Advantages: Additional number of features

i) High input impedance
ii) High gain accuracy than use of sing op-amp
iii) High CMRR

Suppose the voltage

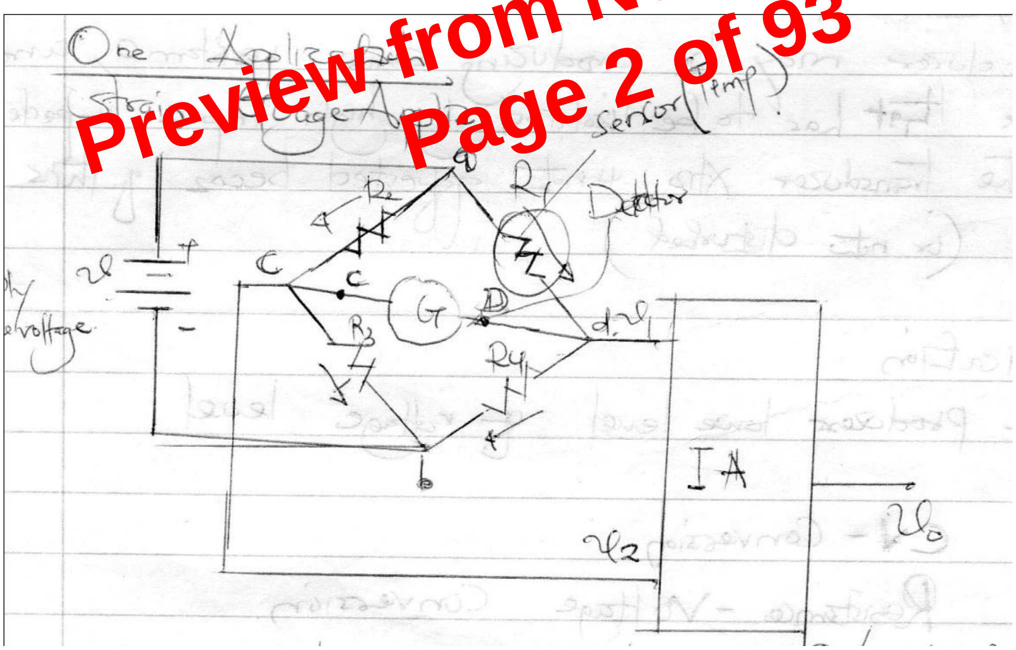
i) $\left.\begin{aligned} u_1 &= -1 \\ u_2 &= +1 \end{aligned}\right\}$ $u_d = 2V$

ii) $u_1 = 1$
$u_2 = 3$ $u_d = 2V$

iii) High gain stability with low temperature coefficient
iv) Low dc off set
v) Low output impedance

One application

Strain Gauge Application



Balanced

$$\left({R_2}/{R_3} = {R_1}/{R_4}\right)$$

Change in small resistance will be measured/translated into v_0

Saying $B_1 + B_2 = 1 + \propto_1 + \propto_4$ making this assumption

$u_{03} = \frac{1}{SGR_1} \quad \frac{-2(1-\propto)S^2C_1C_2R_1R_2}{[S^2C_1C_2R_1R_2+2\propto_2C_2R_2+1]}$

$== -2(1 \propto)SC_sR_2$

= BPF- transfers fxn

$s = jw \qquad u_{03} = 0$

$w = 0 \qquad u_{03} = 0$

$w = \infty$

At $w_0^2 = \frac{1}{GC_2} \quad R_1R_2 \qquad = Reasnant \quad frequency$

Once again integrate $u_{02} = \frac{-2(1-\propto)S^2R_2R_2}{S^2R^2C^2(S^2C_1C_2R_1R_2+2\propto_2C_2R_2+1)}$

$s = jw$

$w = 0 \qquad u_{02} = infinity$

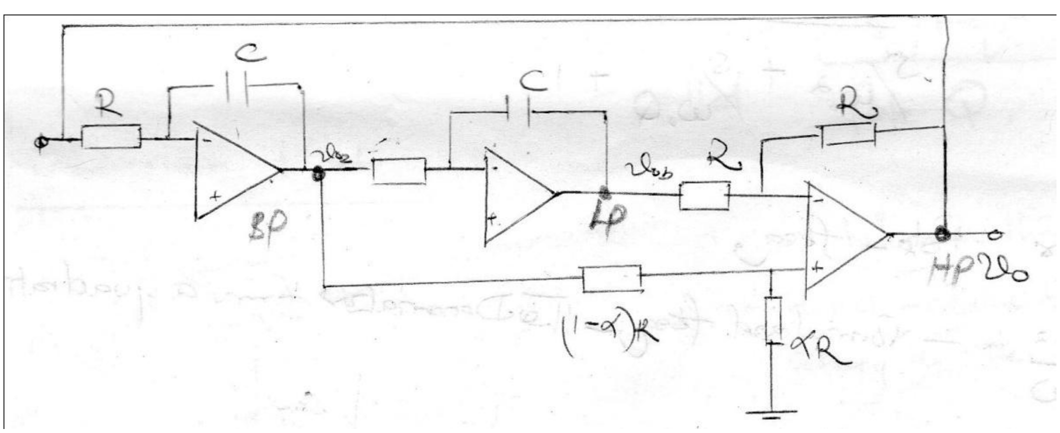
$w = \infty \qquad u_{02} = 0$

Hpf- transfer fxn

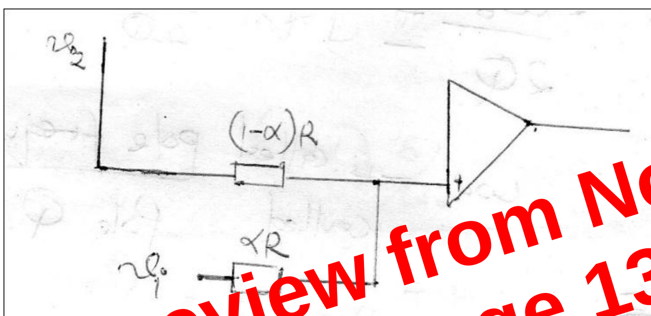
- These three outputs are simultaneously available in this cct hence its called universal active filter.
- Hence one can get HP LP BP and one can get using additional summing amplifier.
- Poles of the system are – lie on the negative side hence the systems is stable filter fxn
- One can cascade such filter block one can get higher order filter block.

ACTIVE FILTERS

Double integrator loop (2 integrator are used)



- High Q reduces horizontal distance $^{w}/_{2Q}$
- jw is going to be close to w_0 - resonant frequency $j\left(\sqrt{1-\frac{1}{4Q^2}}\right)$
- Poles on imaginary axis – forms resonant frequency
- If the pole Q is high the actual frequency is close to resonant frequency
- The LP, HP and BP equations above give us information about the system i.e. 2nd order system, the pole being second order. And the high pole Q- means high quality factor (Q- quality factor)
- If Q is infinity (when $\propto = 0$ since $Q = \frac{1}{2\propto}$, meaning there is no real part the poles fall on imaginary axis.
- It means there is no feedback i.e. there is no $\propto -$ connection of



- $\propto = 0$ i.e. there is no u_i and hence u_{02} is not feedback as shown therefore the cct has two integrators and inversion from the different equation above.

$$\frac{d^2u_0}{dt^2} + \delta u_0$$

- This is second order system of ***harmonic oscillator***
- When $^{du}/_{dt}$ term is not present this is <u>**Harmonic Oscillator**</u>
- It can by itself without input the output will be close to resonant frequency
- $(1-\propto)R$ still can exist as R and u_i can still exist, but as an oscillator u_1 can as well be connected to ground

- Potential across R

$$u_i \longrightarrow \boxed{R} \longrightarrow u_i - \frac{u_i}{SCR}$$

$$\left(u_i - u_i - \frac{u_i}{SCR}\right) = \frac{u_i}{SCR}$$

Current across outermost

$$R = \frac{u_i}{SCR^2}$$

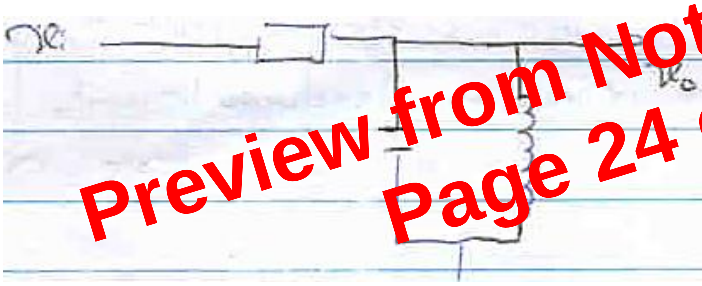
Input impendence Z;

$$Z = \frac{u_o}{I_i} = \frac{u_i}{SCR^2/u_i}$$

$$= SCR^2 \quad ; impendence\ Z\ is\ SCR^2 which\ is\ that\ of\ an\ inductor.$$

Gmesdendinductor $L = SCR^2$(simulated L)

Use of this in tank network – it stores energy.



$$\frac{u_o}{u_i} = \frac{1/R_s}{1/R_s + SC + 1/SL}$$

Conductance linking the output (with source) to output.
Total admittance
(summance of all admittance)

$$= \frac{SL/R_s}{S^2LC + SL/R_s + 1}$$

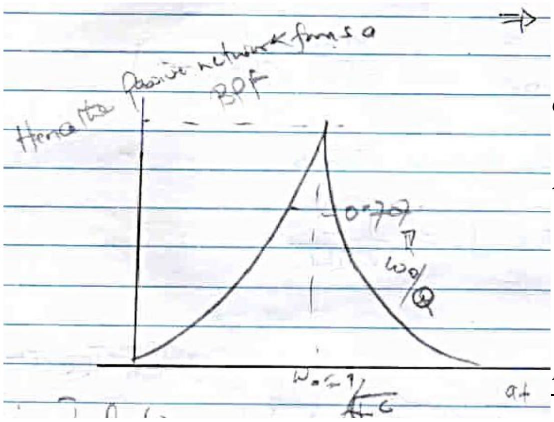
Re-write using state variable felt to KHN network

$$\omega_o = \frac{1}{\sqrt{LC}}$$

$$\omega_o\theta = \frac{R_s}{L}$$

$$\theta = \frac{R_s}{\omega_o L}$$

$$= \frac{S/\omega_o\theta}{S^2/{\omega_o}^2 + S/\omega_o\theta + 1}$$



$$\Rightarrow L = SCR^2$$

$$\omega_o{}^2 = \frac{1}{LC}$$

$$L = \frac{1}{\omega_o{}^2 C}$$

$$Q = \frac{R_s}{L\omega_o} = R_s \omega_o C$$

Or

$$\frac{R_s\sqrt{LC}}{L} = R_s\sqrt{\frac{C}{L}}$$

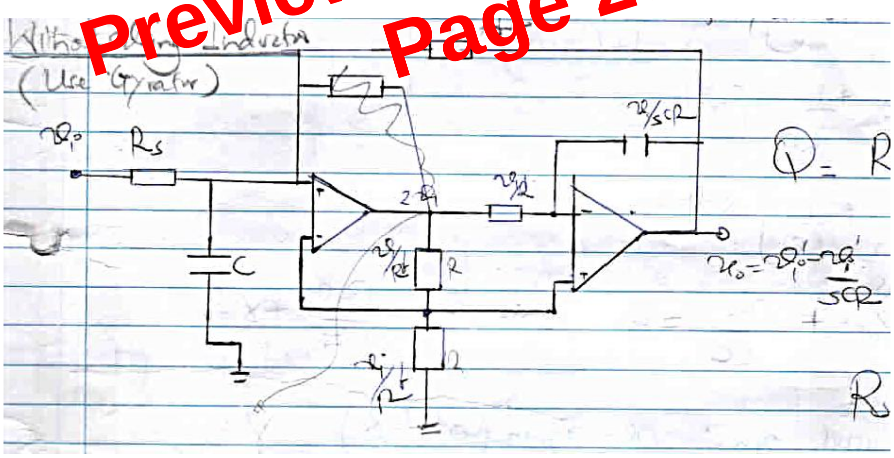
$$\omega_o{}^2 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{CR^2C}}$$

$$= \frac{1}{RC}$$

$$Q = R_s\sqrt{\frac{C}{L}} = R_s\sqrt{\frac{C}{CR^2}}$$

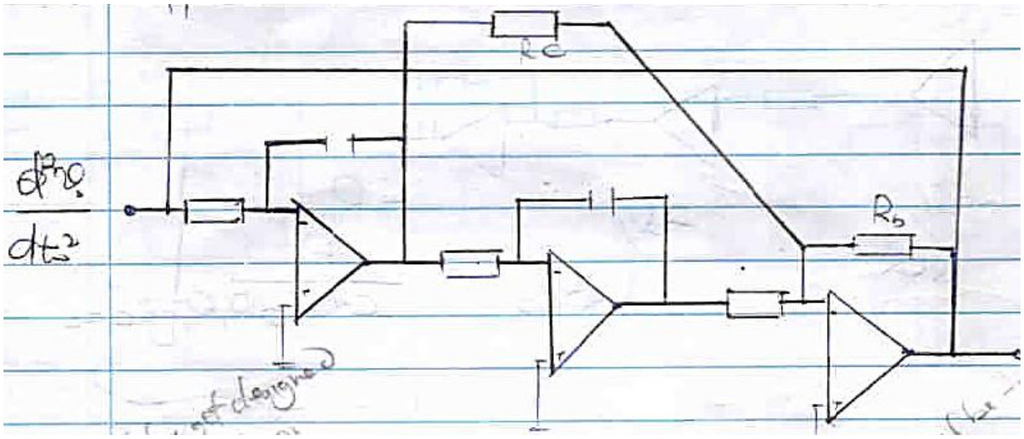
$$= \frac{R_s}{R}$$

$$R_s = QR$$



$$2u_i = \frac{2.5/_{\omega_o \theta}}{S^2/_{\omega_o{}^2} + S/_{\omega_o \theta} + 1}$$

$$\omega_o = \frac{1}{\sqrt{CR^2C}} = \frac{1}{RC} = \frac{1}{\sqrt{LC}}$$



$$\frac{\delta^2\varphi}{\partial t^2} + \alpha\frac{\delta\varphi_o}{\partial t} + \gamma\varphi_o = 0$$

$$\frac{\delta^2\varphi}{\partial t^2} = -\gamma\varphi_o - \alpha\frac{\delta\varphi_o}{\partial t} = 0$$

To make it to go to oscillation in practice we need a small negative value here for $\left(\alpha\frac{\delta\varphi_o}{\partial t}\right)$ which will go to zero at required amplitude.

So how will one make that?

With $\frac{-1}{RC}\frac{\delta\varphi_o}{\partial t}\left(-\gamma\varphi_o = \frac{-R_b/R_a\varphi_o}{R_1R_2C_1C_2}\right)$

Take portion of $\frac{-1}{RC}\frac{\delta\varphi_o}{\partial t}\left(\frac{1}{SRC}\right)$ and take it to the output $\gamma\varphi_o$

$$\alpha\frac{\delta\varphi_o}{\partial t} = \frac{-{R_b}/{R_a}}{R_1C_1}\frac{\delta\varphi_o}{\partial t}$$

RC will facilitate oscillation ($\alpha - ve$).

RC will be large and grow to infinity. At RC =∞ all the poles of the system falls along the imaginary axis hence an oscillation.

RC goes to infinity as amplitude builds up.

NB:

Remember we had seen α being fed to summer on +ve terminal forms/enables a filter to be designed.

Now substitute $s = j\omega$

$$\frac{1 + {}^{R_b}/_{R_a}}{1 + \frac{R_1}{R_2} + \frac{C_2}{C_1} + j\left(\frac{1}{\omega C_2 R_1} + \omega C_1 R_2\right)}$$

In phase $\omega = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}$

At that frequency of oscillation

$$\frac{1 + {}^{R_b}/_{R_a}}{1 + \frac{R_2}{R_1} + \frac{C_1}{C_2}} = 1$$

Then connect the loop from input to output and remove the input signal. Connect input to output.

Conditions for oscillation

$${}^{R_b}/_{R_a} = \frac{R_2}{R_1} + \frac{C_1}{C_2}$$

$$\begin{cases} R_2 = R_1 = R \\ C_2 = C_1 = C \end{cases} \quad then\ 3_o = \frac{1}{RC}$$

Attained by setting

$${}^{R_b}/_{R_a} = 2$$

If ${}^{R_b}/_{R_a} > 2$ it will build up oscillation

at ${}^{R_b}/_{R_a} = 2$ poles line on the imaginary – oscillator

${}^{R_b}/_{R_a} < \alpha\ Decay$

- The condition in equation (iv) and (v) are known as Barkhausen criteria in rectangular form for $A_r(jw) = A_{ro}$
- In polar form Barkhausen criteria is given by

$$B(jw)\ A_r(jw) = |B(jw)A(jw)|\ B(jw)A_r(jw) = 1$$

$$|B(jw)A(jw)| = 1$$

$$B(jw)\ A(jw) = +n360^0$$

- This condition of unit loop-gain and zero loop phase shift is known as criterion for sustained oscillations.
- Since ac power required by the input of an amplifier is lees than output power, it is possible to make the amplifier supply its own input and hence generate self-sustained oscillations.
- The active device in the amplifier circuit thus changes the dc power supplied to it into ac energy at the output.
- The initiating ac triggering signal is provided by the abrupt flow of forward bias device current from its zero value.
- This abrupt signal pulse contains all possible sinusoidal frequencies out of which a particular frequency is selected by the frequency sensitive cct components to provide a positive self-sustaining feedback.

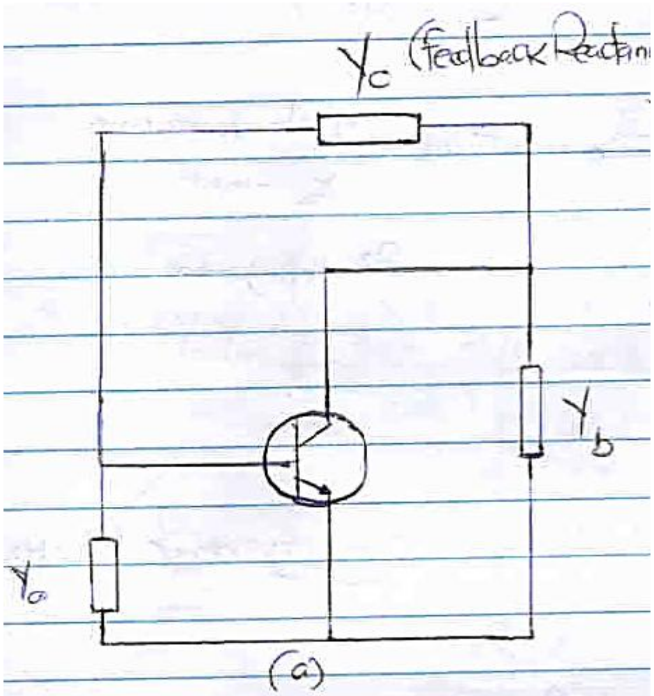
Note the overall fain $A_f = \left(\frac{A}{1-AB}\right)$, under the conditions above, it tends to be infinite and hence the amplitude must be self-limited. This limiting action is generally provided by the non-linear cutoff and saturation regions of the active device characteristics where available amplification ceases to satisfy the condition for oscillations. However, with the help of linear analysis, one can obtain the frequency of oscillations and the conditions for starting of the oscillations.

The choice of feedback network or frequency determining cct is decided by the frequency range in which the oscillator is intended to work.

Frequency determining network can be RC-type and LC type for frequency upto few look HZ.

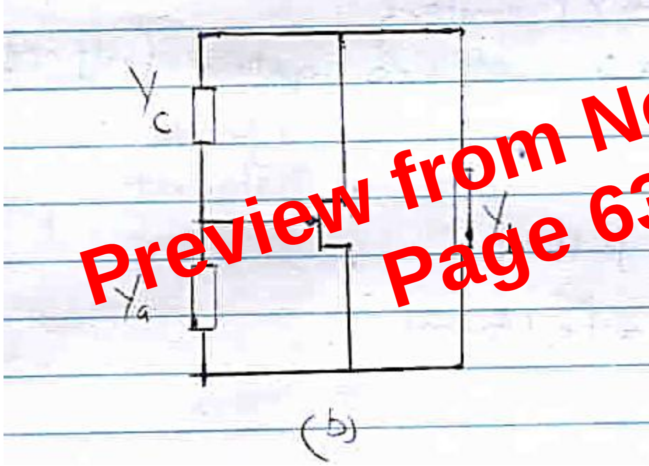
The choice of an optimal cct is detected by its requirements regarding;

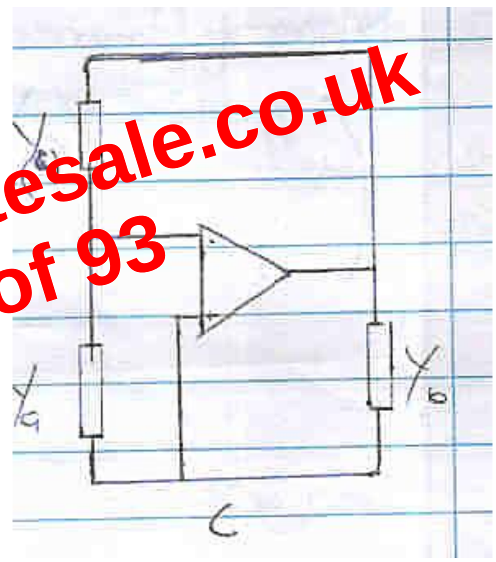
i) Frequency stability
ii) Amp stability
iii) Freedom from non-linear distortion



Y_a - Load and admittance at output load.

Y_c - Feedback reactance.





Y_a - is the active device(s) making the circuit go to saturation. It is not a feedback but a biasing circuit. Also called input impedance. (Takes the active device to oscillation)

Objective

- To know whether such circuit can be made into an oscillator?
- Analysis of such a phenomenon.
- Transistor could be BJT, FET, or Op-Amp

$$\begin{pmatrix} Y_a + \frac{1}{\gamma_e{}^{(\beta+1)}} + Y_c & -Y_c \\ g_m - Y_c & Y_b + \frac{1}{\gamma_{ce}} + Y_c \end{pmatrix} \quad \begin{matrix} Y_p = Y_a \\ Admittance\ at\ output \end{matrix}$$

$$\Delta Y = \left(Y_a + \frac{1}{\gamma_e{}^{(\beta+1)}} + Y_c\right)\left(Y_b + Y_c + \frac{1}{\gamma_{ce}}\right) + Y_c\,(g_m - Y_c) = 0$$

This equation gives the condition as well as the frequency of oscillation. At certain frequency it should be = 0.

Simplify:

$$Y_aY_b + Y_aY_c + \frac{Y_b}{\gamma_e{}^{(\beta+1)}} + \frac{Y_c}{\gamma_e{}^{(\beta+1)}} + \frac{1}{\gamma_e{}^{(\beta+1)}\gamma_e} + Y_bY_c + Y_c{}^2 + \frac{Y_c}{\gamma_{ce}} + Y_cg_m - Y_c{}^2 = 0$$

$$\sum Y_aY_bY_c + \frac{1}{\gamma_e{}^{(\beta+1)}}(Y_b + Y_c) - \frac{1}{\gamma_e{}^{(\beta+1)}\gamma_e} + \frac{1}{\gamma_{ce}}(Y_a + Y_c) + Y_cg_m = 0$$

These are the factors

For such condition to be possible we have to show that =0.

The equation must have the real and imaginary part and they should be made to go to zero. Select up the possible combinations.

Real part =0

Im=0

Choose the possible combination for this to work.

$Y_c = \frac{1}{g\omega L}$ feed back dement takes one part/ one type and other two opposite.

$Y_a = j\omega C_1$

$Y_b = j\omega C_2$

(i) Two capacitive Y_aY_c
One inductive Y_c
(ii) Two inductive Y_a, Y_b
One capacitive Y_c

Two oscillators produced

$$-\frac{1}{w^2L_1L_2}+jwC\left(\frac{1}{jwL_1}+\frac{1}{jwL_2}\right)$$

$$-\frac{1}{w^2L_1L_2}+jwC\frac{(L_1L_2)}{jwL_1L_2}+\frac{1}{r_e(B+1)r_{ce}}=0$$

$$w^2=C(L_1L_2)$$

$$w\cong\sqrt{CL_1L_2}$$

Imaginary part

$$\frac{1}{r_e(B+1)}(Y_b+Y_c)+\frac{Y_a+Y_c}{r_{ce}}+gmY_c=0$$

$$\frac{jwC-\frac{j}{wL_2}}{r_e(B+1)}+\frac{jwC-\frac{j}{wL_1}}{r_{ce}}+jwcgm=0$$

Collect the coefficient of $^1/_w$

$$jw\left(cgm+\frac{C}{r_e(B+1)}+\frac{C}{r_{ce}}\right)=\frac{j}{w}\left[\frac{1}{rL_2}+\frac{1}{L_2}\right]$$

$$w^2C\left[gm+\frac{1}{r_e(B+1)}+\frac{1}{r_{ce}}\right]=\left(\frac{1}{r_e(B+1)}+\frac{1}{r_{ce}L_2}\right)$$

$$w^2C(gm)$$

$$w_0=C(L_1+L_2)$$

$$C^2(L_1+L_2)gm=\left(\frac{1}{r_e(B+1)L_2}+\frac{1}{r_{ce}L_2}\right)$$

Summary

These are two of the most popular $LC-$ oscillators' transistor or FET oscillator existing today.

The analysis is valid only that in FET we replace open cct for $r_e(B+1)$ and for r_{ce})the rest remain the same). The same analysis remains.

Hartley	**2-**	**inductors**	**1- capacitor**
Culprit	2-	inductor	2- capacitors

NB: the phase shift oscillator in figure above have been implemented by inter-changing R and C in the phase shift sections. It follow that for such an oscillator the frequency of oscillation is given by $w_0 = \frac{\sqrt{6}}{RC}$ and given condition is $|A_{uo}| > 29$.

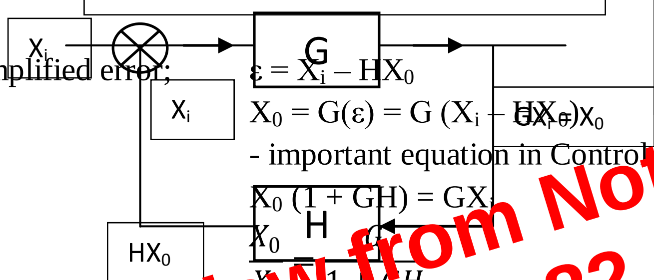
FEEDBACK THEORY

- Important for circuit design.
- Negative and positive.
- Advantages and disadvantages.

Consider

Commonly called error detector
$\varepsilon = X_i - HX_0$

$\mu = G\mu_1$
G = feed forward block
H – Feedback block



Amplified error; $\varepsilon = X_i - HX_0$

$X_0 = G(\varepsilon) = G(X_i - HX_0)$

- important equation in Control Eng. X can be any variable .

$X_0(1 + GH) = GX_i$

$$\frac{X_0}{X_i} = \frac{G}{1 + GH}$$

This is a negative feedback because we are finding the error.
If the error is $\varepsilon(Xi - HX_0)$ *it will be positive feedback*

$$\left(\frac{X_0}{X_i} = \frac{G}{1 - GH}\right)$$

Discussing negative feedback:

- To remove distortion used to improve the performance of circuit (Used in eplepsy).

$$\frac{X_0}{X_i} = \frac{G}{1 + GH}$$

If G and H are positive quantities then

$$\frac{G}{1 + GH} < G$$

- Hence a feedback (negative) amplifier has less gain than open-loop gain amplifier (reduction in transfer parameter).
- Reduction in active parameter sensitivity.

- The active components depends on operating point.
- BJT = $g_m \infty I$ and dependent on temperature

Feedback situation makes an amplifier with gain more than 1, using positive, attenuators, resistors, capacitors, inductors.

In this case H is made more stable hence

$$G_f = \frac{X_0}{X_i} = \frac{G}{1 + GH}$$

$$\cong \frac{1}{H} \; if \; GH \gg 1$$

$$G \; is \; the \; active \; parameter \; now \; made \; insetive$$

$$H \; made \; from \; passive \; device \; e.g. R, C \; and \; linear$$

The resultant gain is G_f

$$\frac{\partial G_f / G_f}{\partial G / G} = \int_{G}^{G_f}$$

$(Sensitivity \; factor \; of \; G_f \; relation \; to \; G$
$= \% \; variation \; in \; G_f \; \; compare \; it \; with \; \% \; variation \; in \; G \; is \; called \; sensitivity)$

$$= \frac{\partial G_f}{\partial G} \times \frac{G}{G_f}$$

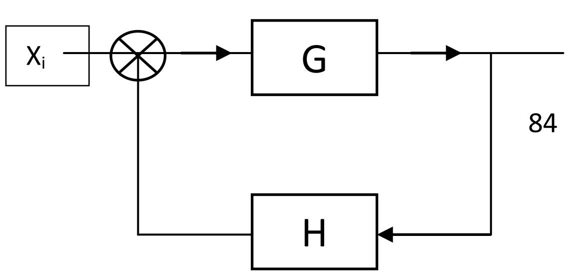
$$= \frac{1}{1 + GH}$$

$\frac{1}{1+GH}$; is important equation for sensitivity in designing amplifiers G – H forms a loop hence GH – loop gain. If GH >> very high $\frac{1}{1+GH} \ll 1$ hence sensitivity factor gets to zero.

Loop Gain

- GH (negative feedback)

+ GH (positive feedback)



NB: RC network produces/introduces definite phase shift.

Phase Lead

$\mu_o R = \mu_o \left(R + \frac{1}{J\omega x}\right)$

$\mu_o = \left(\frac{JX_c}{R+JXC}\right)^{\theta^0}$

$\frac{\mu_o}{\mu_i} = \left(\frac{R}{R} - jx\right)$

$\frac{\mu_o}{\mu_i} = \frac{1}{J\omega x} \Big/ R + \frac{1}{J\omega x}$

$= \frac{R}{R^2+X^2}(R - jxc)$

$= \left(\frac{-jx}{R-jx}\right)$

Phase shift between output and input

$\tan \emptyset = \left(\frac{X_c}{R}\right)$

$= \frac{X}{R^2+X^2}(X - JR)$

$\emptyset = \tan^{-}\left(\frac{X_c}{R}\right)$

$\text{Gain} = \frac{X}{R^2+X^2}$

$\emptyset$Can be 0^0 or 90^0 depending on values of X_c and R

Hence phase shift due to an RC circuit is always $\leq 90^0$ and it is a fraction of frequency.

$\emptyset = \tan^{-}\left(\frac{X_c}{R}\right) = -\tan^{-}\left(\frac{X_c}{R}\right).$

Hence if we want positive with 180^0 phase shift we need attest three RC networks. Remember, since X_1, is frequency sensitive$A_1 = \frac{1}{2\pi f_c}$, the 180^0 phase lift also can be achieved only at a particular frequency.

Thus a simple RC oscillator can be built with an amplifier and a feedback network with three RC combination.

Such as oscillator is called phase shift oscillator.