TU4A-4

Analysis of a Sensor Based on an Injection-Locked Oscillator Driven by a Chirp Signal

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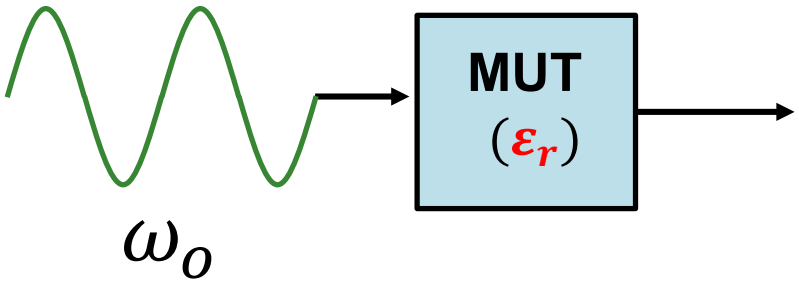
Principle of operation

Material under test (MUT):



Analysis frequency

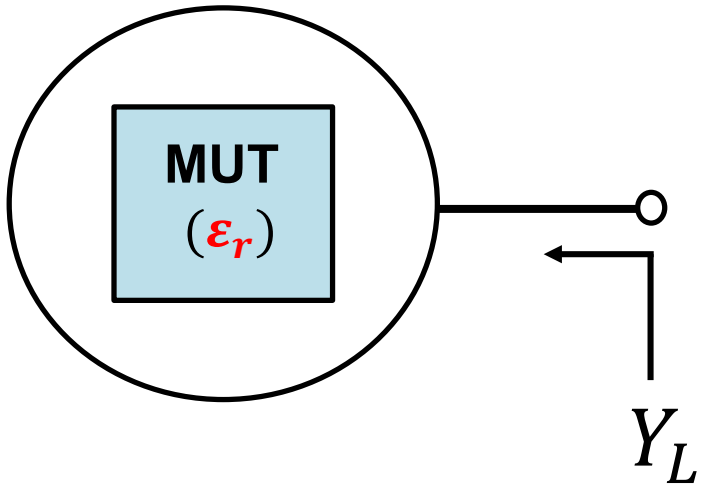
Dielectric constant at ω_o:

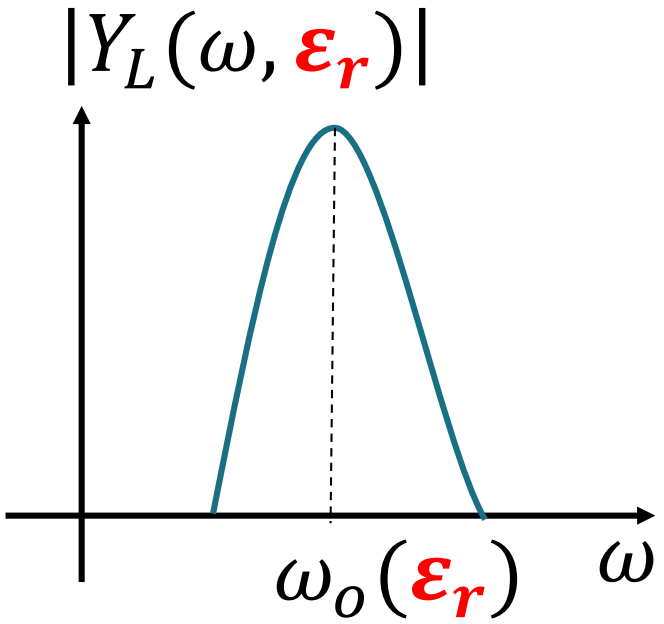
$$\varepsilon_r = \varepsilon' + j\varepsilon'' = \varepsilon'(1 + \tan\delta)$$

Parameters to be detected

Principle of operation

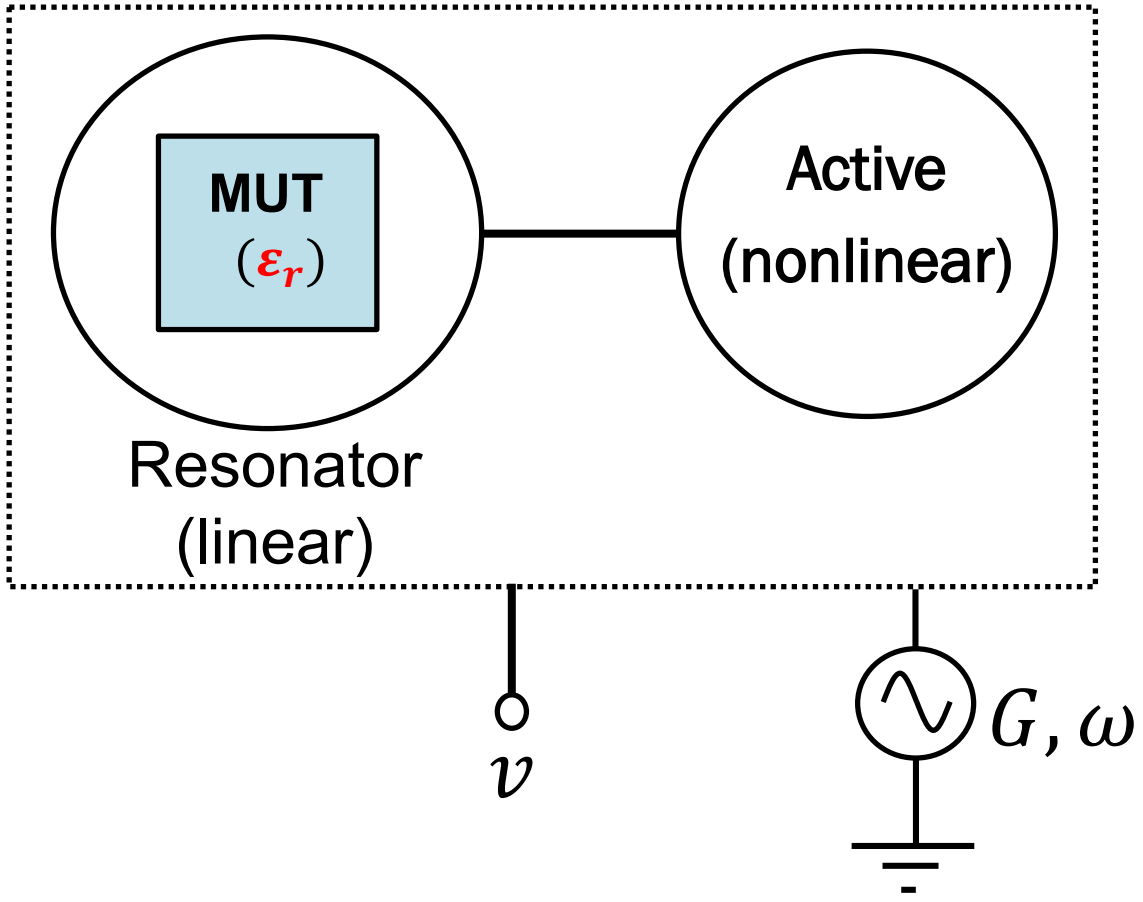
Resonator: linear circuit





Principle of operation

Injection locked oscillator (ILO) sensor:

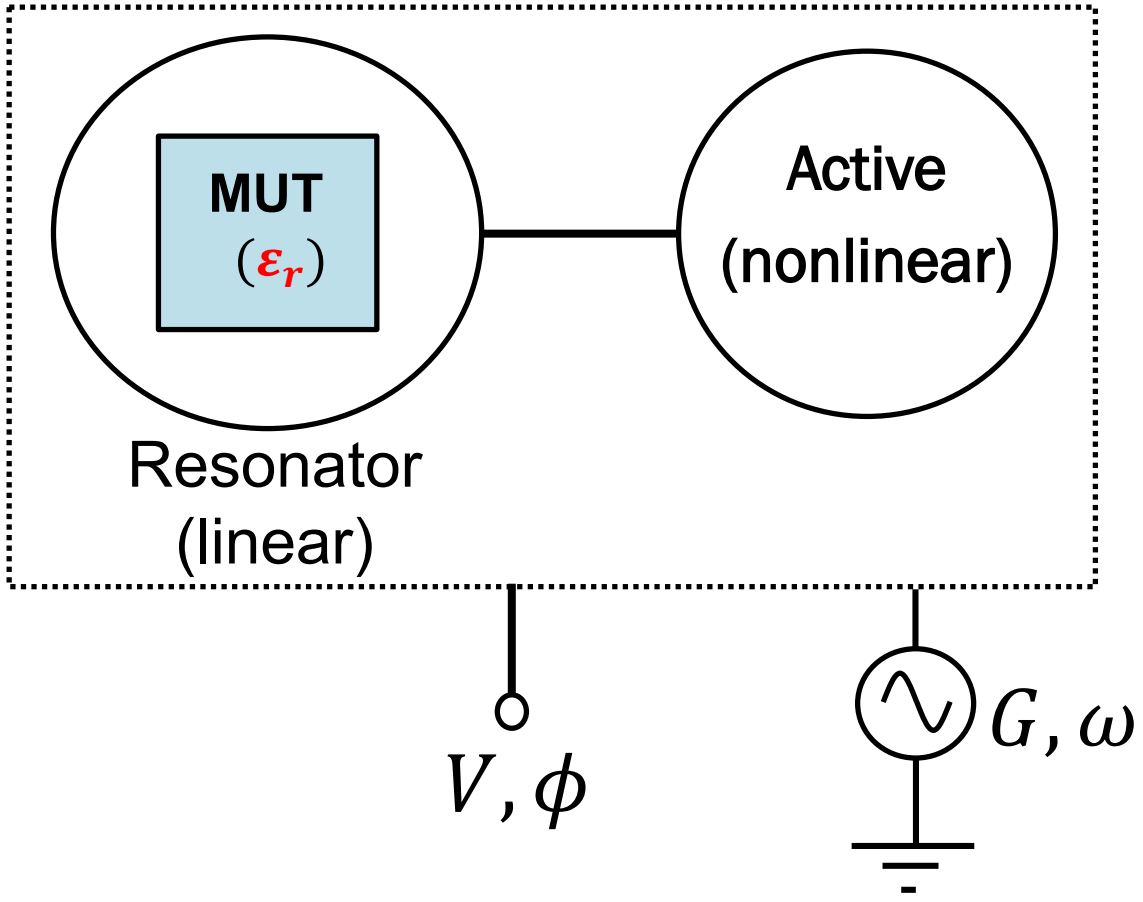


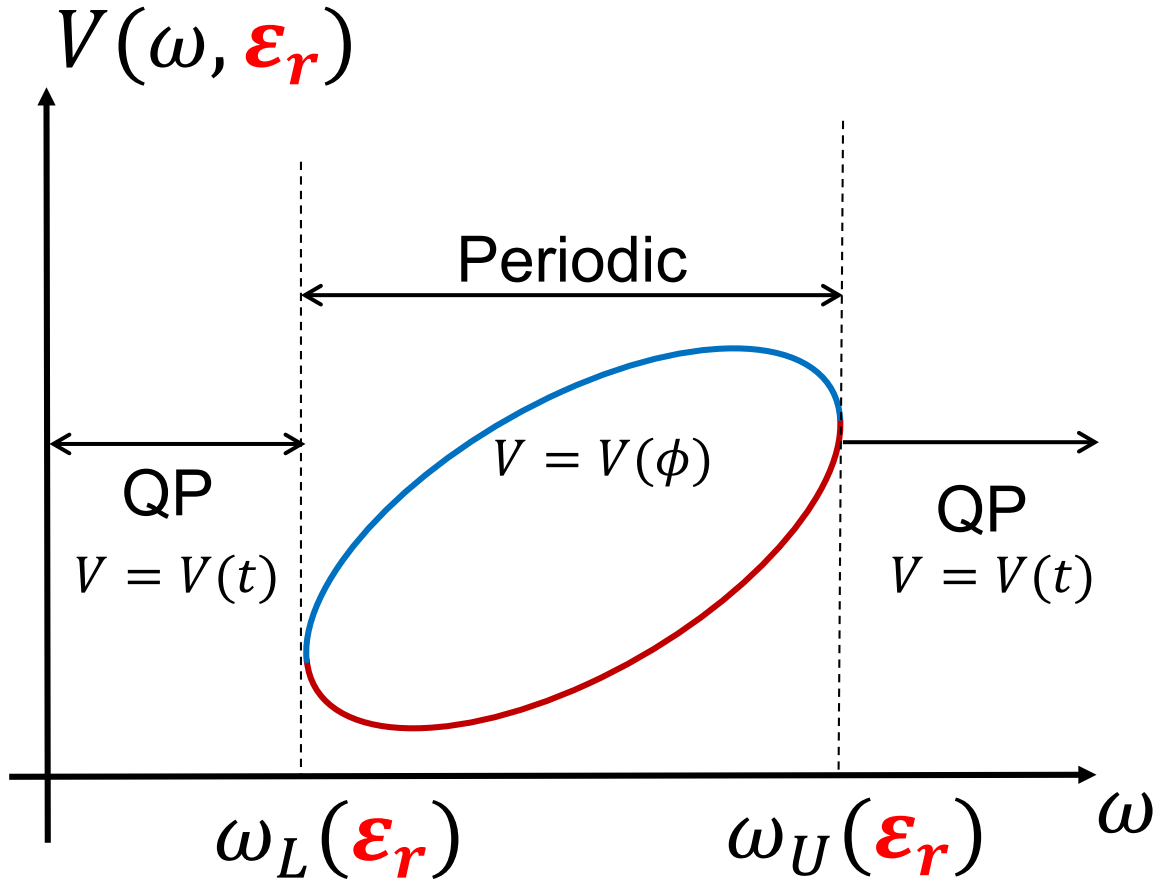
$$v(t) = \sum_k V_k(t) e^{j(k\omega t + \phi_k(t))}$$

$V = V_1(t, \varepsilon_r) \longrightarrow$ Observation variable

Principle of operation

Injection locked oscillator (ILO) sensor:





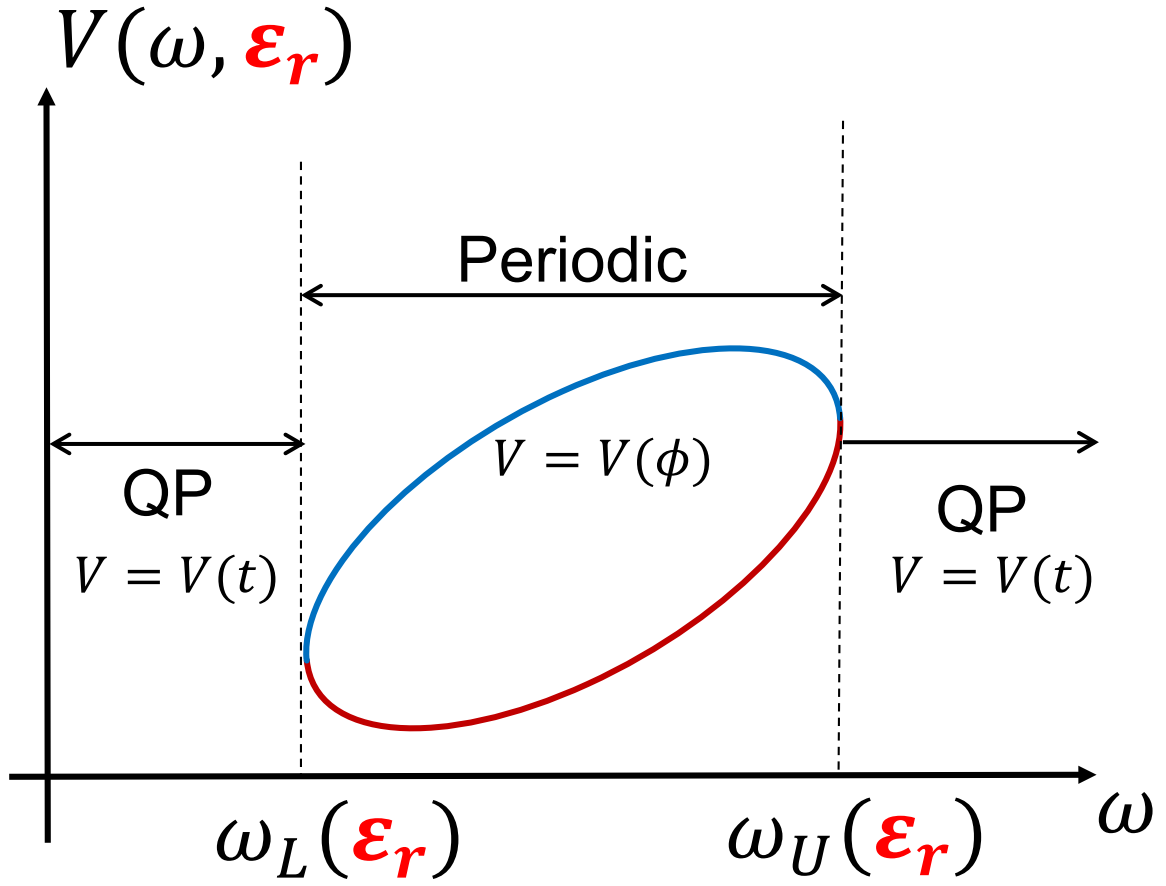
Principle of operation

Estimation:

(ω_L, ω_U) known

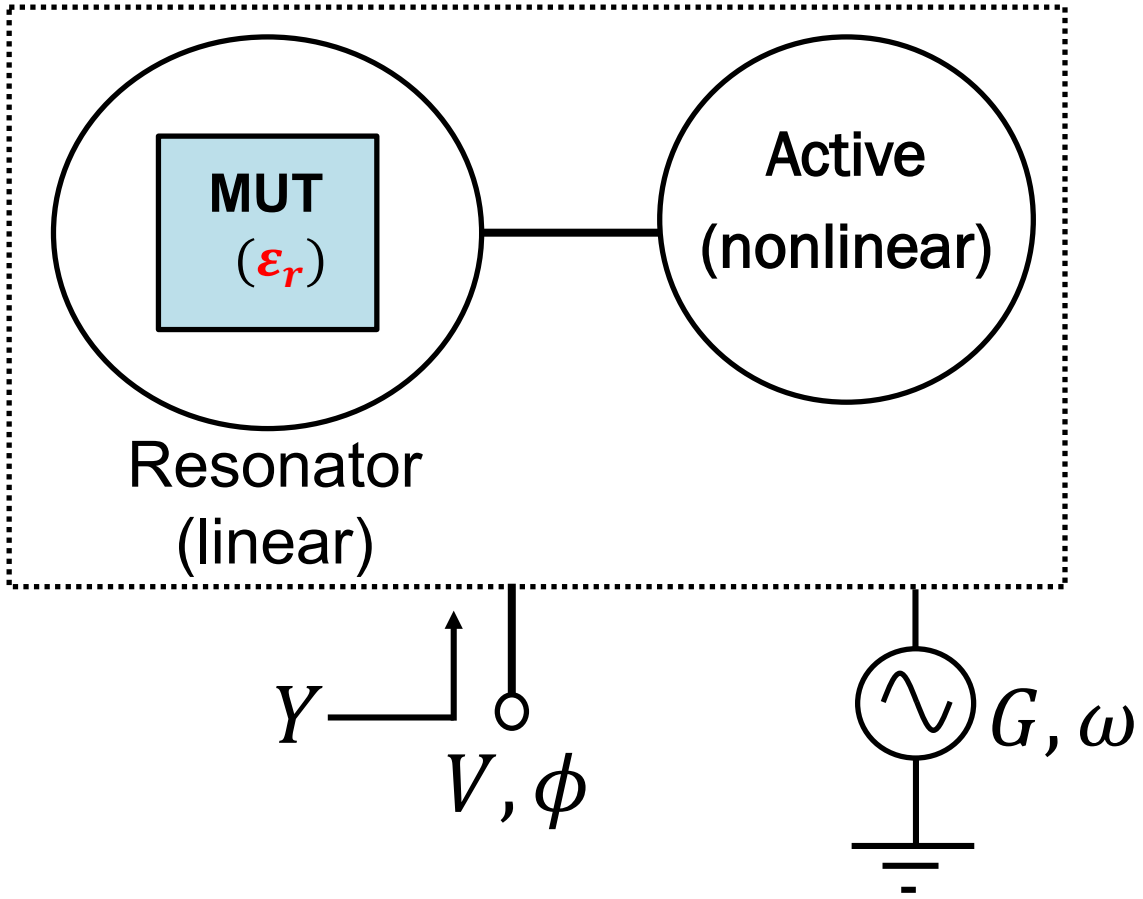
↓ ?

$(\varepsilon', \varepsilon'')$ determined



Principle of operation

System equations:



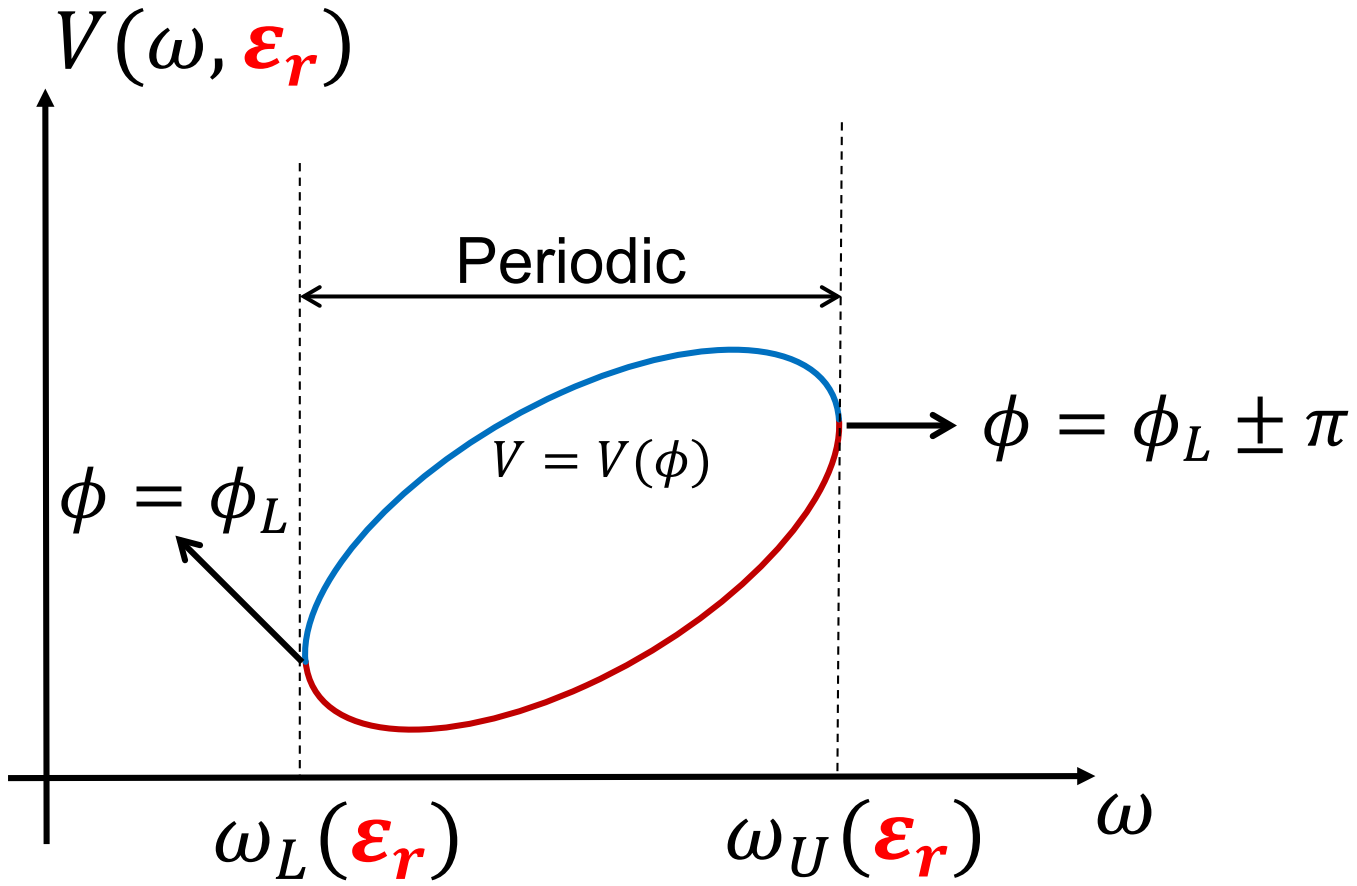
HB system

↓ Implicit function theorem

$$Y(V, \omega, \boldsymbol{\varepsilon_r}) = 0 \quad \text{(Inner tier)}$$

Principle of operation

System equations:



Border conditions:

$$\frac{\partial \omega}{\partial \alpha} = 0$$

$$\omega(\phi) - \omega_U = 0$$

$$\omega(\phi \pm \pi) - \omega_L = 0$$

Principle of operation

System equations: $u = \{V, \omega, \phi, \varepsilon', \varepsilon''\}$

$$Y(V, \omega, \boldsymbol{\varepsilon_r}) = 0$$

$$\frac{\partial \omega}{\partial \alpha} = 0$$

$$\omega(\phi) - \omega_U = 0$$

$$\omega(\phi \pm \pi) - \omega_L = 0$$

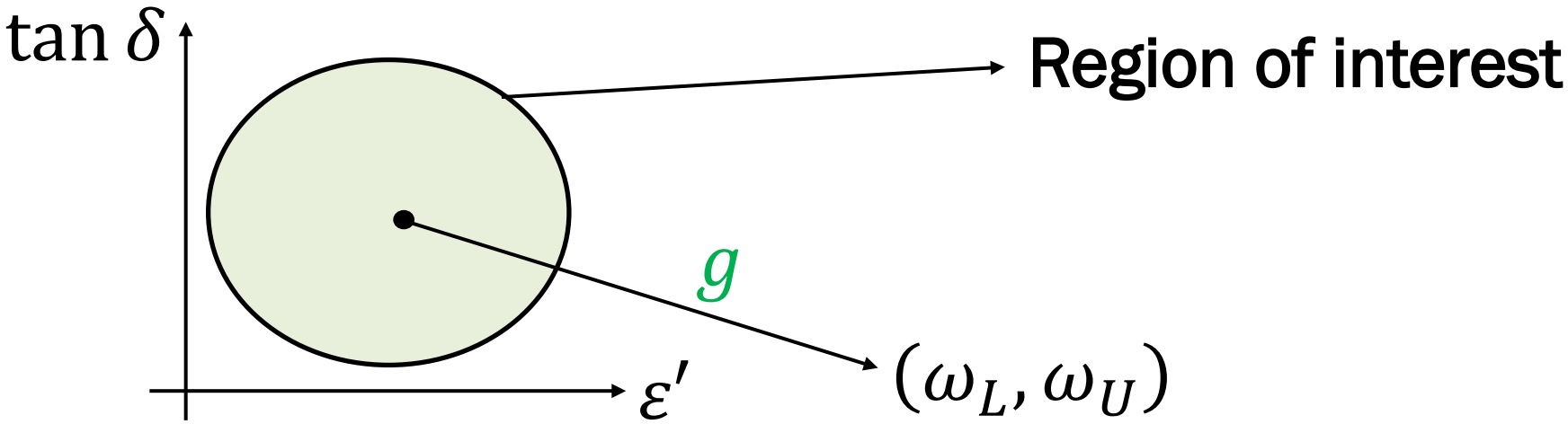
$$\longrightarrow F(u, \omega_L, \omega_U) = 0$$

$$(\varepsilon', \varepsilon'') = f(\omega_L, \omega_U) \Leftrightarrow \det \frac{\partial F(u, \omega_L, \omega_U)}{\partial u} \neq 0$$

Principle of operation

Calibration of the Sensing function: $(\varepsilon', \tan\delta) = f(\omega_L, \omega_U)$

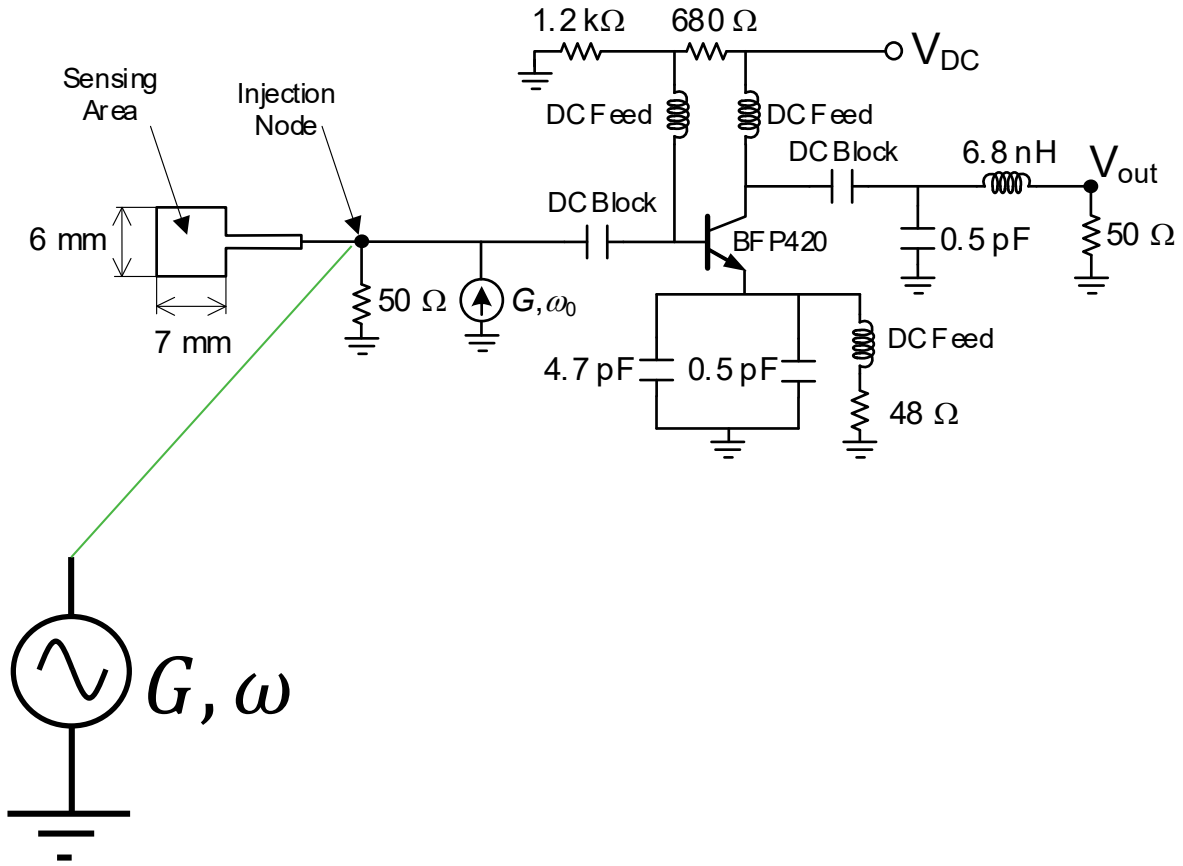
1) Detection of $(\omega_L, \omega_U) = g(\varepsilon', \tan\delta)$



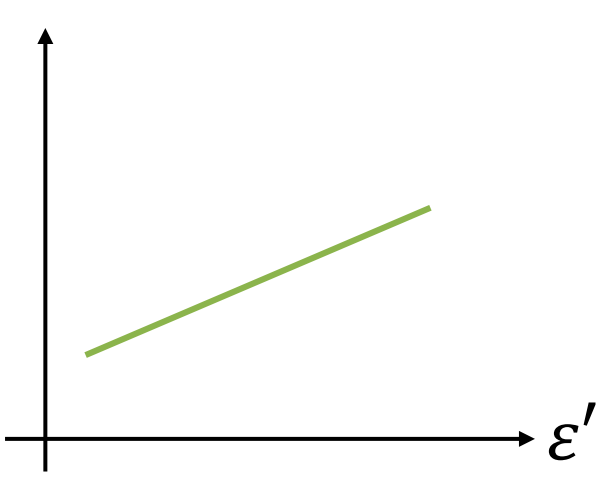
2) Obtain $f = g^{-1}$

Simulation

Injection-locked oscillator based on the NPN bipolar transistor BFP420



Region of interest:

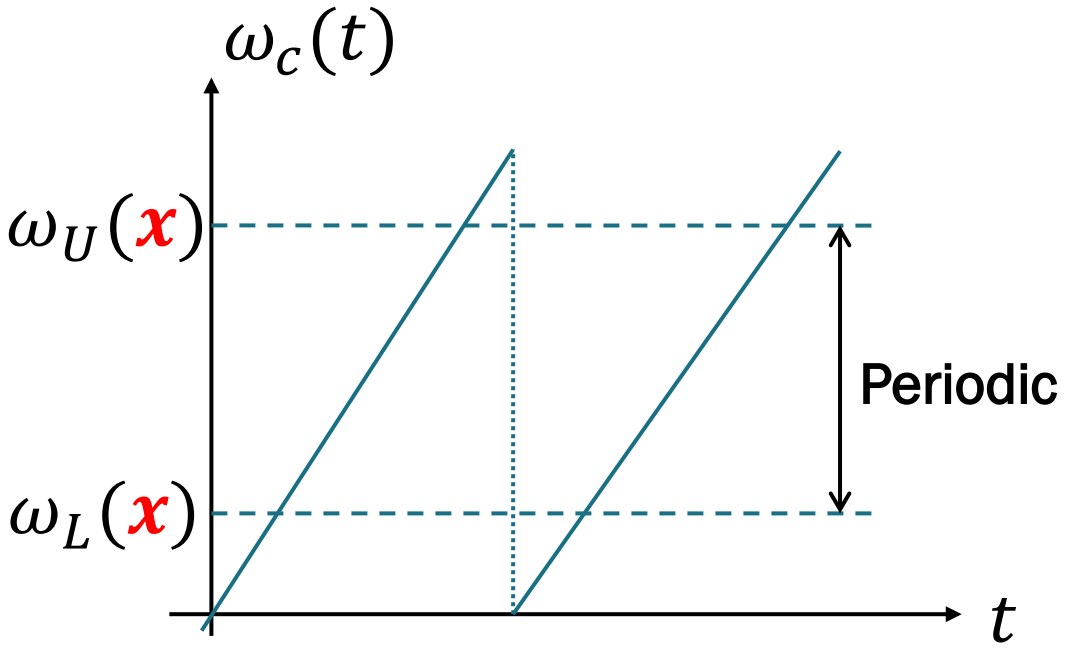


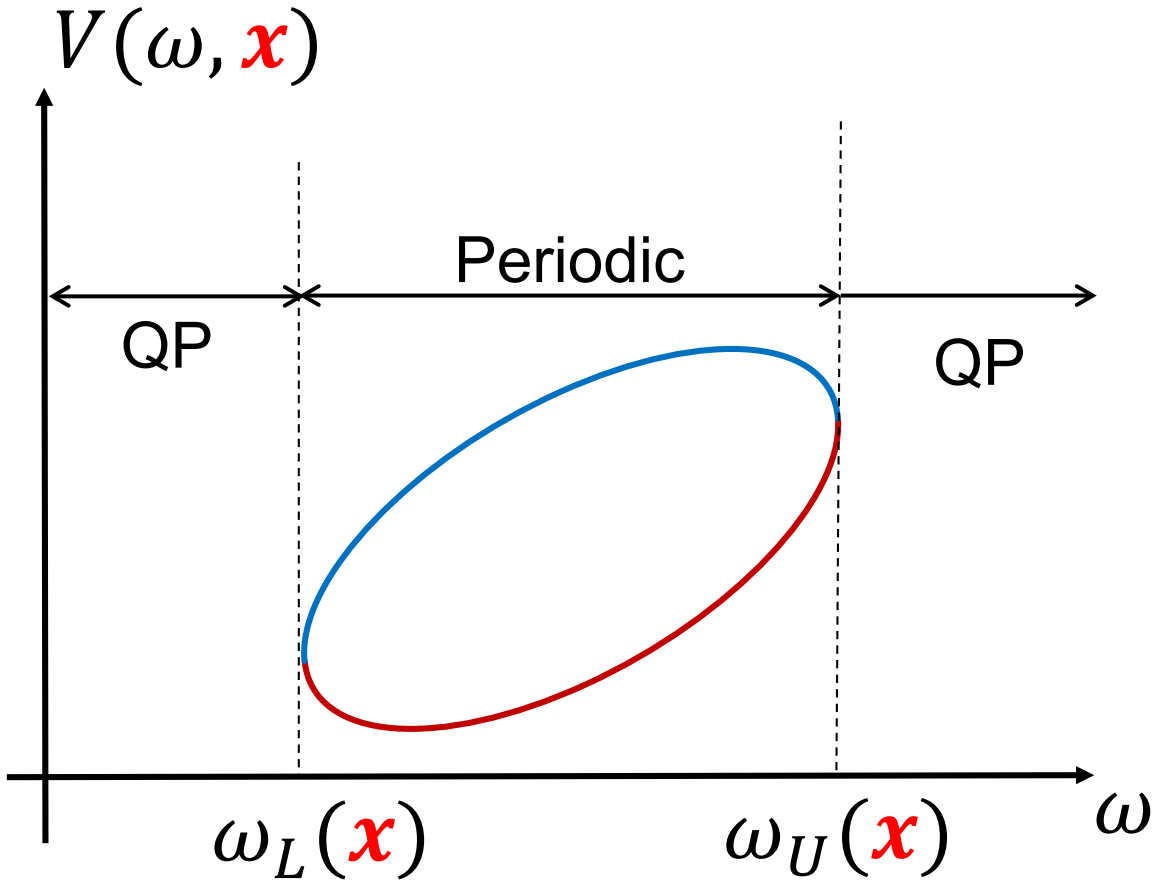
$$\varepsilon' = 1 + x$$

$$\tan\delta = 0.002 + 0.001x$$

Simulation

Injection source: chirp signal



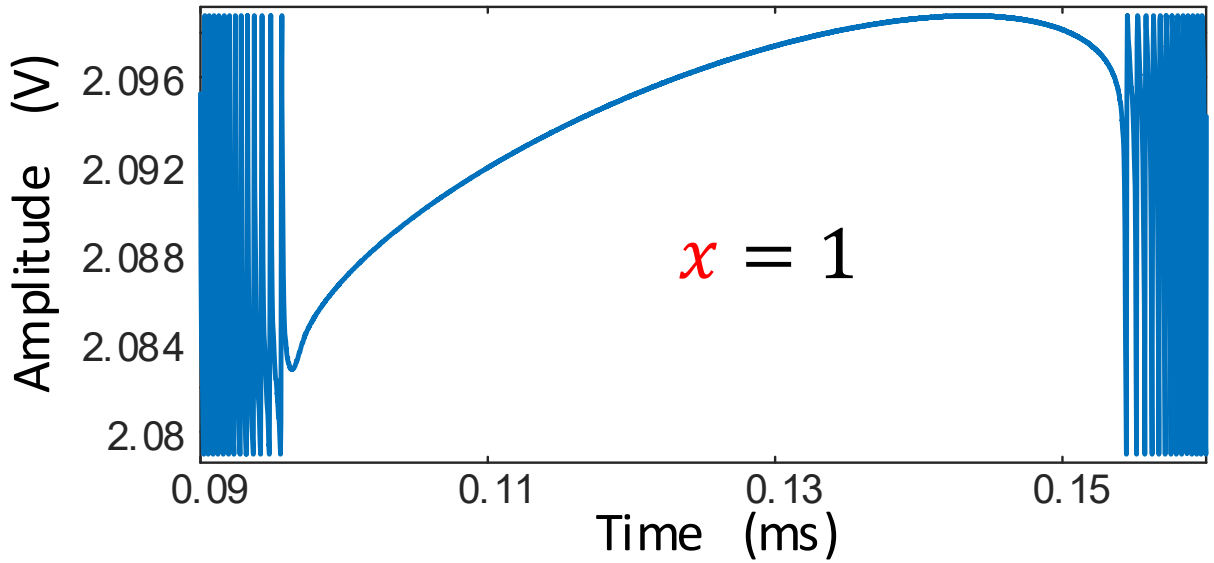


Simulation

Injection source: chirp signal

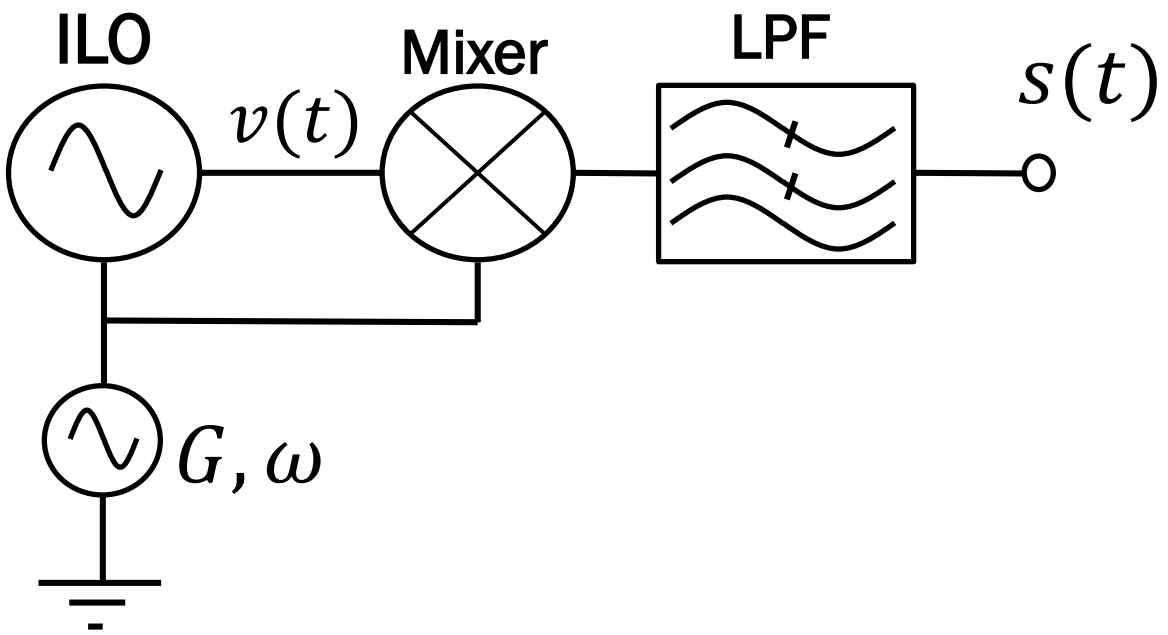
Inner tier: $Y(V, \omega, \boldsymbol{x}) = 0$

$$\longrightarrow Y_V(V - V_o) + Y_\omega\left(\omega_c - \omega_o + \dot{\phi} - j\frac{\dot{V}}{V}\right) + GY_g(\phi) = 0$$



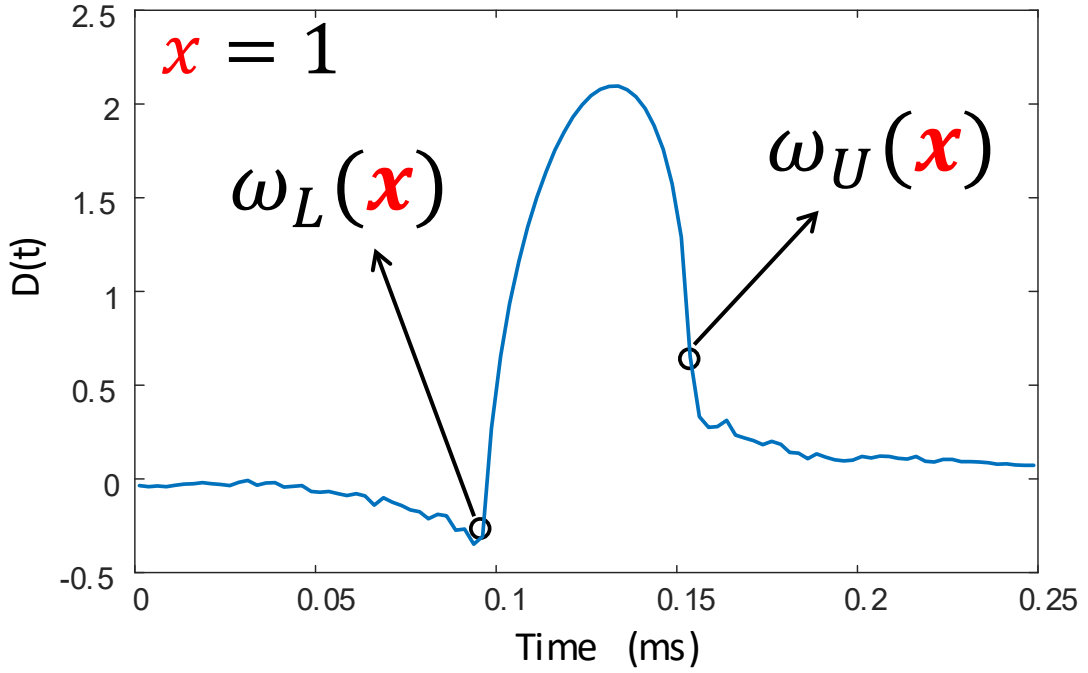
Simulation

Detection of ω_L and ω_U



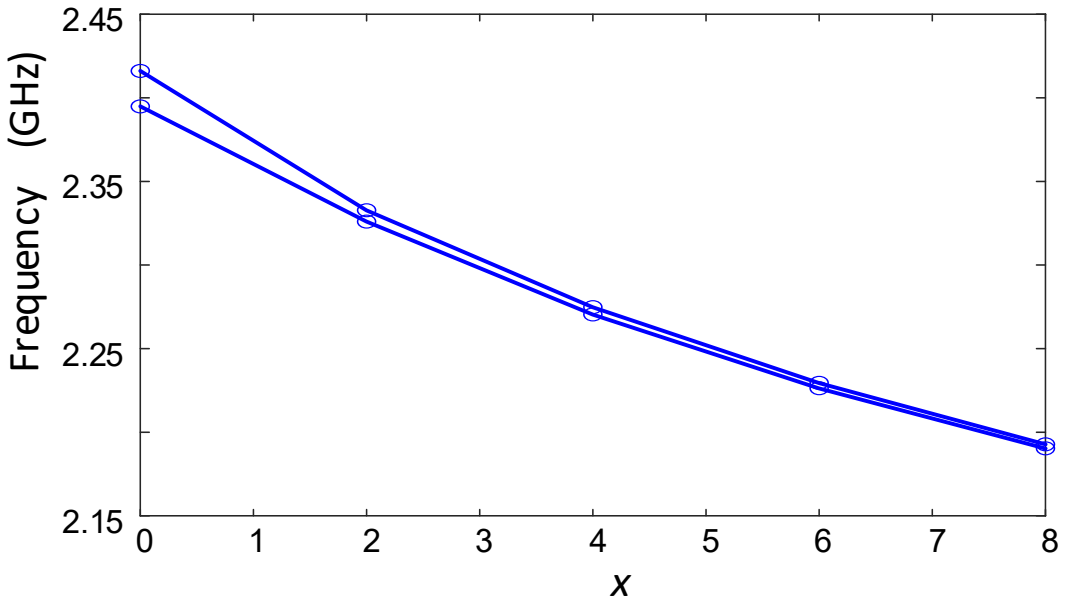
Averaging:

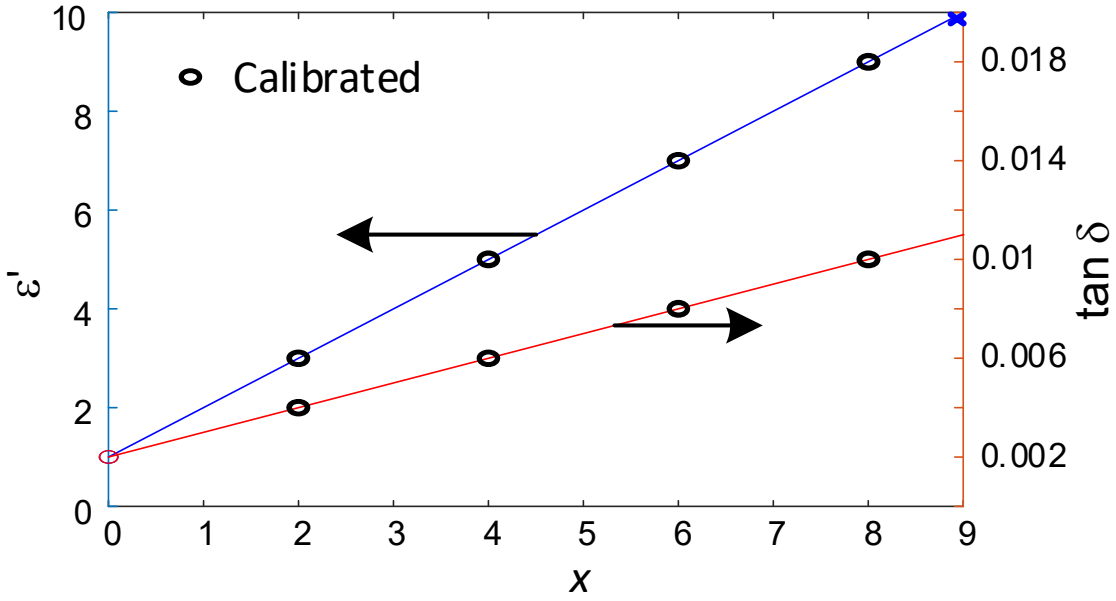
$$D(t_k) = \int_{t_k-\Delta t}^{t_k+\Delta t} s(t)dt$$



Simulation

Calibration:



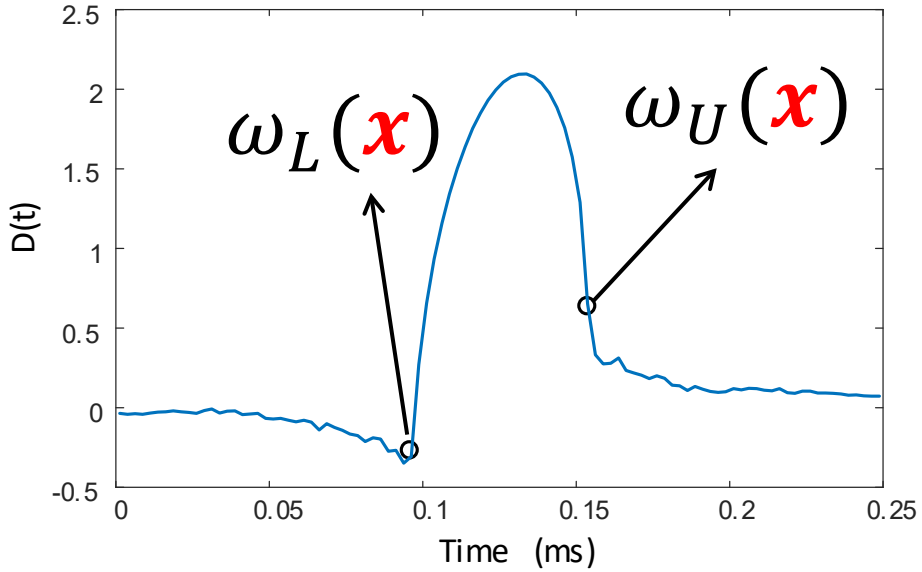


$$(\omega_L(x), \omega_U(x)) = g(\varepsilon'(x), \tan\delta\,(x))$$

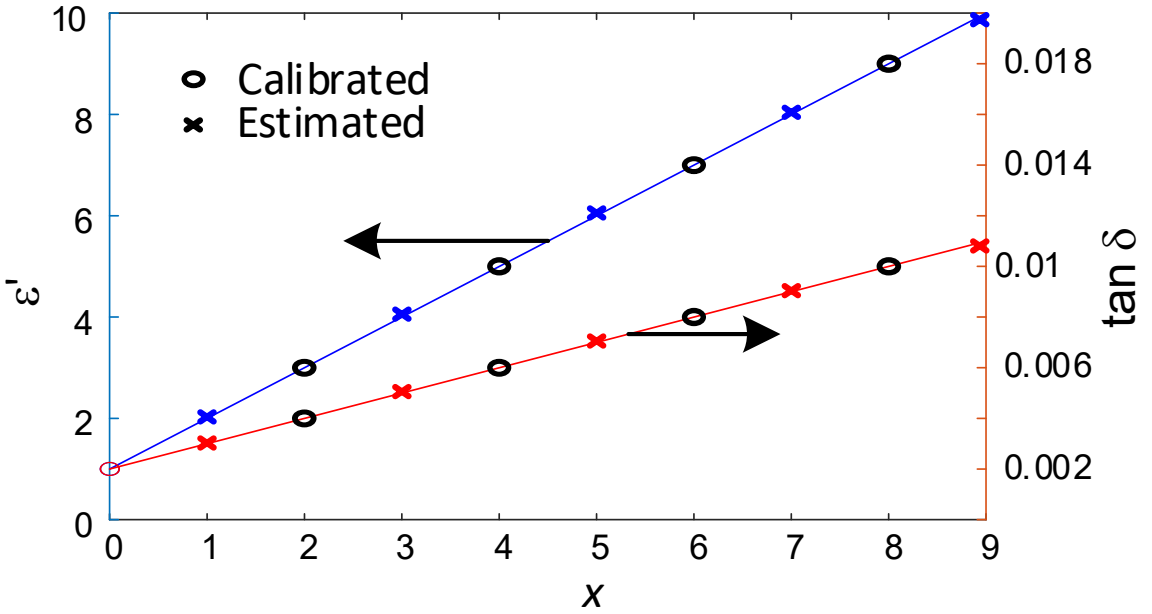
$$(\varepsilon'(x), \tan\delta\,(x)) = f(\omega_L(x), \omega_U(x))$$

Simulation

Estimation:

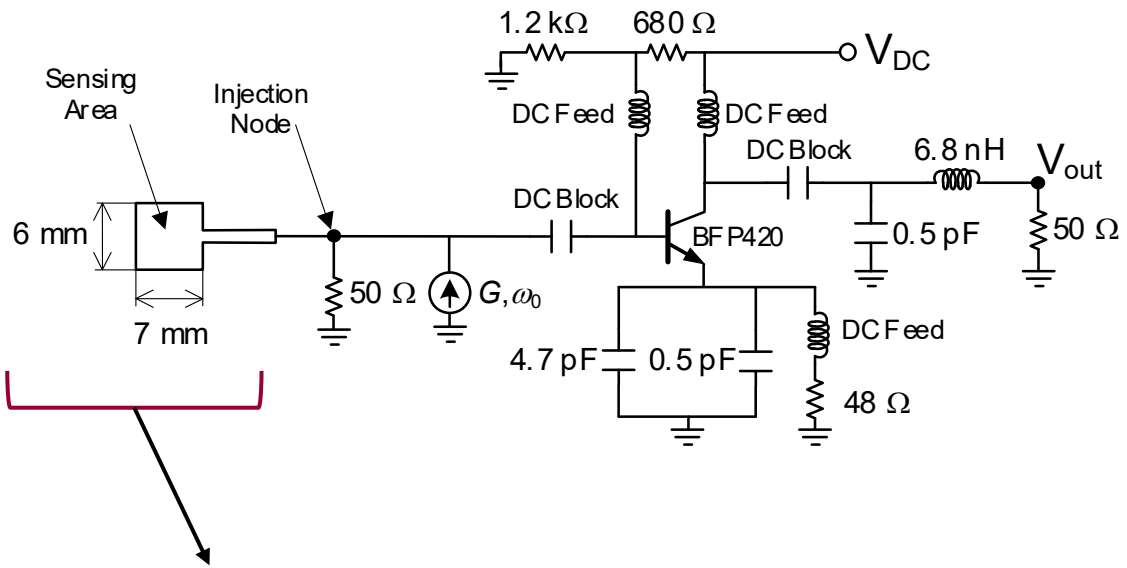


f

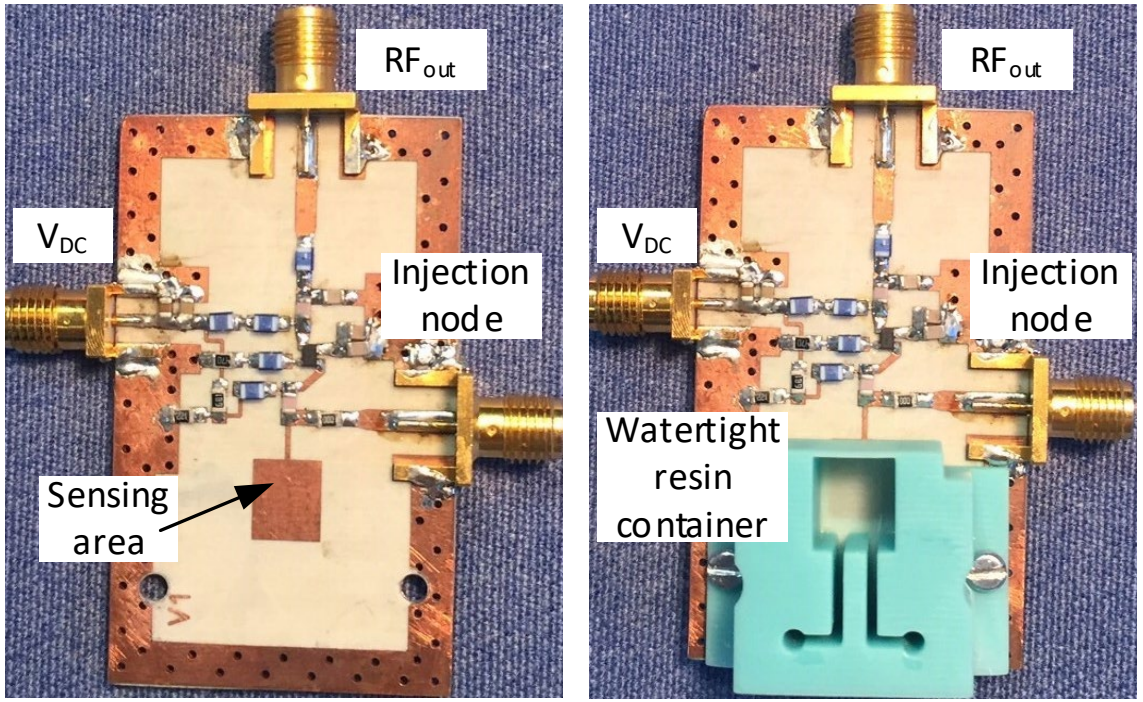


Application

x: Concentration of ethanol in water



Capacitive section of the resonator

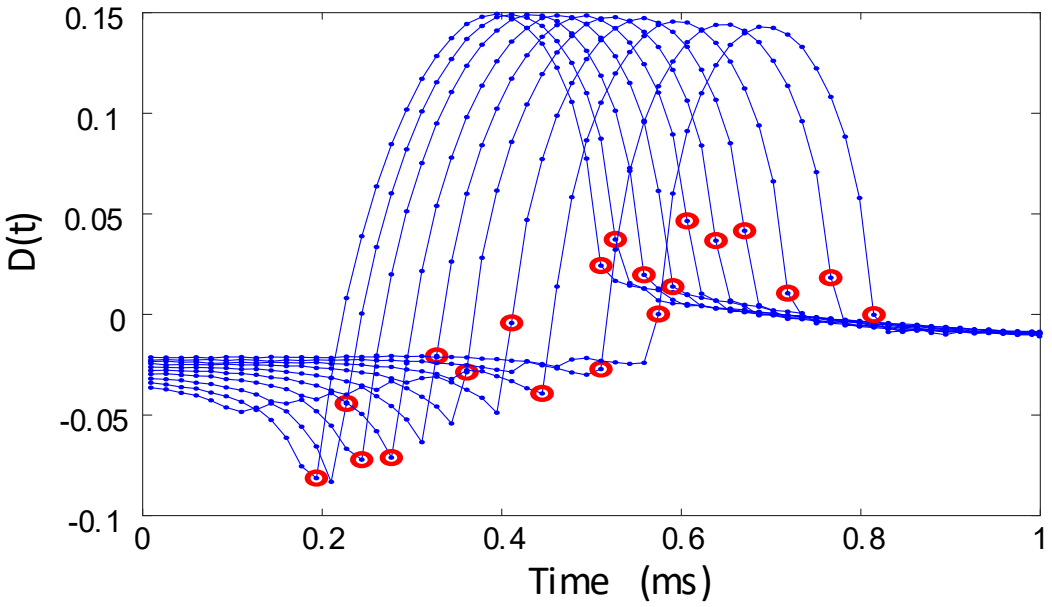


Prototype built on Rogers 4003C substrate with and without the resin container

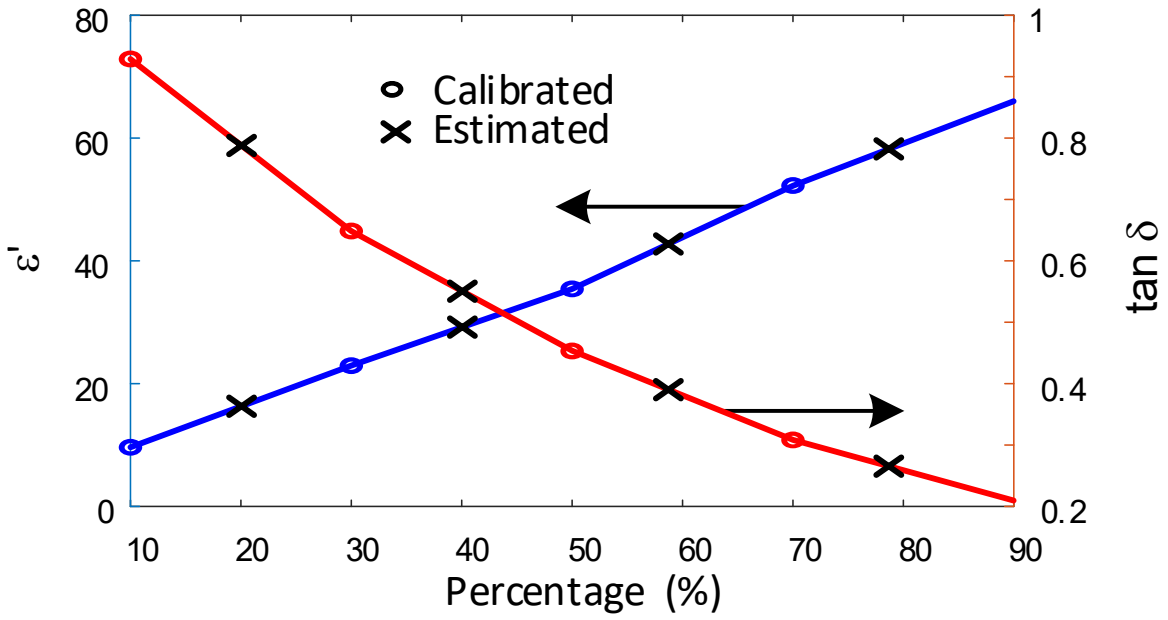
Application

x: Concentration of ethanol in water

Detection of ω_L and ω_U



Estimation of ε' and $\tan\delta$



Summary

- Sensor based on an injection-locked oscillator driven by a chirp signal
- The time interval for which the oscillator gets locked to the injection source depends on the MUT
- This time interval can be detected and used to estimate the MUT