# Modelling Injection Locked Spin-Wave Active Ring Oscillator

(Poster)

Anirban Mukhopadhyay[a], and Anil Prabhakar[a]

a: *Indian Institute of Technology Madras, Chennai, Tamil Nadu, India*

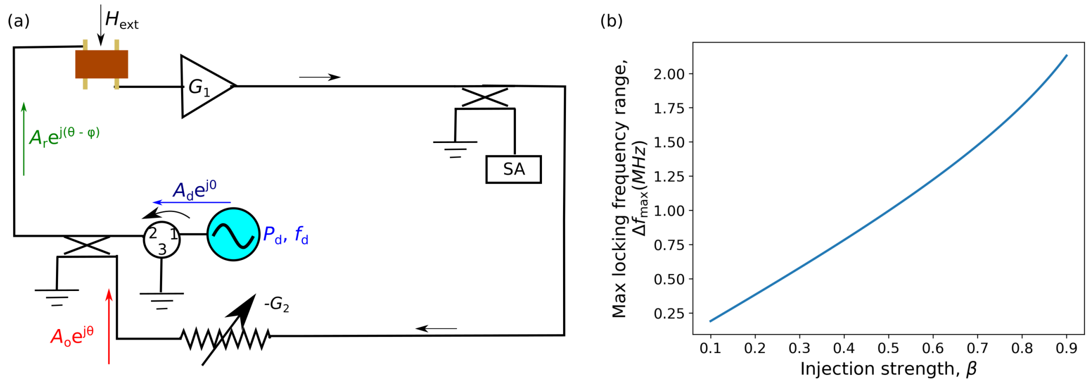


Figure 1: (a) Circuit of spin-wave active ring oscillator (SWARO) with drive source, (b) Maximum locking frequency range, $\Delta f_{\max}$ as a function of injection strength, $\beta$.

We have built a model to predict the locking frequency range for injection-locked spin-wave active ring oscillators (SWAROs), following the approach from [1, 2]. Figure 1(a) shows the experimental setup for SWARO, where a yttrium iron garnet (YIG) film acts as a lossy medium, and $G = G_1 - G_2$ is total ring gain that compensates for the losses occurring in the ring. By tuning $G_2$, we can excite different SWARO eigen-modes. The YIG film is 6.9 $\mu$m thick and has a saturation magnetization, $M_s = 138.46$ kA/m. The applied external field is perpendicular to the spin-wave propagation direction in a magnetostatic surface spin-wave (MSSW) geometry. We have estimated the effective field, $H_{\text{eff}}$ from the lower edge of the experimentally measured spin-wave manifold as $H_{\text{eff}} = 24.9$ kA/m [3].

We inject a GHz signal of frequency, $f_d$, and power, $P_d = |A_d|^2$ into the SWARO, to lock it with the drive signal. The total round-trip phase difference, $\varphi(f)$, has two parts, one from spin-wave propagation and the other from RF and electronic circuits. We represent the signals in the SWARO circuit as phasors, shown in Fig. 1(a). Using vector algebra, we expressed $\varphi(f_d)$, as a function of injection strength, $\beta \left(= \frac{A_d}{A_o} = \sqrt{\frac{P_d}{P_o}}\right)$, and phase angle between feedback and drive signals, $\theta$,

$$\varphi(f_d) \cong k_{\text{sw}}(f_d) l_{\text{sw}} + \frac{2\pi f_d}{v} l_{\text{rf}} = \tan^{-1}\left(\frac{\beta \sin\theta}{1 + \beta\cos\theta}\right), \tag{1}$$

where, $k_{\text{sw}}(f)$ is the MSSW dispersion relation, $l_{\text{sw}} = 9$ mm is the distance between $\mu$-stripline antenna pair, $v = 2.1 \times 10^8$ m/s is the velocity of the RF signal through the circuit, $l_{\text{rf}} = 1$ m is the length of circuit [4, 5]. Now, we have made our second assumption that the drive frequency ($f_d$) is close to SWARO eigenmodes ($f_n$), and as a consequence, we can approximate $\varphi(f_d)$ as a first-order Taylor series at $f = f_n$,

$$\varphi(f_d) \cong \varphi(f_n) + (f_d - f_n) \left.\frac{\partial \varphi}{\partial f}\right|_{f_n}, \tag{2}$$

where, $\varphi(f_n) = 2\pi n$ which is effectively zero phase shift. $\Delta f = (f_d - f_n)$ is the locking range. Using Eq. 1 and 2, we found out $\Delta f$ attains its maximum value at $\theta = \cos^{-1}(-\beta)$,

$$\Delta f_{\max} = \tan^{-1}\left(\frac{\beta}{\sqrt{1-\beta^2}}\right)\left(\left.\frac{\partial \varphi}{\partial f}\right|_{f_n}\right)^{-1}. \tag{3}$$

Next, we captured the output spectrum from the SWARO by setting $G_2$ at 8 dB. We estimated the maximum locking frequency ranges for different injection strengths in the neighbourhood of a SWARO mode at 2.25 GHz, using Eq. 3. Fig. 1(b) shows that the $\Delta f_{\max}$ changes from 0.19 to 2.13 MHz as $\beta$ increases from 0.1 to 0.9.

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