Energy Balance and Pole Movement in Dual Loop Optoelectronic Oscillator

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Abstract

In the present paper a theoretical analysis of pole movement in a dual loop Optoelectronic oscillator has been carried out. While auditing the previous works on dual loop optoelectronic oscillator, it has come to the notice of the authors that nothing has been said about the movement of poles in the dual loop. The amplitude equation of the oscillator has been derived using the energy balance principle and the free running amplitude is calculated. Some new findings regarding the pole movement have been presented. Simulation results have been presented in support of the theoretical finding.

1. Introduction

In the recent days a new type of photonic oscillator, known as Optoelectronic Oscillator (OEO) has drawn a great attraction of researchers. It converts the continuous light energy into stable and spectrally pure microwave signals. The construction and different configurations (single and dual loop) of OEOs has been studied in different literatures [1-4]. Recently Chatterjee et al, has reported in [5], the mechanism of pole movement in electronic and single loop OEO. It is well known that when the poles of an oscillator circuit lies in the right hand plane (RHP) oscillation is produced. In the present paper the mechanism of pole movement of a dual loop OEO is reported, which to the best knowledge of the authors, nothing has been reported yet. The equation for amplitude of oscillation has been derived from energy balance principle.

2. Amplitude of Oscillation from Energy balance principle

Let us assume that the RF input to the Mach-Zehnder modulator (MZM) is, $V_{in}(t) = V(t)e^{j[\omega_0 t]}$ where ‘$V(t)$’ is the amplitude of the signal with free-running frequency ω_0.

The output power of MZM can be expressed as [4]

$$P(t) = \frac{1}{2}\alpha P_0\left[1 - \eta\, sin\pi\left(\frac{V_{in}(t) + V_B}{V_\pi}\right)\right] \tag{1}$$

For the dual loop OEO, it is not difficult to show that

$$\beta_1(s) = \left[\frac{N(V(t-\tau_1))}{V}G(s).e^{-s\tau_1}\right] \qquad \beta_2(s) = \left[\frac{N(V(t-\tau_2))}{V}G(s).e^{-s\tau_2}\right] \tag{2}$$

where $N[V(t-\tau)] = 2J_1[V(t-\tau)]$

and $G(s)$ is the transfer function of the RF tuned amplifier .Again, $G(s) = gm.Z(s)$ where gm is the gain of the tuned circuit . When the input signal $V_{in}(t)$ passes through the dual loop OEO the output voltage can be expressed as

$$V_0(t) = (\beta_1(s) + \beta_2(s)).V_{in}(t) \tag{3}$$

Using (2) and (3) it can be shown that

$$\frac{1}{Z(s)} = 2gm\left[\frac{J_1(V(t-\tau_1))}{V}.e^{-s\tau_1} + \frac{pJ_1(V(t-\tau_2))}{V}.e^{-s\tau_2}\right] \tag{4}$$

Here p is considered as attenuation in the longer loop. Now $e^{-s\tau_1} = e^{-j\omega_0\tau_1} = 1$, $e^{-s\tau_2} = e^{-j\omega_0\tau_2} = 1$, and when $\omega_0\tau_1 = \omega_0\tau_2 = 2n\pi$, (4) can be approximated as

$$\frac{V}{Z(s)} \cong \left[2J_1(V(t-\tau_1)+2pJ_1(V(t-\tau_2))\right]gm \tag{5}$$

$$\left[\frac{V}{R}+C\frac{dV}{dt}+\frac{1}{L}\int Vdt\right]=\left[2J_1(V(t-\tau_1)+2pJ_1(V(t-\tau_2))\right]gm=G_{eq}.V \tag{6}$$

where

$$Geq=g_m\left[\frac{2J_1(V(t-\tau_1)+2pJ_1(V(t-\tau_2))}{V}\right]$$

Now the total energy stored in complete cycle is written as $E=\frac{1}{2}Li_L{}^2+\frac{1}{2}CV$ (7)

Therefore $\frac{dE}{dt}=V(i_C+i_L)=\left[V\left[G_{eq}-G\right]\right]V=\left[G_{eq}-G\right]V^2$ (8)

At steady state: $\int_0^T \frac{dE}{dt}dt=0$ and $Geq=2g_m\frac{J_1(V)+pJ_2(V)}{V}$ (9)

Expanding $2J_1(x)$ in series as $2J_1(x)\cong x-\frac{x^3}{8}$ and assuming $V\cong A\cos(\omega_0 t)$ one can obtain from (9)

$$A^2=\frac{32}{3}\left[1-\frac{G}{gm(1+p)}\right] \tag{10}$$

In order to appreciate for the transient behavior we consider the operation of the system near resonance

$$\left(\frac{1}{R}+j\omega C+\frac{1}{j\omega L}\right)\cong G+2C(\mathrm{j}\omega-j\omega_0) \tag{11}$$

and $j\omega=\frac{1}{V(t)}.\frac{dv}{dt}+j\omega_0+j\frac{d\theta}{dt}$ (12)

Using (11) and (12), the time varying amplitude of dual loop OEO can be written as

$$\frac{dV}{dt}=\frac{\omega_0}{2Q}G[2J_1(V(t-\tau_1))+2pJ_1(V(t-\tau_2))]-V \tag{13}$$

$g_m R=G=$ Gain at resonance

Now at steady state $\frac{dV}{dt}=0$, and from (13) it is not difficult to show that $V=\sqrt{2}\sqrt{2-\frac{1}{G}}$ (14)

where 'V' is the free-running oscillation amplitude.

3.0 Pole Movement in a Dual Loop OEO

Considering fig.1, the system equation of the dual loop OEO can be written as

$$N(V)\ G(s)=V \tag{15}$$

$$GV+C\frac{dV}{dt}+\frac{1}{L}\int Vdt=gm\ N(V) \tag{16}$$

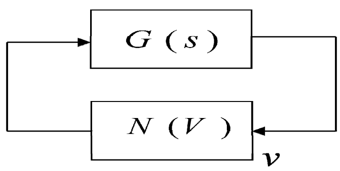

Fig1. Closed loop representation of an oscillator

Differentiating (16) with respect to time one get

$$s^2+\frac{gm}{C}\left(G-\frac{N(V)}{V}\right)s+\omega_0^2=0 \tag{17}$$

Now considering the linear case and assuming

$V_\pi=\pi$ and $V_{ph}=\dfrac{V_\pi}{\pi}$, one gets

$$N(V)=\eta V_{ph}\frac{\pi}{V_\pi}V(t-\tau_1)+\eta V_{ph}\frac{\pi}{V_\pi}V(t-\tau_2)=\eta V(t-\tau_1)+\eta V(t-\tau_2) \tag{18}$$

Now substituting

$$N(V)=\eta e^{-s\tau_1}+\eta e^{-s\tau_2} \tag{19}$$

$$s^2+\frac{gm}{C}\left[G-(\eta e^{-s\tau_1}+\eta e^{-s\tau_2})\right]s+\omega_0^2=0 \tag{20}$$

$$x^2+\frac{gm}{Q}\left[1-\frac{(\eta e^{-xq_1}+\eta e^{-xq_2})}{G}\right]x+1=0$$; where $Q=\dfrac{C\omega_0}{G}, x=\dfrac{s}{\omega_0}, q_1=\omega_0\tau_1, q_2=\omega_0\tau_2$

When $q_1,q_2=0$ $\quad x^2+\dfrac{gm}{Q}\left(1-\dfrac{2\eta}{G}\right)x+1=0$ (21)

The poles of the double loop OEO when the delay is zero are $s_{1,2}=-\sigma\pm j\omega$ and the solution of the oscillator equation in time domain becomes $v(t)=Ae^{-\sigma t}\cos\omega t=V(t)\cos\omega t$ and therefore

$$\sigma(t)=\frac{1}{V(t)}\frac{dV(t)}{dt} \tag{22}$$

4. Results and Discussion

Using MATHCAD™ , variation of $\sigma(t)$ with time i.e., the pole movement with time can be computed from (22), using the amplitude equations for single-loop and dual-loop OEO. For a single-loop delay, from the figure (2) and (3) it can be appreciated that before attaining the steady state oscillation the amplitude and frequency goes on changing. Thus it takes a finite time to settle down to the final value. Moreover, from the phase-plane diagram it is evident that the transient part is having improvement over the dual-loop OEO. The theoretical and simulated result of variation of oscillation amplitude as a function of RF gain is shown in fig. 7.

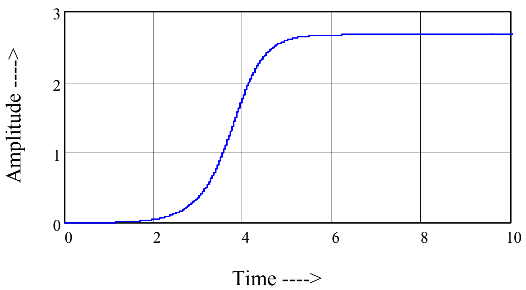

Fig 2. Growth of amplitude of oscillation for single loop OEO

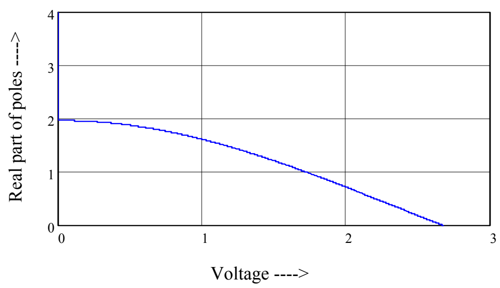

Fig 3. Phase plane plot of single loop OEO

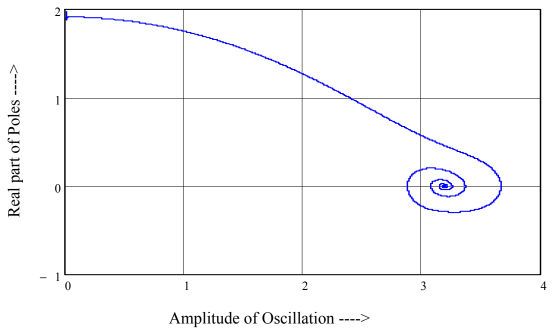

Fig 4. Movement of real part of poles in a dual loop OEO

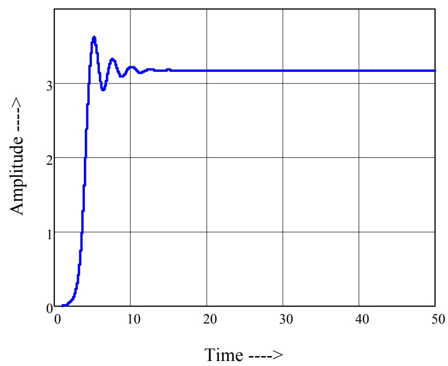

Fig 5. Growth of oscillation in a dual loop OEO

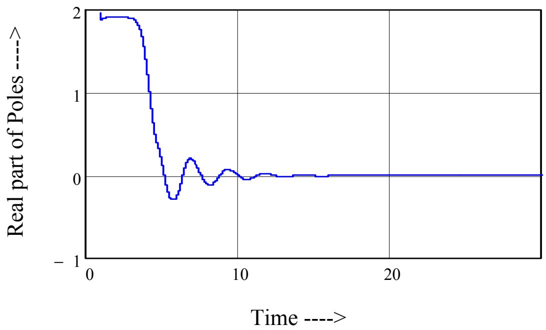

Fig 6. Variation of damping of dual loop OEO

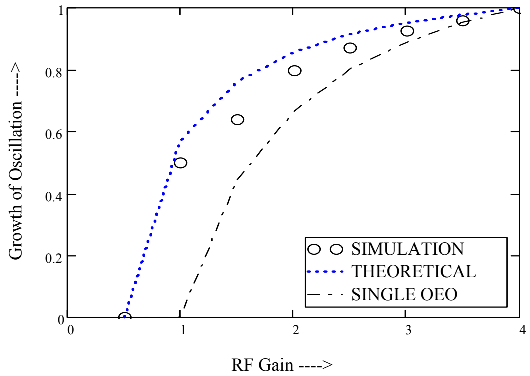

Fig 7. Variation Oscillation amplitude with Gain

5. Conclusion

In this literature the mechanism of pole movement in dual loop OEO is analyzed theoretically. The steady state amplitude of a double loop OEO is investigated and the variation of open loop gain with amplitude is studied. While auditing the double loop OEO, it came to the notice of the authors that the real part of the pole takes a spiral motion before it settles down to its steady state value. This reflects the transient motion of the OEO amplitude.

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