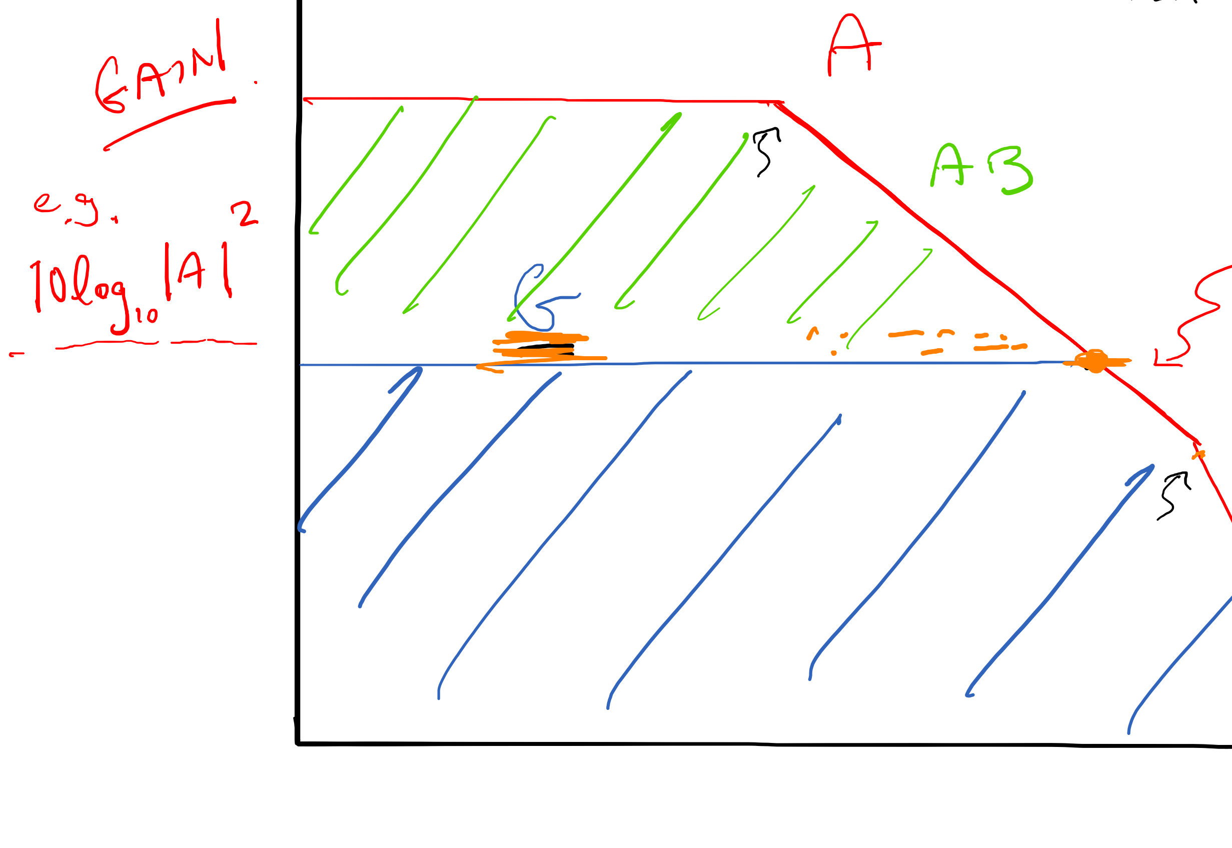
OP AMP STABILITY

"BODE PLOT"



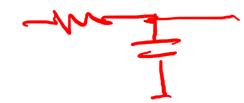
$$A = \underbrace{(AB)}_{\text{LOOP GAIN}}\frac{1}{B} = (AB)\,G$$

OPEN — LOOP GAIN — CLOSED

$$\log A = \log(AB) + \log G$$

−6 dB/OCTAVE

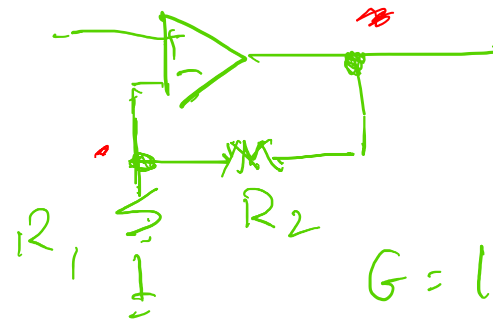
eg



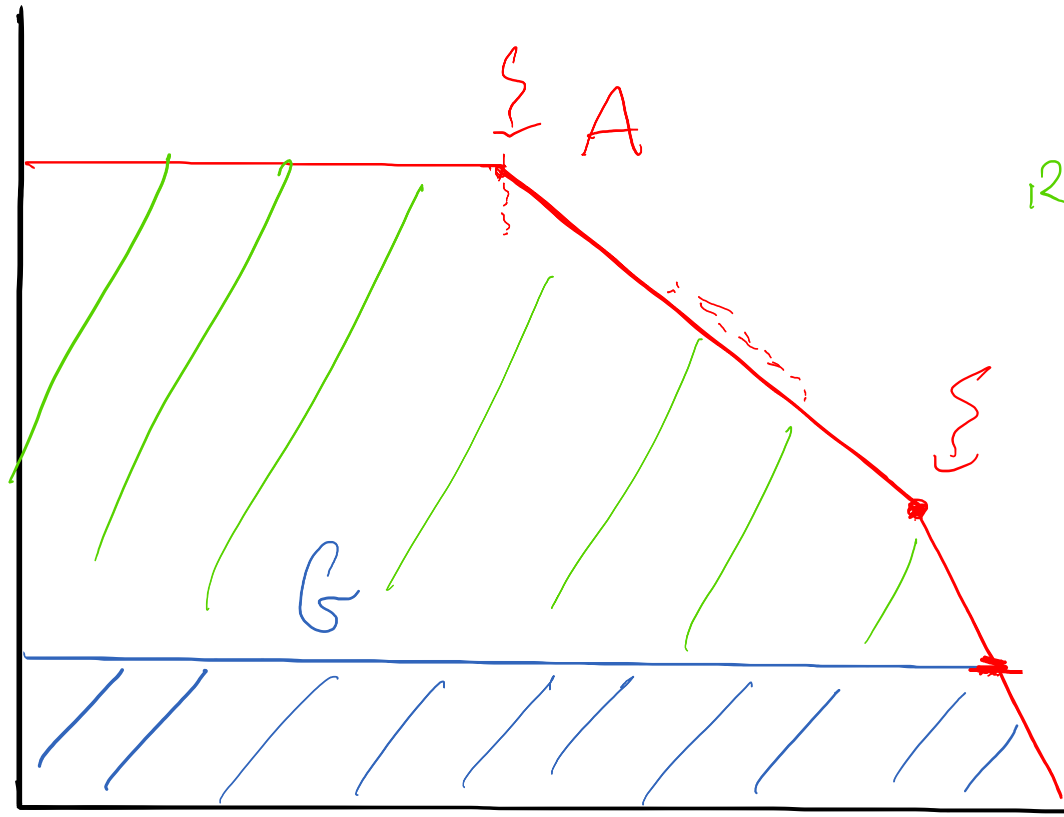
SINGLE-POLE LOW-PASS

−12 dB/OCTAVE.

OP AMP STABILITY



$$G = 1 + \frac{R_2}{R_1}$$



f

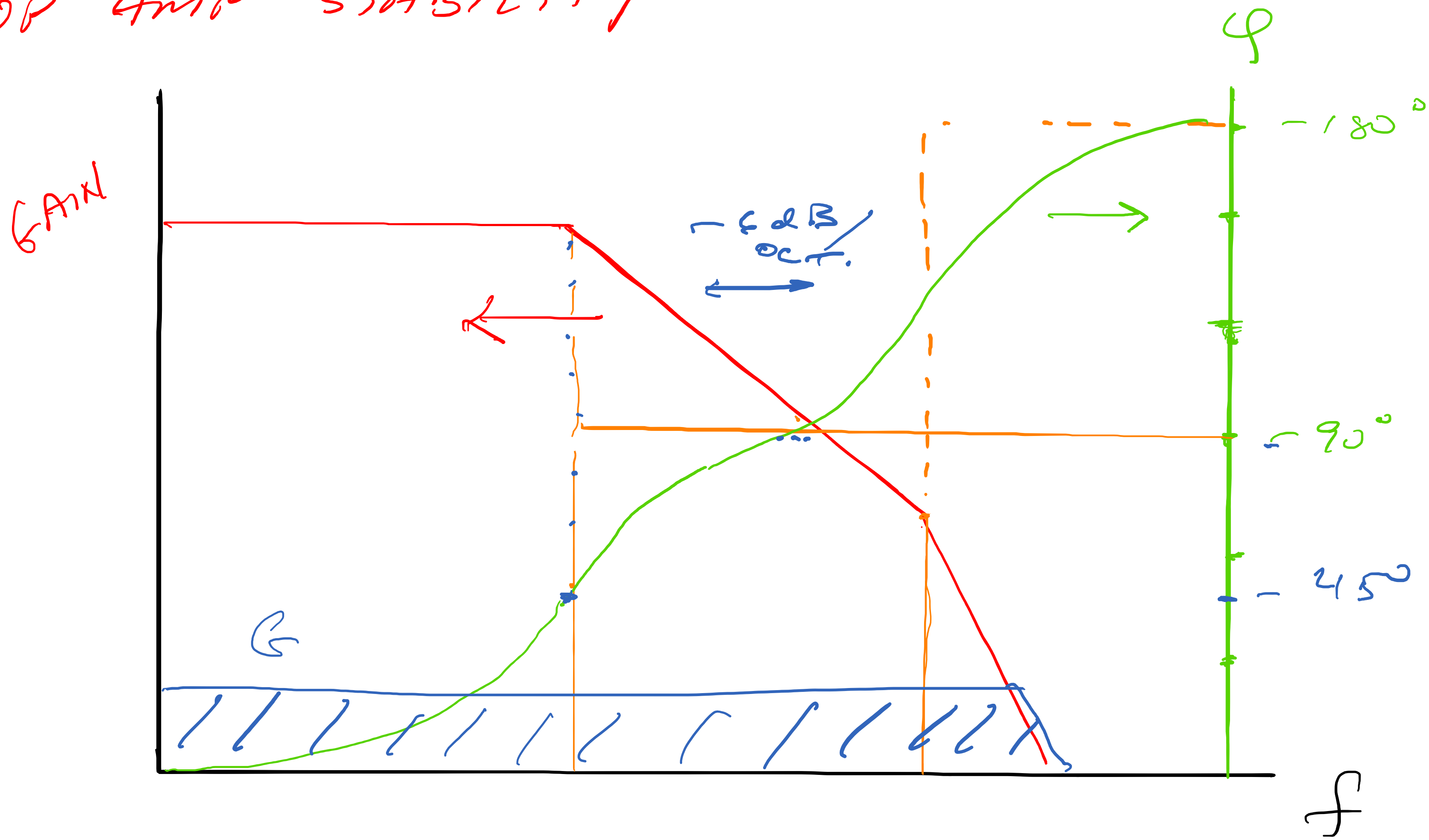
"PHASE MARGIN"

HOW FAR ACCUM. PHASE IN FB LOOP IS FROM −180° @ POINT WHERE LOOP GAIN = 1.

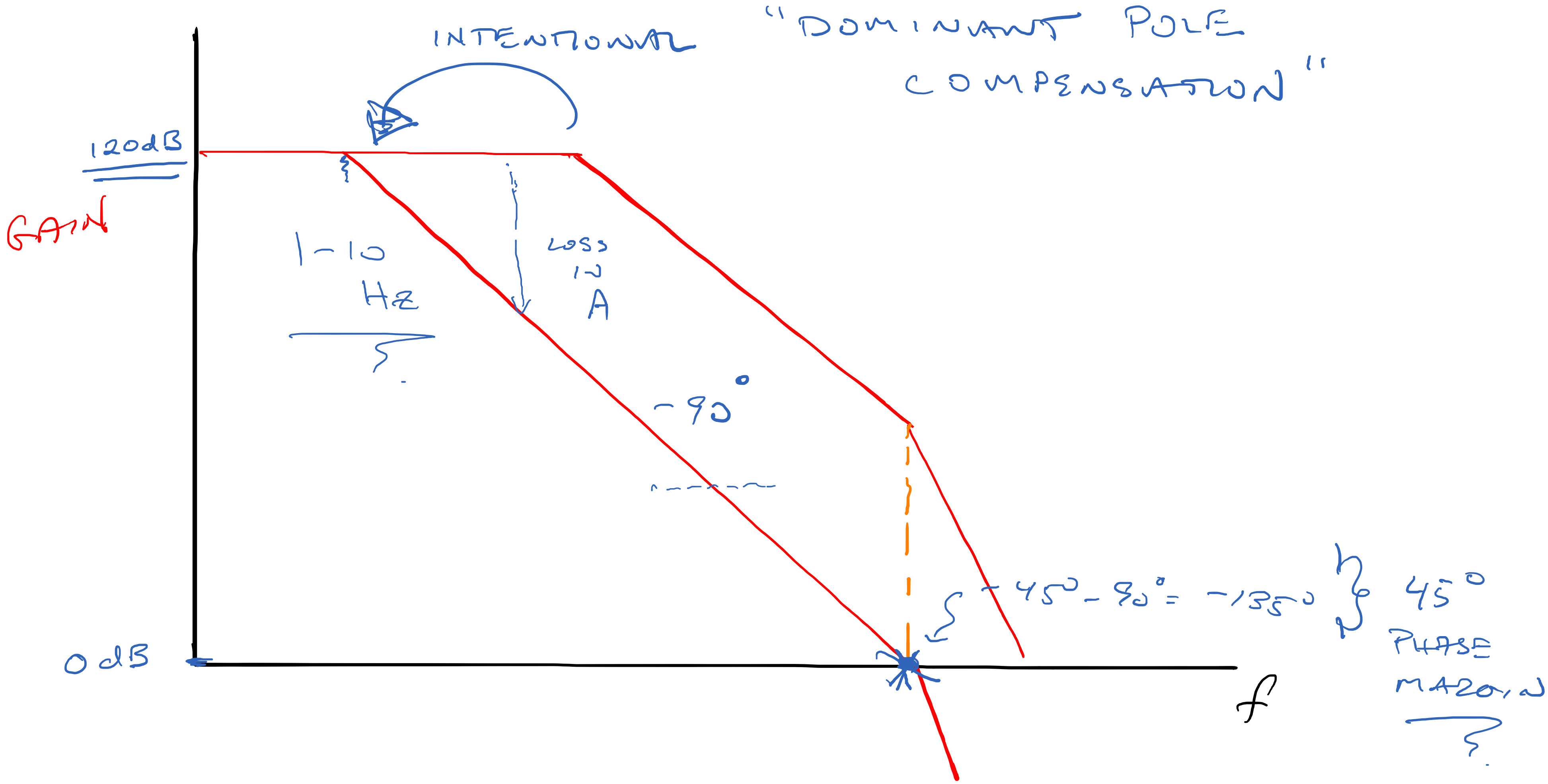
WORST CASE:

FOLLOWER: G = 1

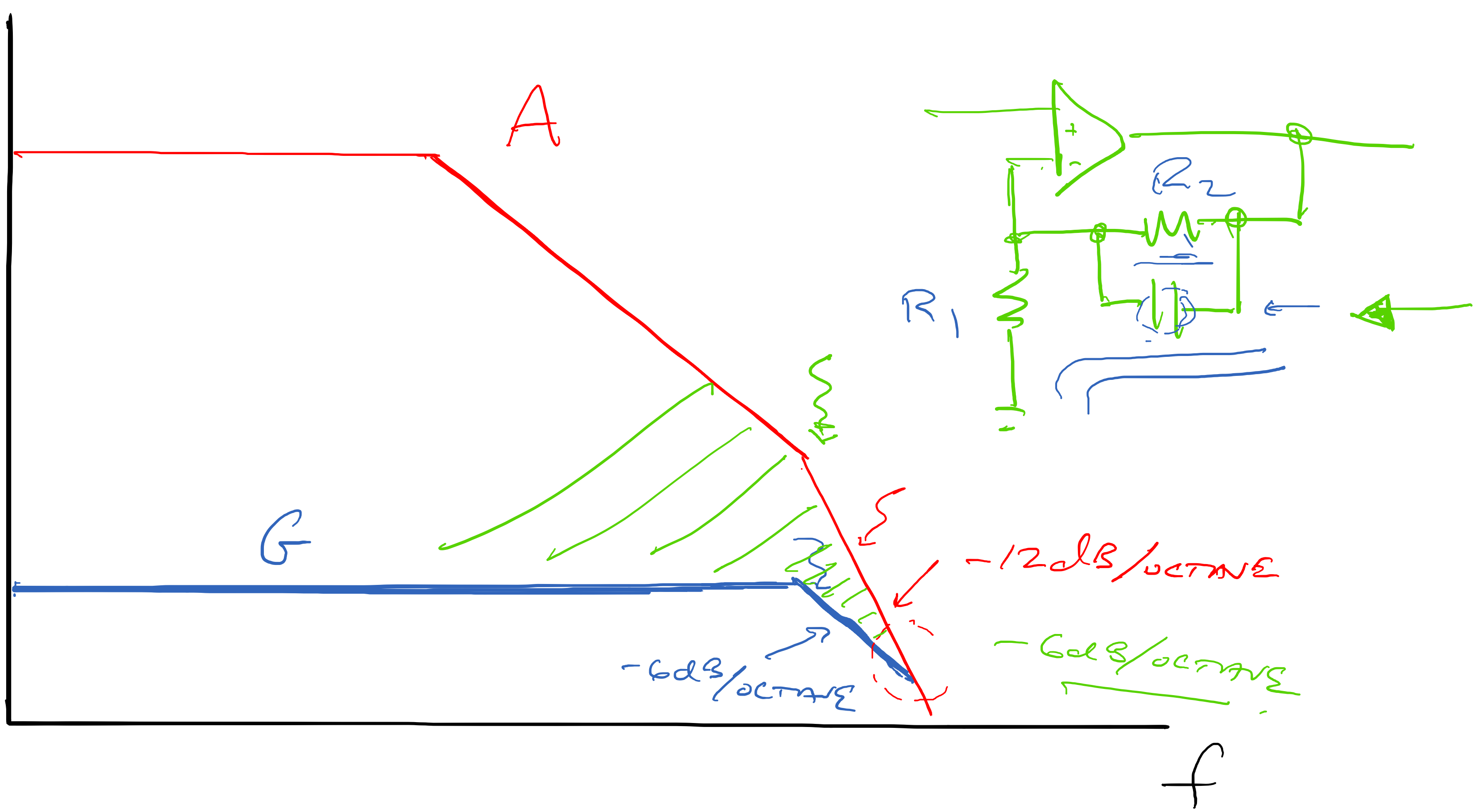
OP AMP STABILITY



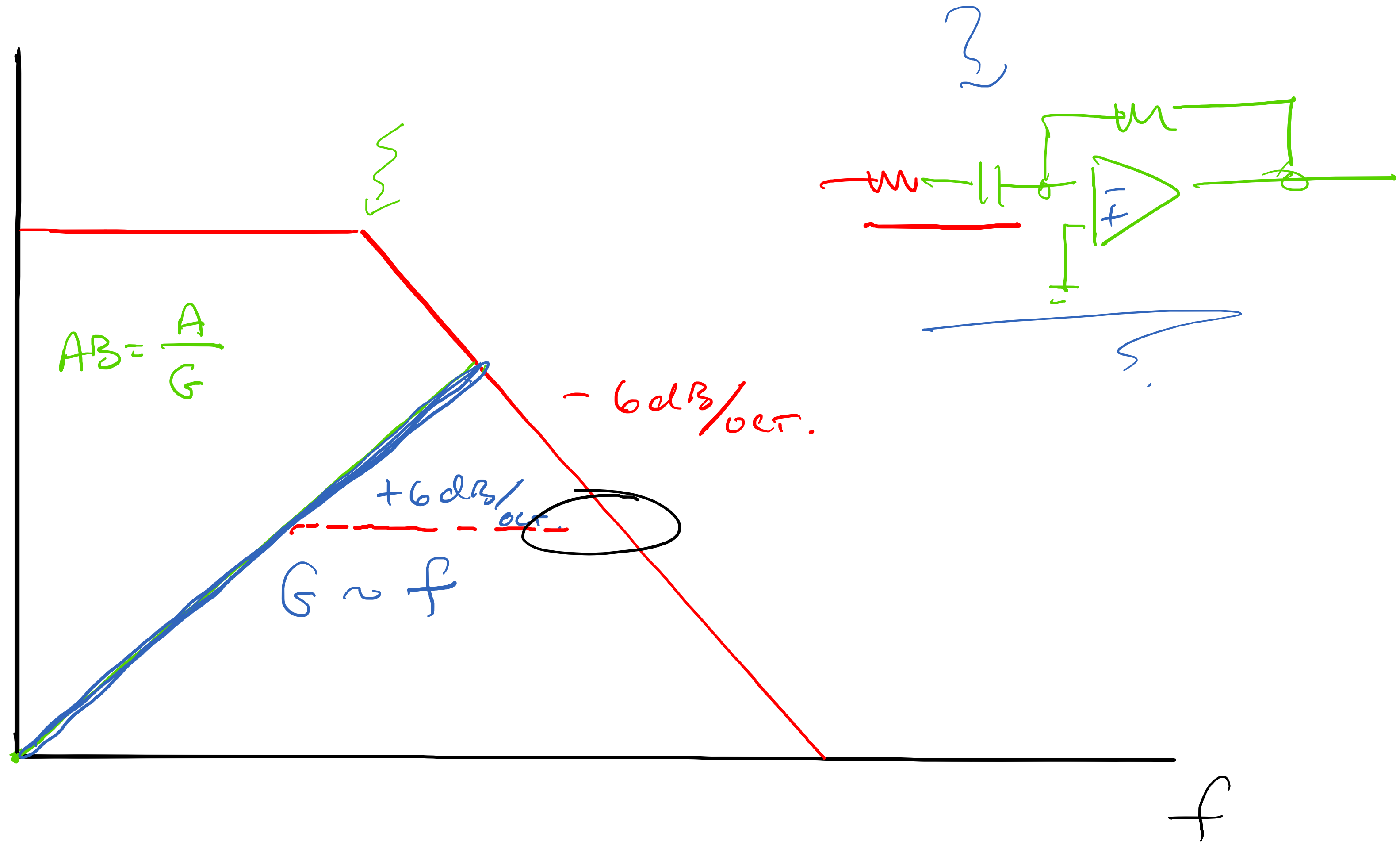
OP AMP STABILITY



OP AMP STABILITY



OP AMP STABILITY



FOURIER THEORY

CONSIDER PERIODIC SIGNAL

$$V(t \pm T) = V(t)$$

FUNDAMENTAL (ANGULAR) FREQUENCY $\omega_0 = 2\pi / T$

$$V(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} \left[a_n \cos n\omega_0 t + b_n \sin n\omega_0 t \right]$$

USE ORTHOGONALITY OF sin/cos TO SOLVE

FOR a_n, b_n

$$\int_{-T/2}^{T/2} \cos n\omega_0 t \, \cos m\omega_0 t \, dt = \frac{T}{2}\,\delta_{nm}$$

$$\int_{-T/2}^{T/2} \sin n\omega_0 t \, \sin m\omega_0 t \, dt = \frac{T}{2}\,\delta_{nm}$$

$$\int_{-T/2}^{T/2} \sin n\omega_0 t \, \cos m\omega_0 t \, dt = 0$$

$$a_n = \frac{2}{T}\int_{-T/2}^{T/2} v(t)\cos n\omega_0 t \, dt$$

$$b_n = \frac{2}{T}\int_{-T/2}^{T/2} v(t)\sin n\omega_0 t \, dt$$

CONSIDER ODD/EVEN SYMMETRY OF WAVEFORM

ODD: ONLY sin COMPONENTS

EVEN: ONLY cos COMPONENTS

OR// USE COMPLEX NOTATION

$$v(t) = \sum_{n=-\infty}^{\infty} C_n e^{jn\omega_0 t}$$

$C_{-n} = C_n^*$

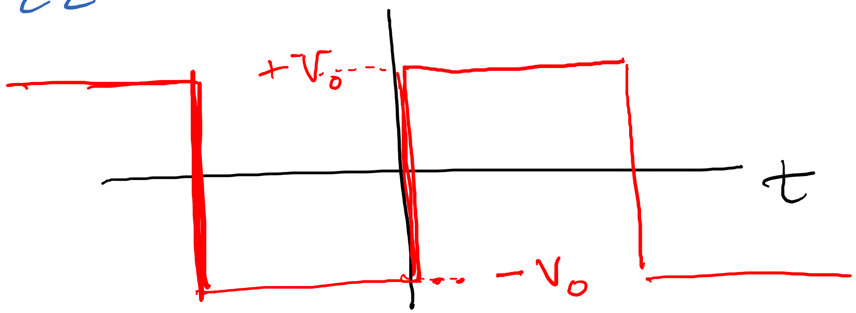
ENSURES $v(t)$ REAL

ORTHOGONALITY:

$$\int_{-T/2}^{T/2} e^{j(n-m)\omega_0 t}\, dt = T\,\delta_{nm}$$

$$\Rightarrow C_n = \frac{1}{T}\int_{-T/2}^{T/2} v(t)\, e^{-jn\omega_0 t}\, dt$$

EXAMPLE



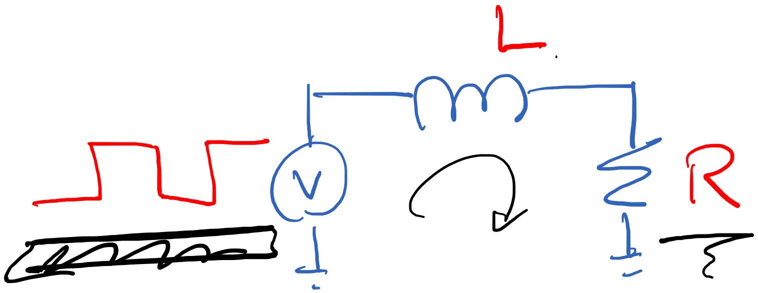
$$C_n = \frac{2}{T}\int_0^{T/2} V_0\, e^{-jn\omega_0 t}\, dt$$

n ODD

$$C_n = \frac{2}{T} V_0 \left(\frac{-1}{jn\omega_0}\right)\left(e^{-jn\omega_0 \frac{T}{2}} - 1\right) = \frac{2V_0}{\pi j}\frac{1}{n}$$

$$\boxed{v(t) = \frac{2V_0}{\pi j} \sum_{n \text{ ODD}} \frac{1}{n} e^{jn\omega_0 t}}$$

$$e^{jx} = \cos x + j \sin x$$



$$Z = R + j\omega L$$

SOLVE FOR V_R

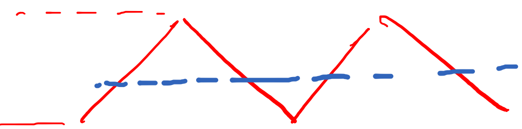
$$I = \frac{V}{Z} = \frac{2V_0}{\pi j}\sum_{n\ \mathrm{odd}} \frac{1}{n[R + jn\omega_0 L]}\, e^{jn\omega_0 t}$$

$$V_R = \frac{2V_0}{\pi}\sum \frac{1}{-n^2\omega_0\tau + jn}\, e^{jn\omega_0 t} \quad ; \quad \tau \equiv L/R$$

TAKE $\omega_0 \tau >> 1$

$$V_R \approx \frac{2V_0}{\pi} \sum_{n \text{ ODD}} \left(-\frac{1}{n^2 \omega_0 \tau} \right) e^{jn\omega_0 t}$$

$\pm \frac{\pi}{2} \frac{V_0}{\omega_0 \tau}$



$$V_R \approx \frac{1}{\tau} \int V_{in} \, dt$$

FOURIER TRANSFORM

$$v(t) = \sum c_n e^{jn\omega_0 t}$$

LET $\omega = n\omega_0$;

TAKE $\omega_0 \to 0$ WITH

$$\frac{T\Delta\omega}{2\pi} = 1$$

$$v(t) = \sum c_n e^{j\omega t} \frac{T}{2\pi} \Delta\omega$$

$$v(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \underbrace{c_n T}_{c_n \cdot T \longleftrightarrow \tilde{V}(\omega)} e^{j\omega t} d\omega$$

$c_n \cdot T \longleftrightarrow \tilde{V}(\omega)$

FOURIER TRANSFORM

$$v(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \tilde{V}(\omega) e^{j\omega t} d\omega$$

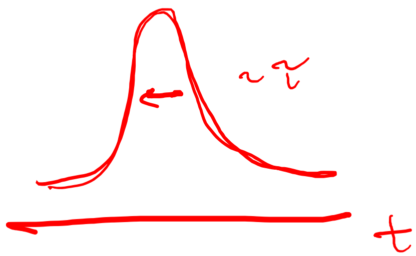
FOURIER X'FORM

$$\tilde{V}(\omega) = \int_{-\infty}^{\infty} v(t) e^{-j\omega t} dt$$

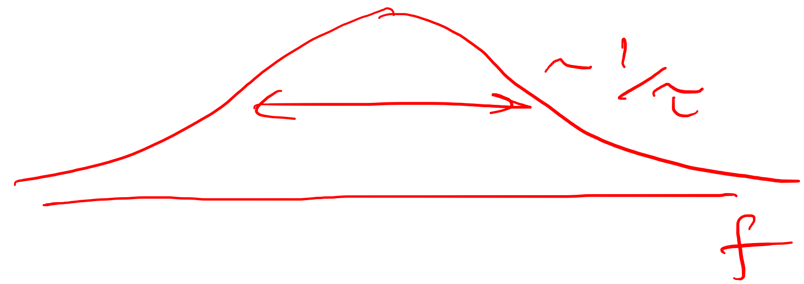
INVERSE F.T.

$$v(t) = V_0 \, e^{-t^2/\tau^2}$$

GAUSSIAN



$$\tilde{V}(\omega) = \sqrt{\pi}\, V_0 \tau \, e^{-(\omega\tau/2)^2}$$



$$v(t) = V_0 \, e^{-|t|/\tau}$$

EXP. DECAY

$$\tilde{V}(\omega) = \frac{2 V_0 \tau}{1 + j\omega\tau}$$

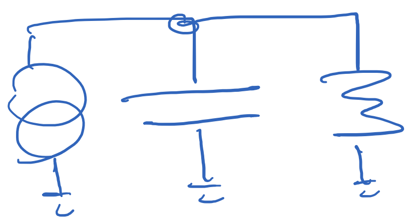
LORENZIAN

T?

EXAMPLE

ARBITRARY

$I(t)$



} MODE @ $\omega_0 = \frac{1}{\sqrt{LC}}$

ENERGY COUPLED TO MODE ?

FIRST TAKE $I(t) = Q\,\delta(t)$, LINEAR RESPONSE THEORY.

$V(t) = \frac{Q}{C}\cos\omega_0 t$, GREEN'S FUNCTION/ IMPULSE RESPONSE.

FOR ARBITRARY $I(t)$,

$$V(t) = \frac{1}{C}\int_{-\infty}^{t} I(t')\cos[\omega_0(t-t')]\,dt'$$

→

$$\underline{V(t)} = \frac{1}{C}\,\mathrm{Re}\left\{ e^{j\omega_0 t} \underbrace{\int_{-\infty}^{t} I(t')\, e^{-j\omega_0 t'}\, dt'}_{} \right\}$$

TAKE $\underline{t \to \infty}$ LOOK LONG AFTER $I(t) \to 0$

→ ENERGY STORED IN MODE ?

$$\underline{E = \frac{1}{2} C V_{MAX}^2} = \underbrace{\underline{\frac{1}{2C} \left| \tilde{I}(\omega_0) \right|^2}}_{}$$

LOOKS LIKE CURRENT ENERGY → $\frac{Q^2}{2C}$.

DIMENSIONALLY,

$$\tilde{I}(\omega_0) \to Q$$