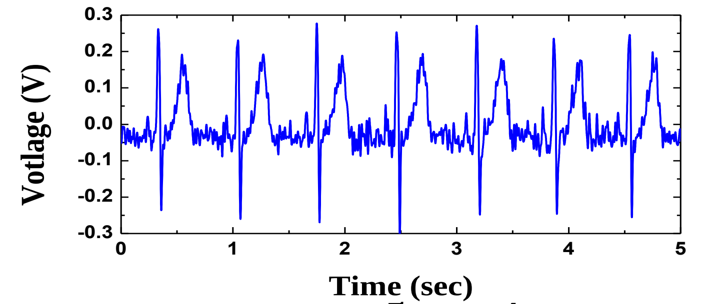


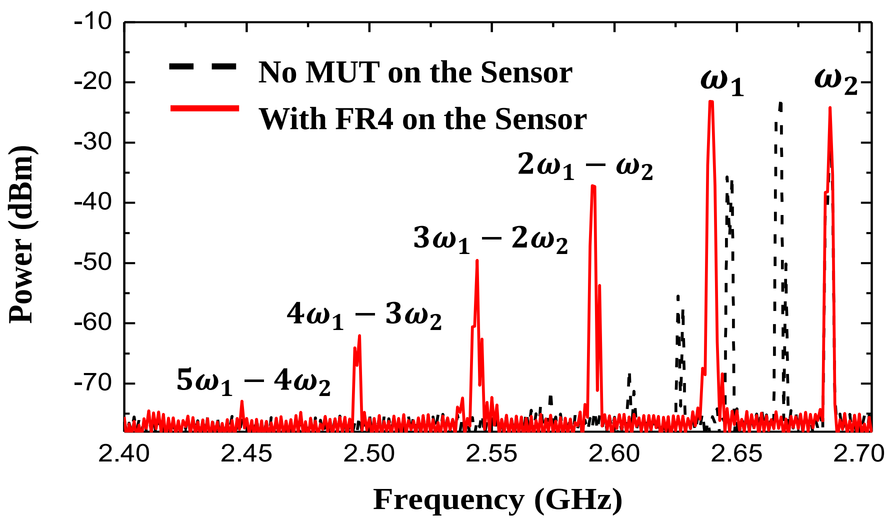
Measurement Results – Wrist signal

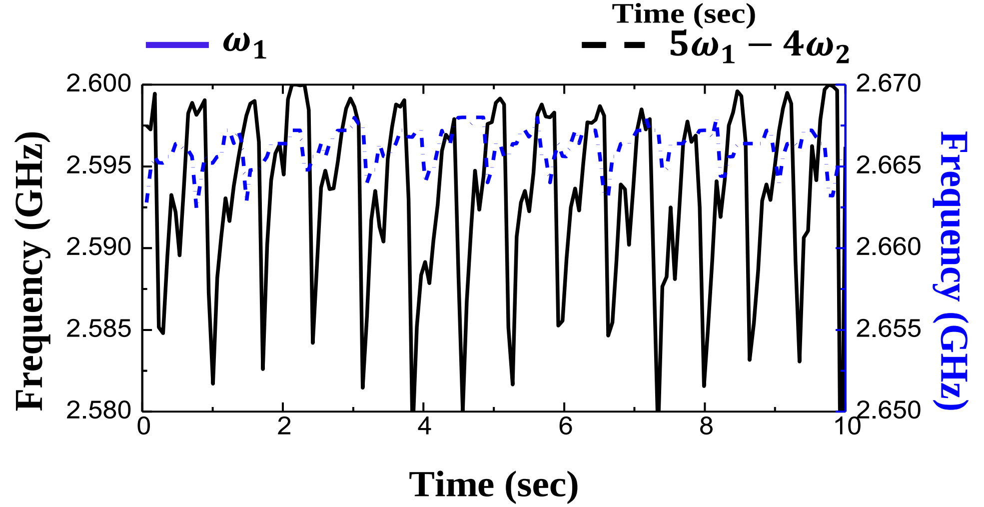
- **Frequency shift by IM products with/without the MUT**
  - IM components near the primitive frequency are odd harmonics and located at $2\omega_1-\omega_2$, $3\omega_1-2\omega_2$, $4\omega_1-3\omega_2$ and $5\omega_1-4\omega_2$
  - The sensing frequency is shifted as Δf_1 , $\Delta 2f_1$, $\Delta 3f_1$ …



- **Pulse signal that use the frequency shift in 9_{th} IM.**
  - Pulse signal
  - ECG signal







Measurement Results – Fingertip signal

- **The weak pulses from the microvascular inside the fingertip can be detected by the proposed SRR sensor.**