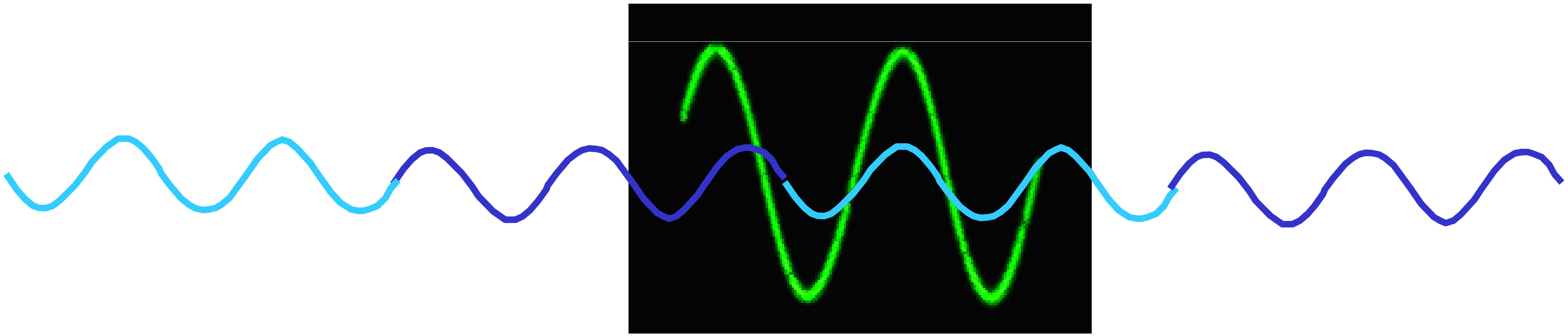
(Analog) Electronics

Lesson III
(Linear) Oscillators



Murphy's Law of Electronics:

Amplifiers oscillate and oscillators amplify

What are we going to talk about?

Linear Electronic Oscillators

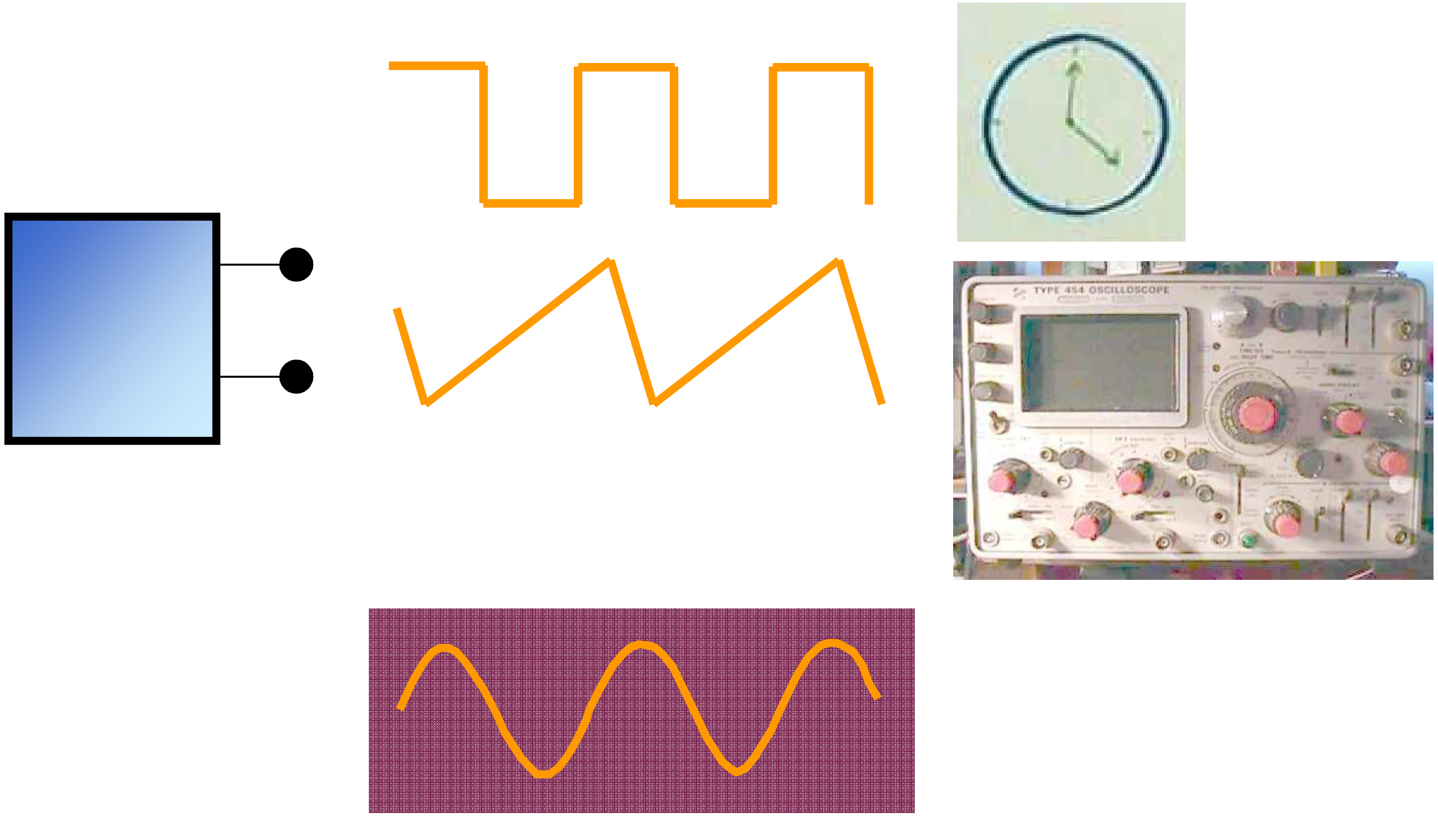
Circuits that

produces an **electronic signal** (volts or amps),

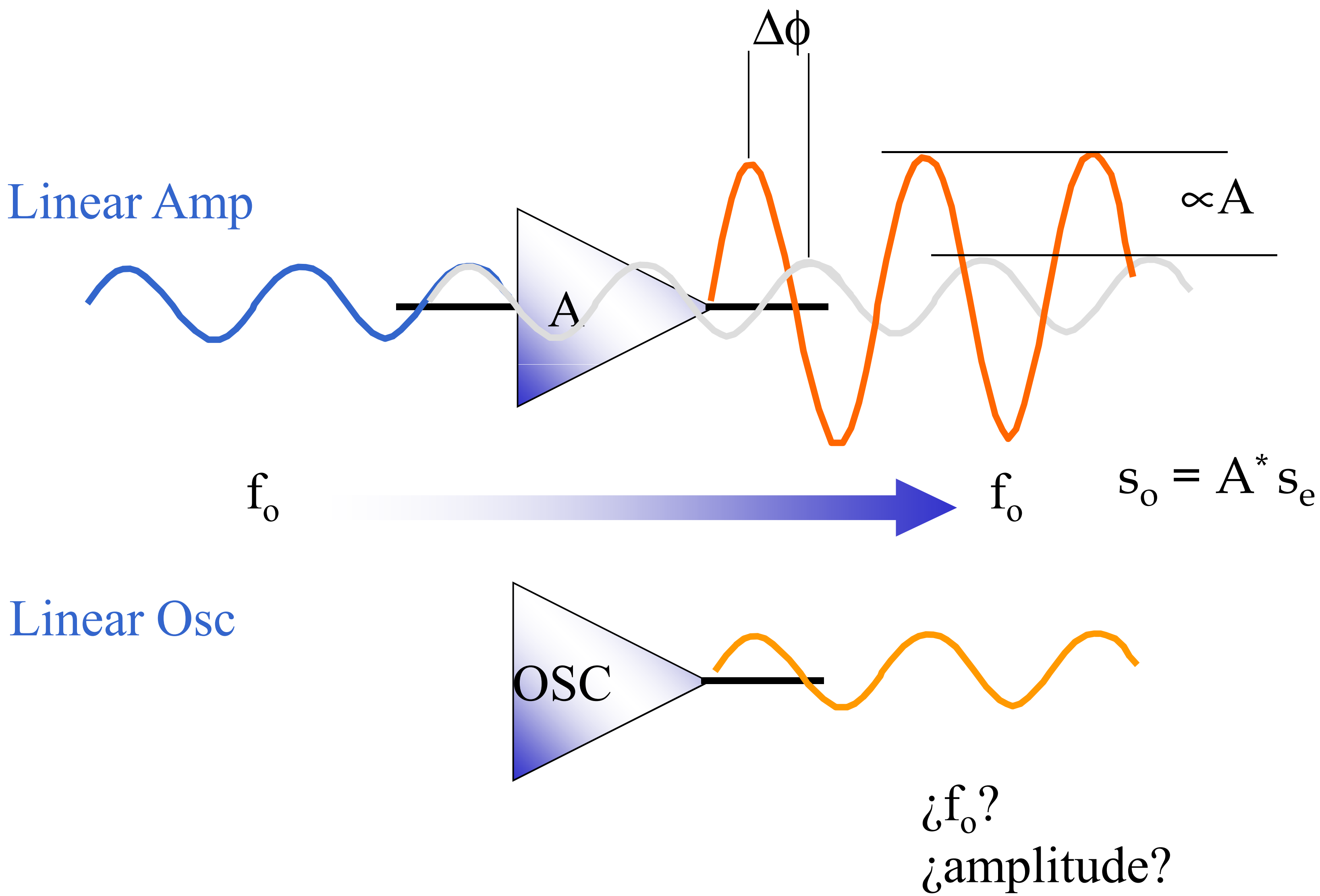
which varies in time (with **temporal dependence**)

without need of an input.

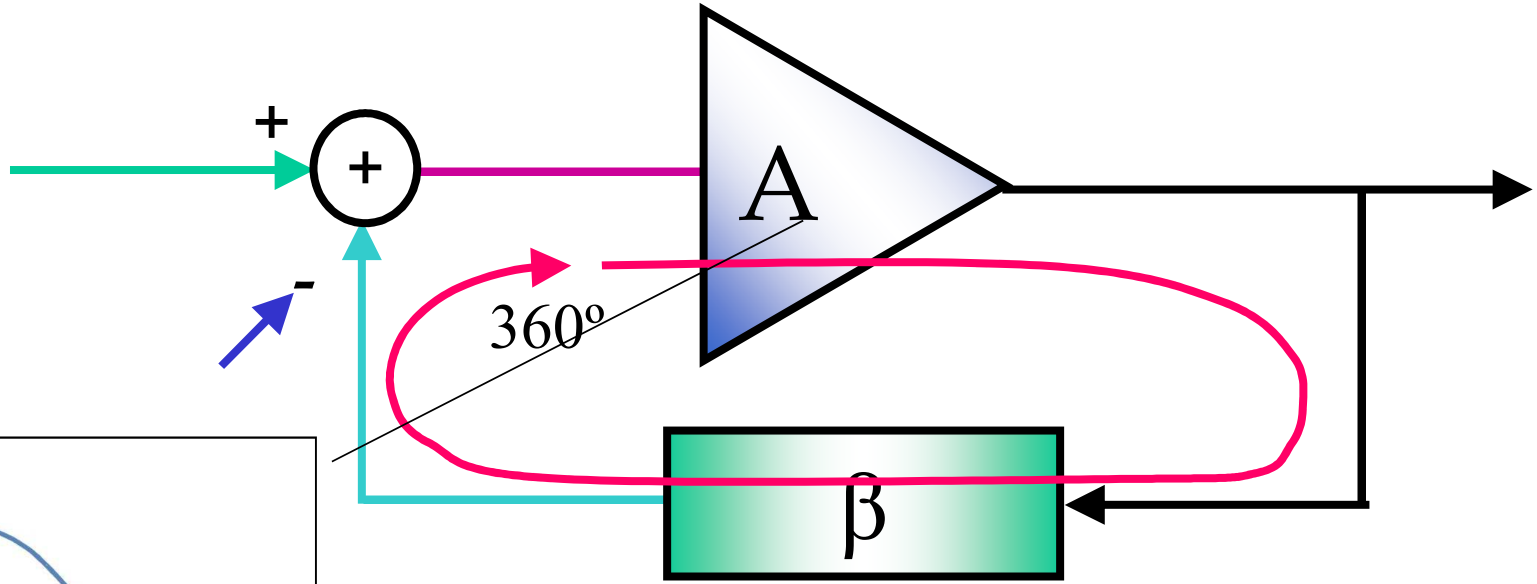
Is there a need for this?

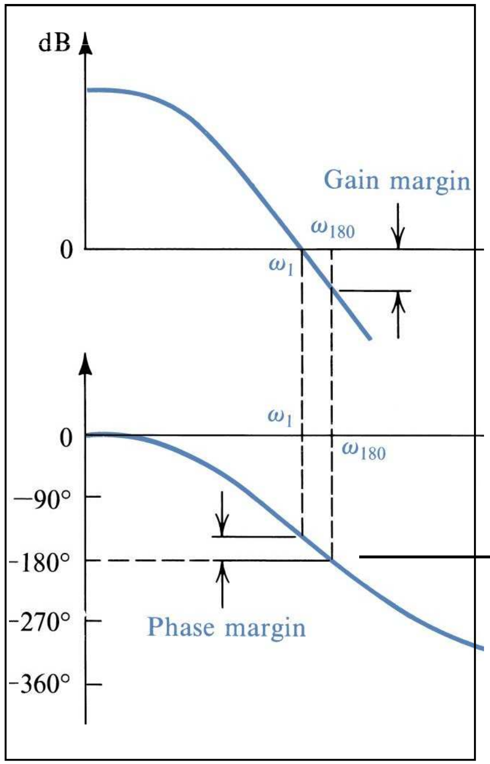


Amplifier vs. Oscillator



Oscillation in an Amplifier

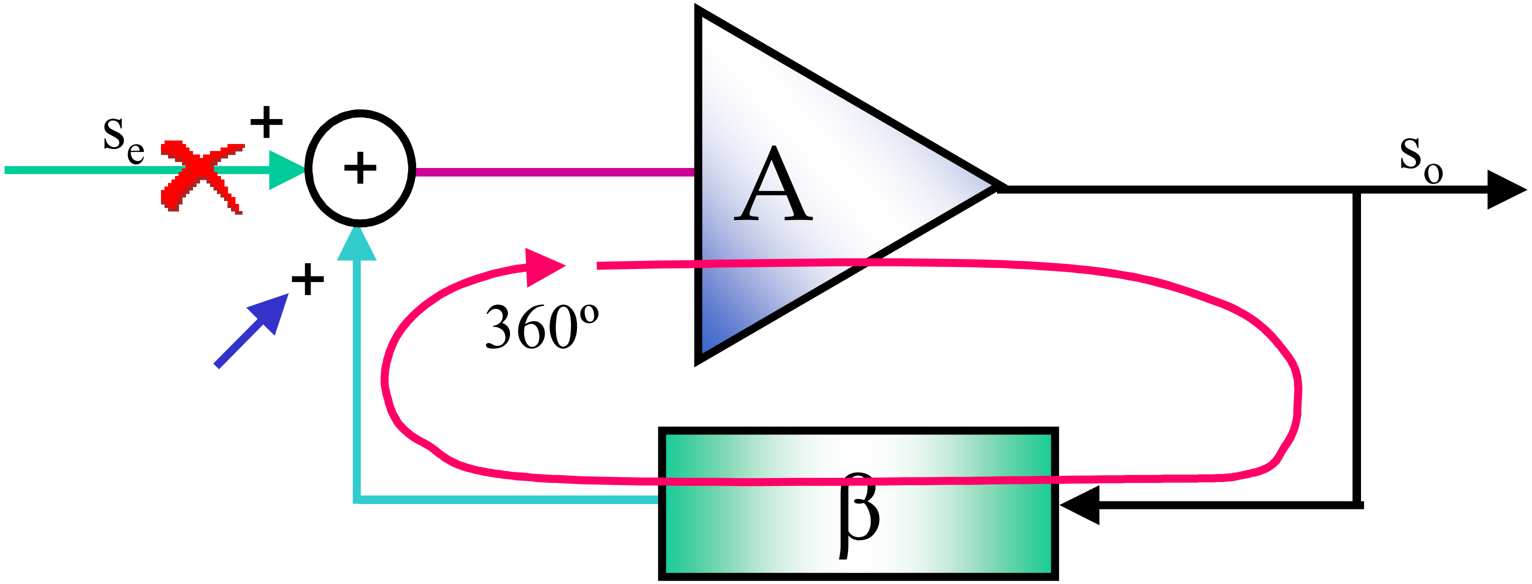




ω_π → $a(\omega_\pi) f > 1$

Positive feedback

The Oscillator Feedback Loop



$$A_f(s) = \frac{A(s)}{1 - A(s)\beta(s)}$$

¿What happens when Aβ = 1?

There can be an output signal, s_o, without input, s_e.

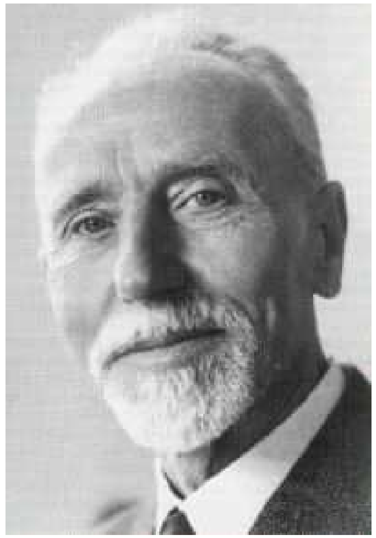
¿Aβ = 1?

$$A\beta = 1$$

$$A\beta = 1\, e^{j0}$$

f_o
amplitude

Barkhausen
Criterion



Conditions for Oscillation

$|A\beta| = 1$

Gain Condition

Amp GAIN = Feedback Net LOSS

A = **β**

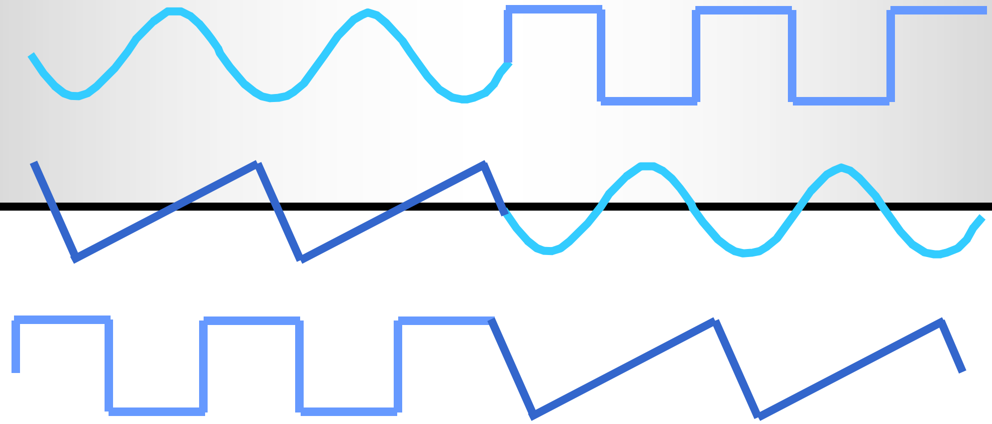
$|\underline{A\beta} = e^{j0}$

Phase Condition

Total phase change in the LOOP = 0 / 2π

For a unique $\mathbf{f_o}$

ELEMENTS FOR OSCILLATION



Electronic Oscillator Basics (I)

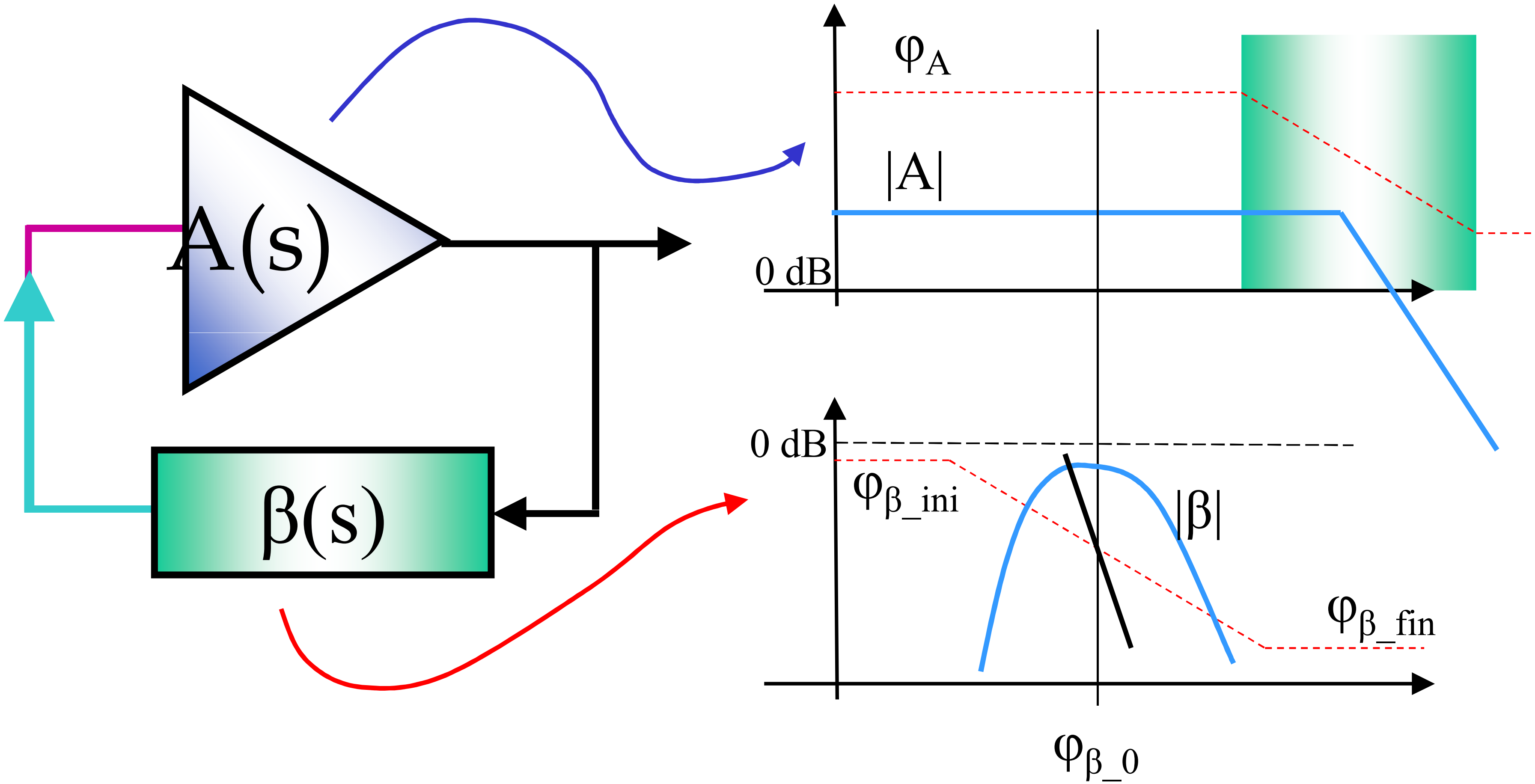
- **Basic Amplifier , . . .**

  providing for **GAIN** (with a given phase change).

- **Feedback Network, . . .**

  SELECTIVE WITH FREQUENCY to determine the oscillation frequency, introducing **LOSSES**.

Electronic Oscillator Basics (II)



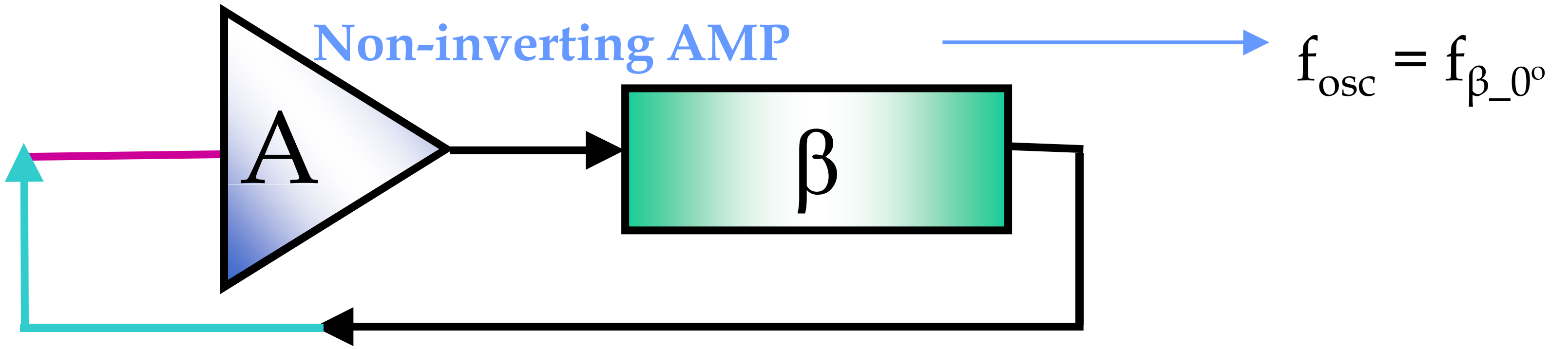
$\varphi_A + \varphi_{\beta\_0} = 2\pi, 0$

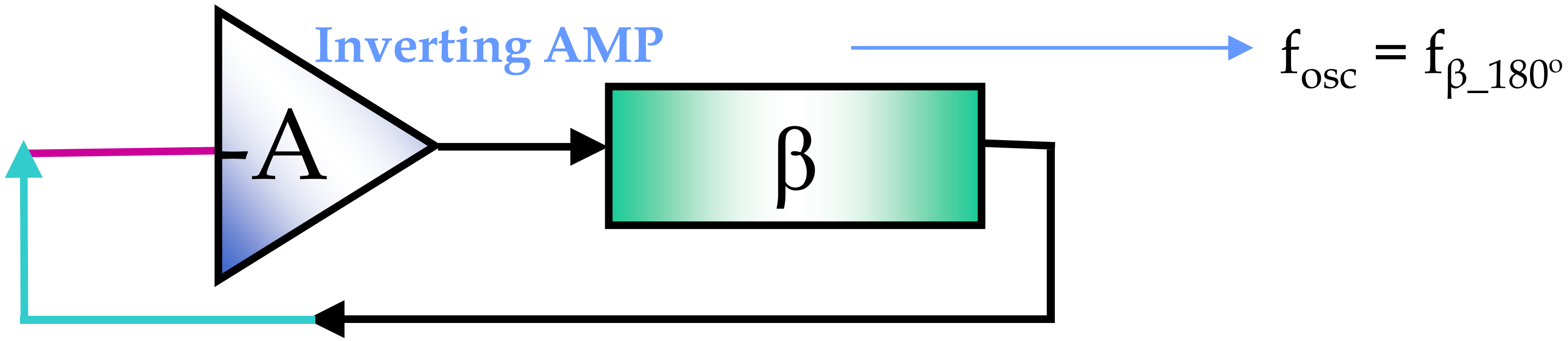
$|A| = 1/\,|\beta|$

Phase Condition

$|\underline{A\beta} = e^{j0}$

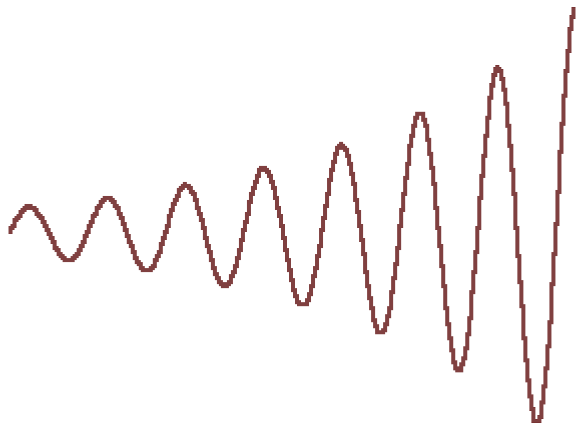
Total phase change in the loop = 0 ó 2π



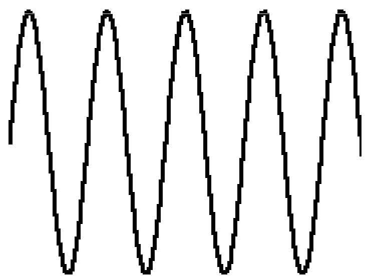


Gain Condition (I)

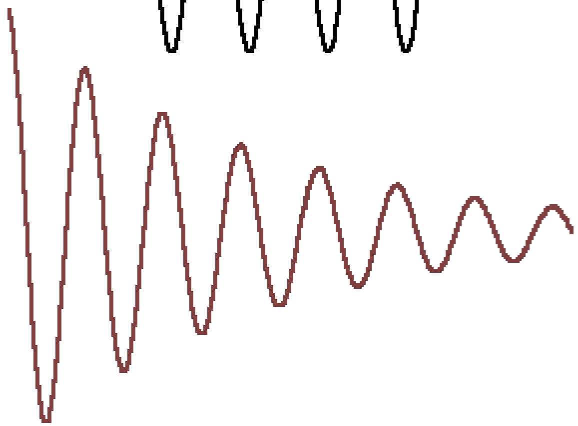
$|A| > 1/\,|\beta|$



$|A| = 1/\,|\beta|$



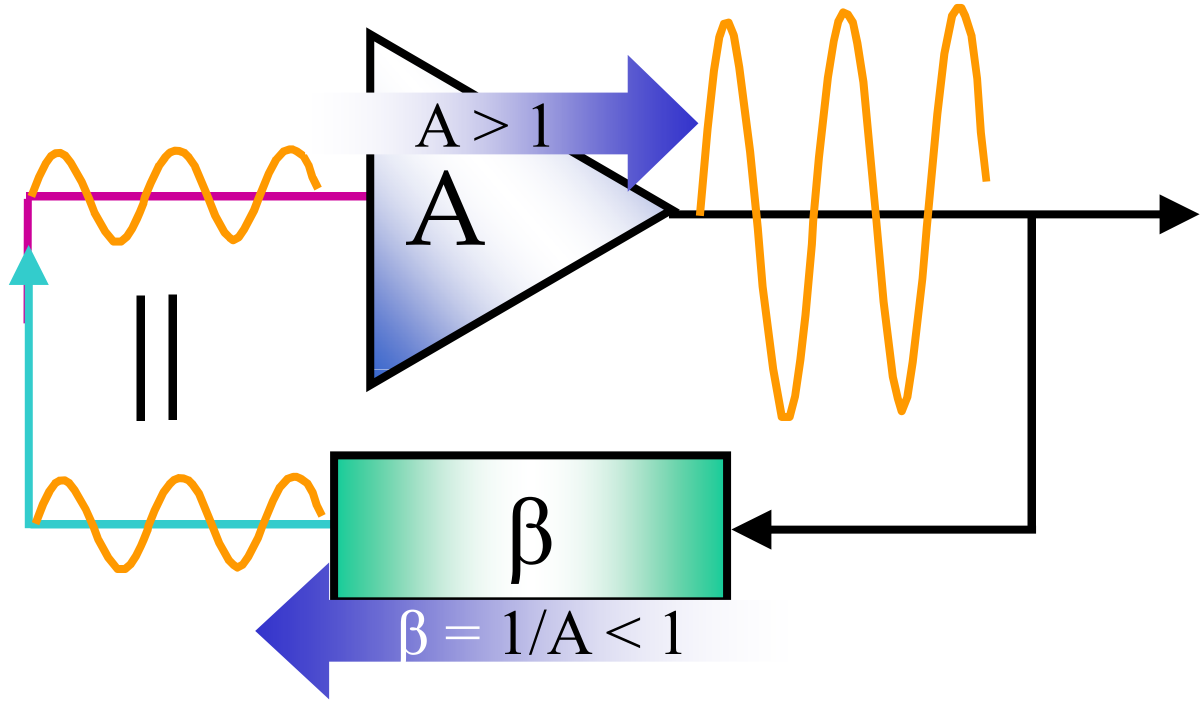
$|A| < 1/\,|\beta|$



Gain Condition (II)

Relation with stability

$$|A\beta| = 1$$

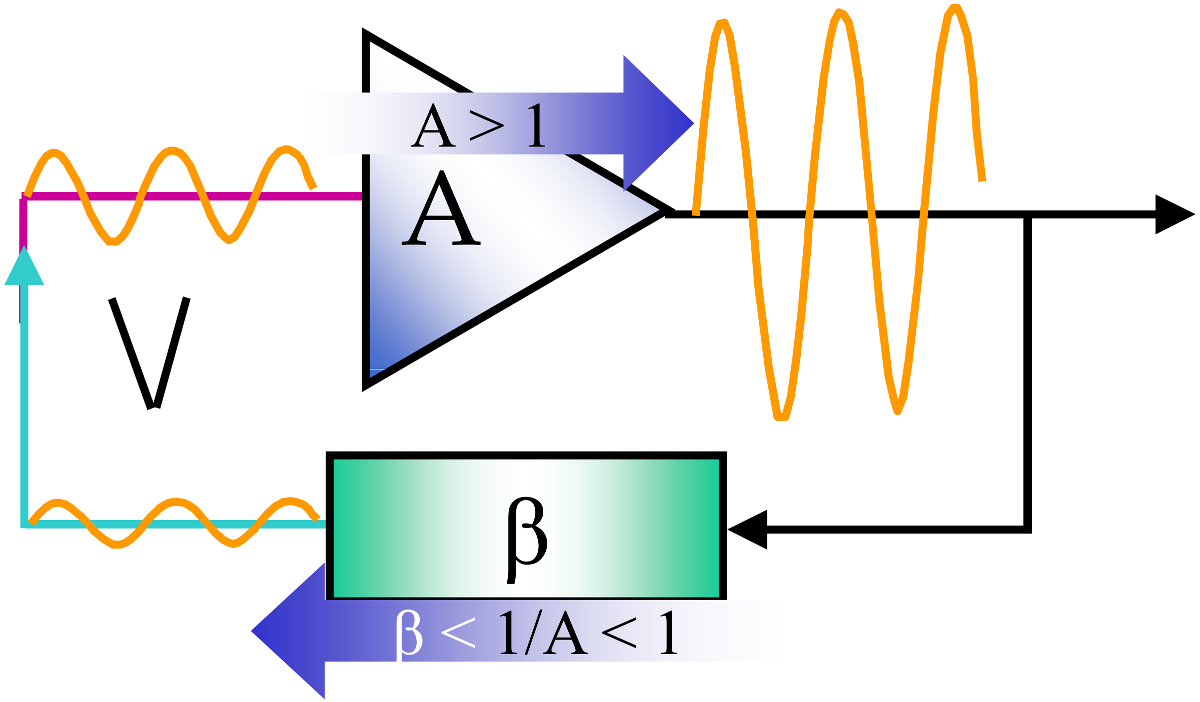


Sustained oscillations

Gain Condition (III)

Relation with stability

$|A\beta| < 1$

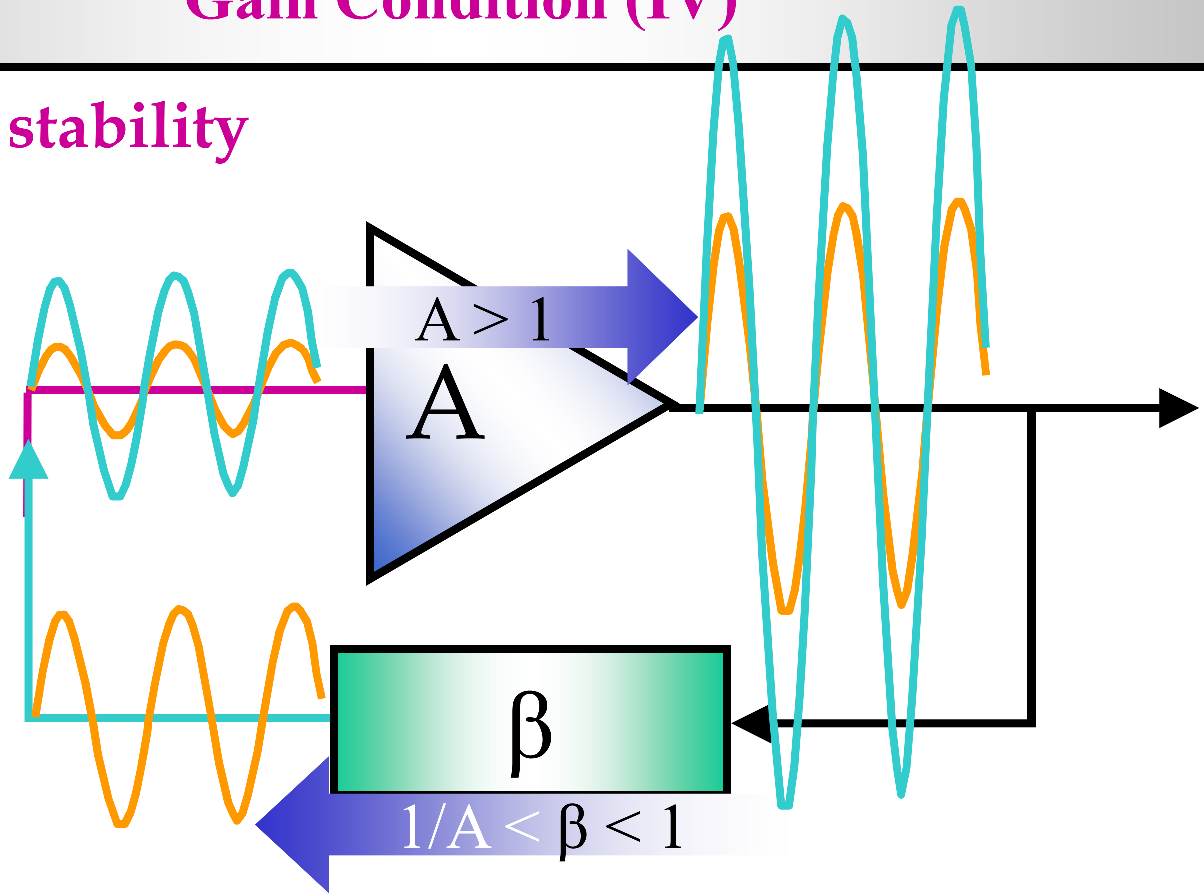


Decay of the oscillation = STABLE

Gain Condition (IV)

Relation with stability

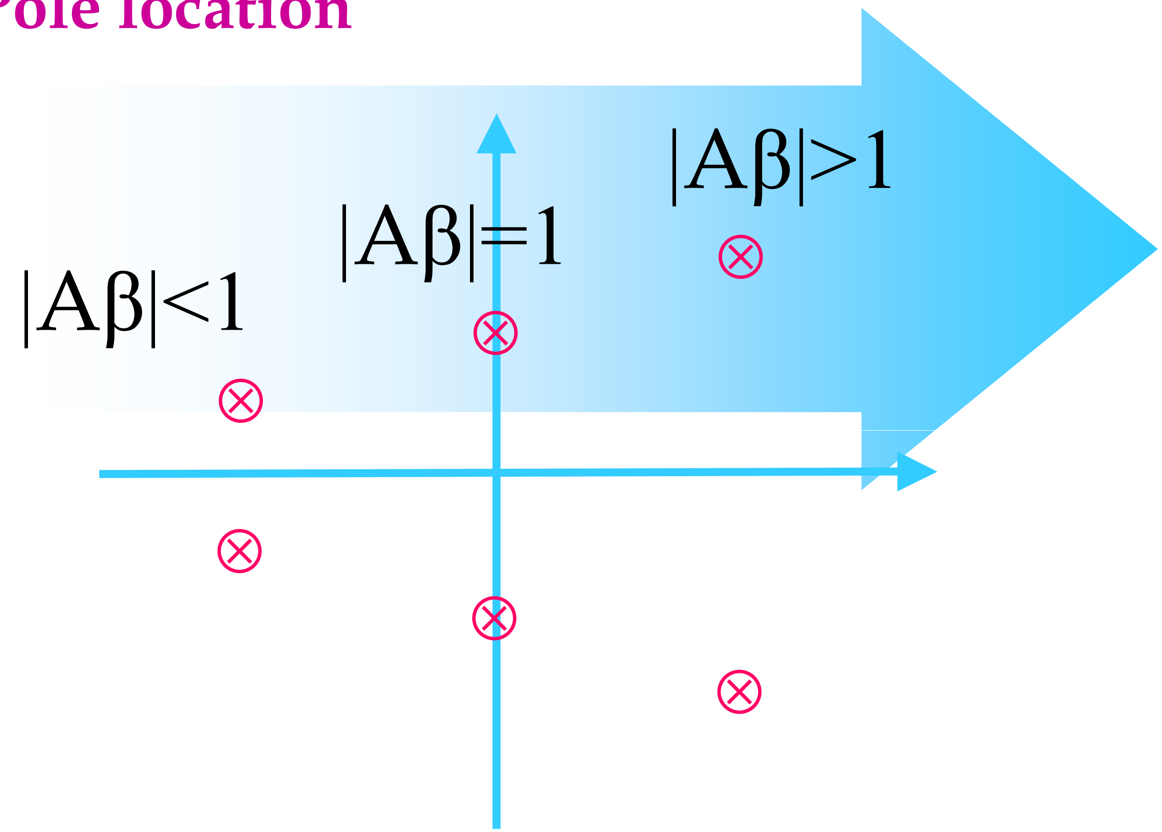
$|A\beta| > 1$



Exponential growth = UNSTABLE

Gain Condition (V)

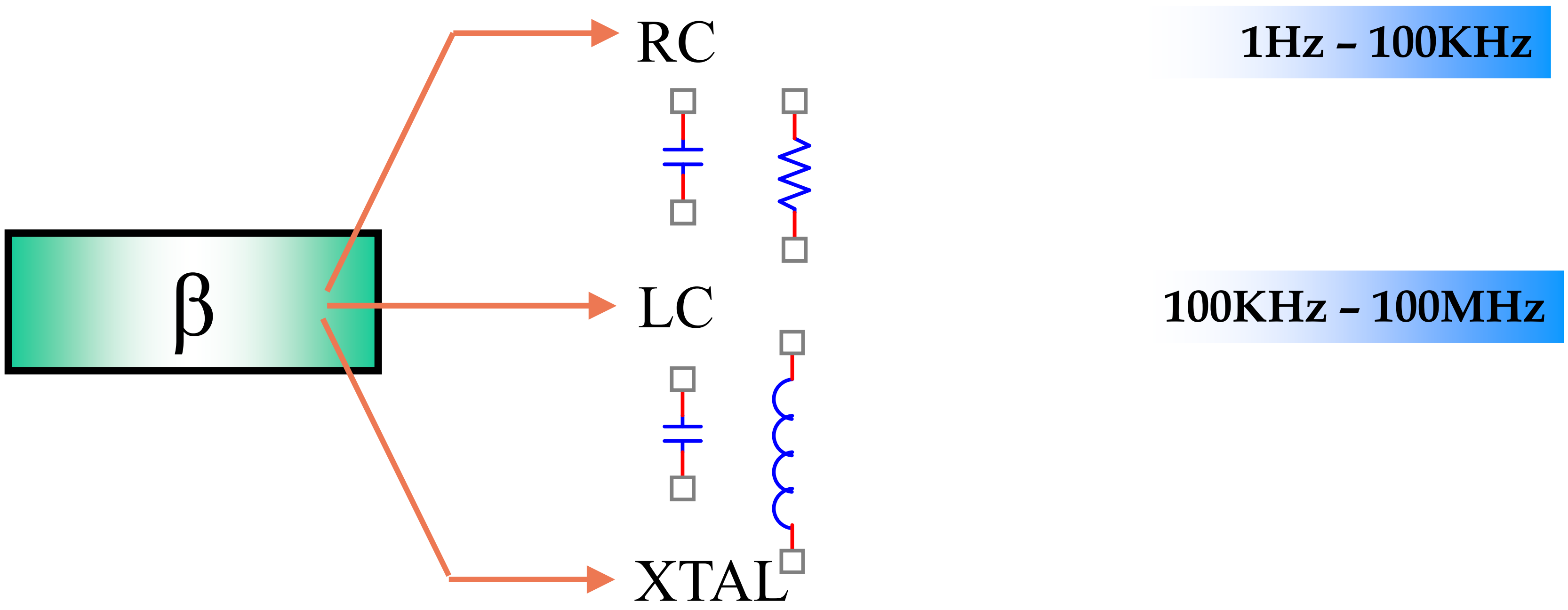
Stability ~ Pole location



Poles move as the loop gain changes

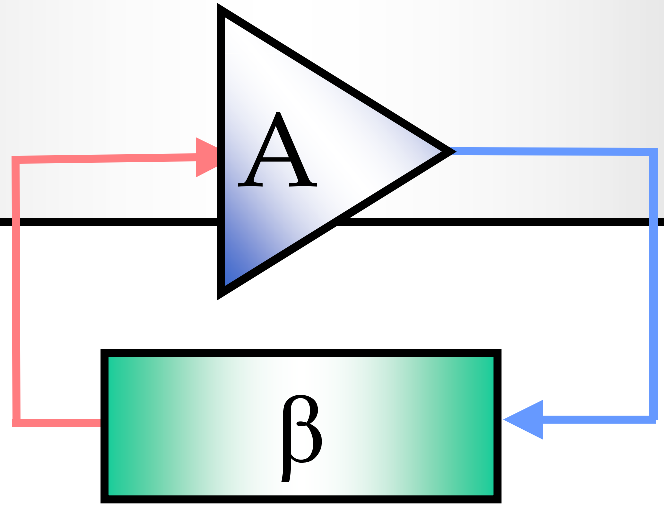
Feedback network implementation

Allows to classify the oscillators,



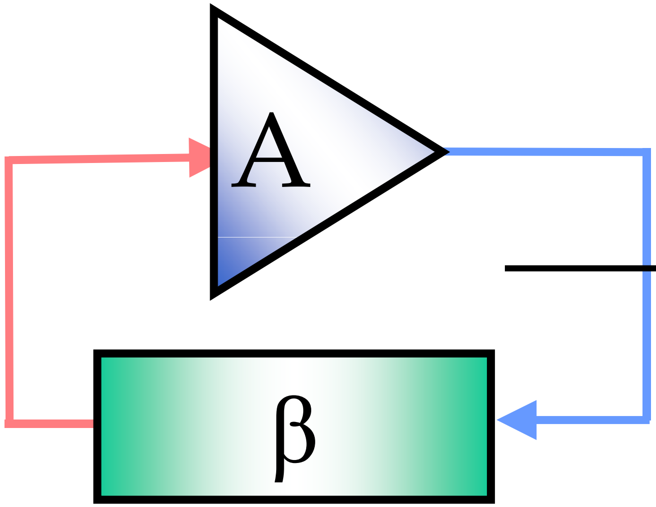
OSCILADOR ANALYSIS

Loop Gain Calculation



Transfer Function

The behaviour of any circuit is known from its transfer function.



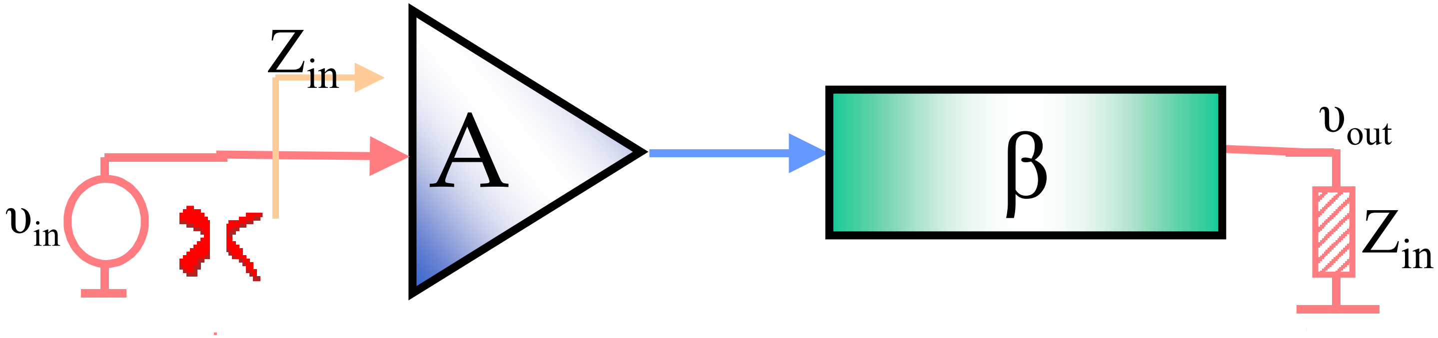
$$A_f(s) = \frac{A(s)}{1 - A(s)\beta(s)}$$

For an oscillator, we need to know the LOOP GAIN

From it, poles can be found solving the characteristic equation:

$$1 - A(s)\beta(s) = 0$$

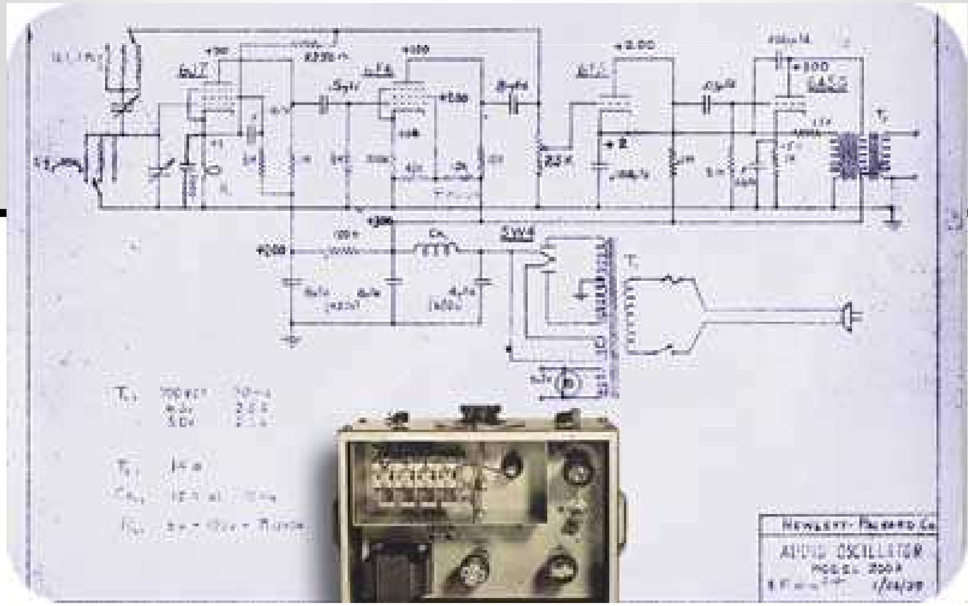
Loop gain [Aβ] calculation steps



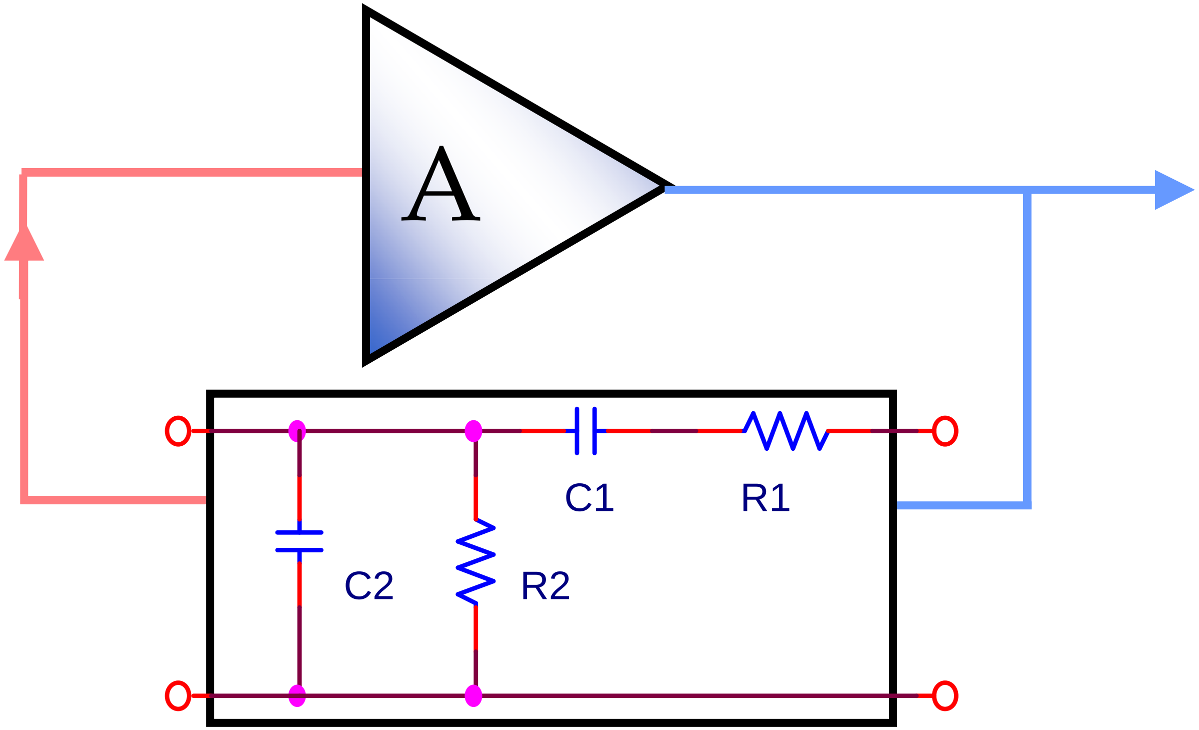
1. Open the feedback loop.
2. Load the output with input impedance, Zin.
3. Apply an input signal source, υ_{in}.
4. Calculate the transfer funtion (Aβ) as $\upsilon_{out}/\upsilon_{in}$.
5. Apply the Barkhausen criterion by forcing $\upsilon_{out} = \upsilon_{in}$.

OSCILLATOR EXAMPLE

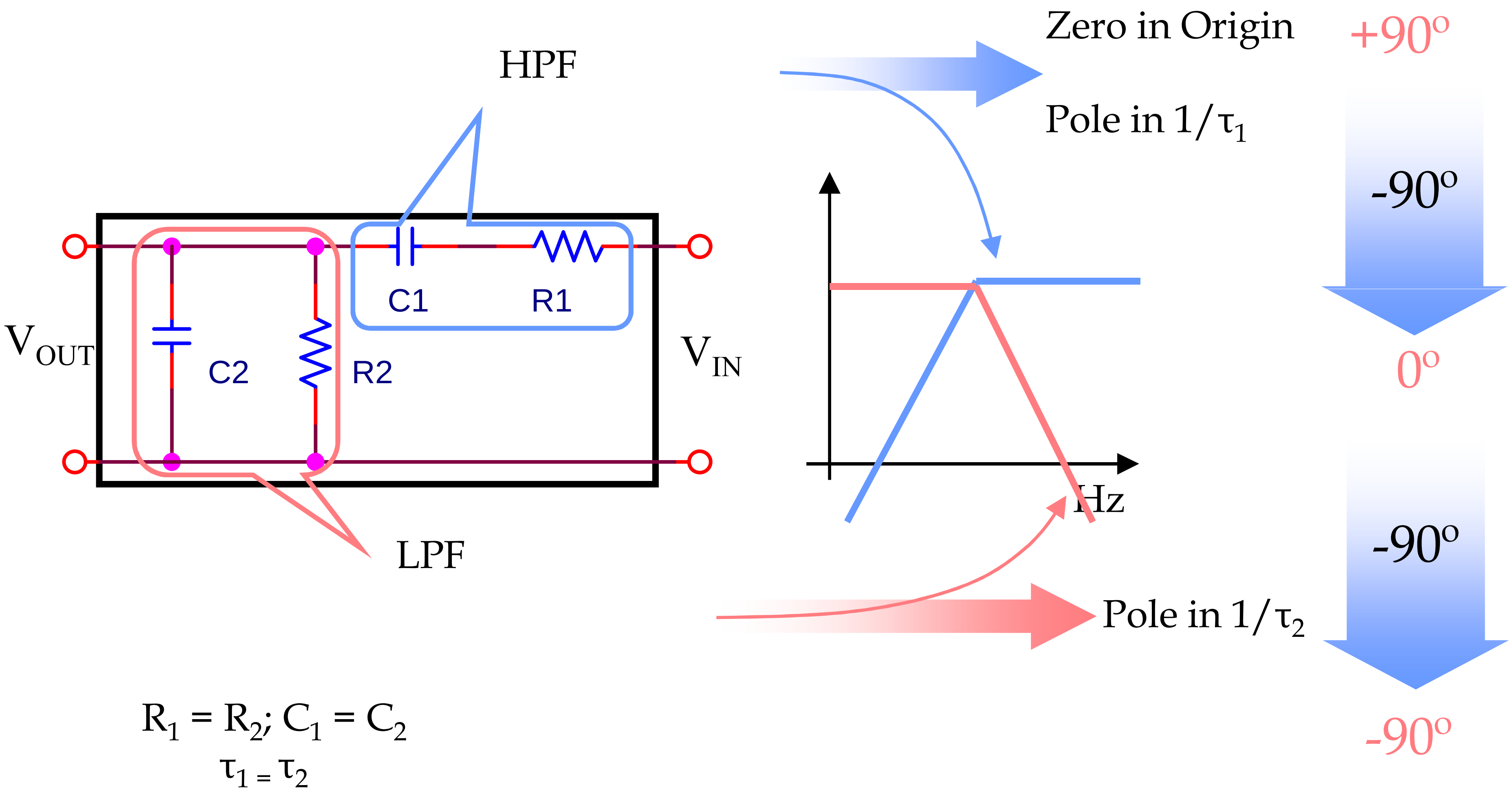
The Wien bridge oscillator



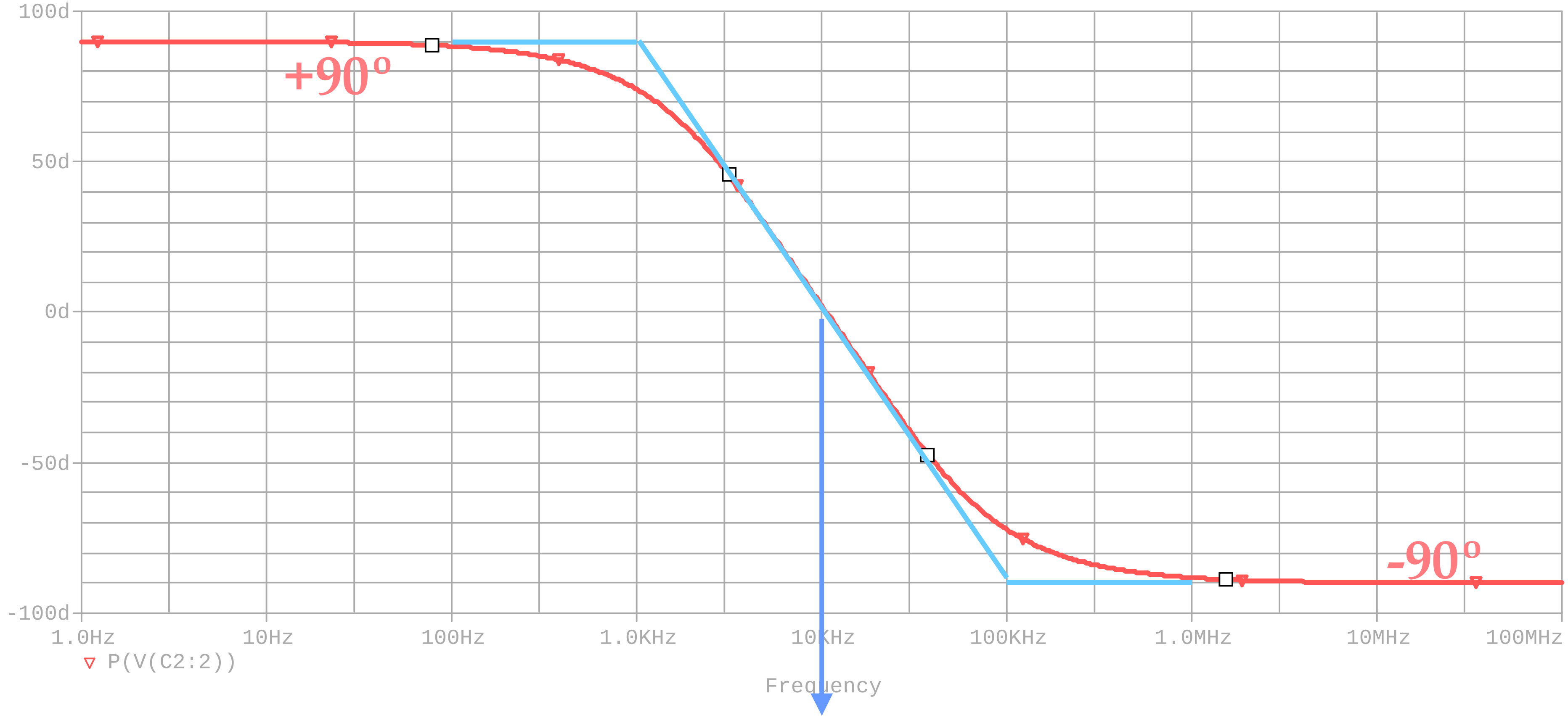
Wien bridge feedback network



Qualitative analysis

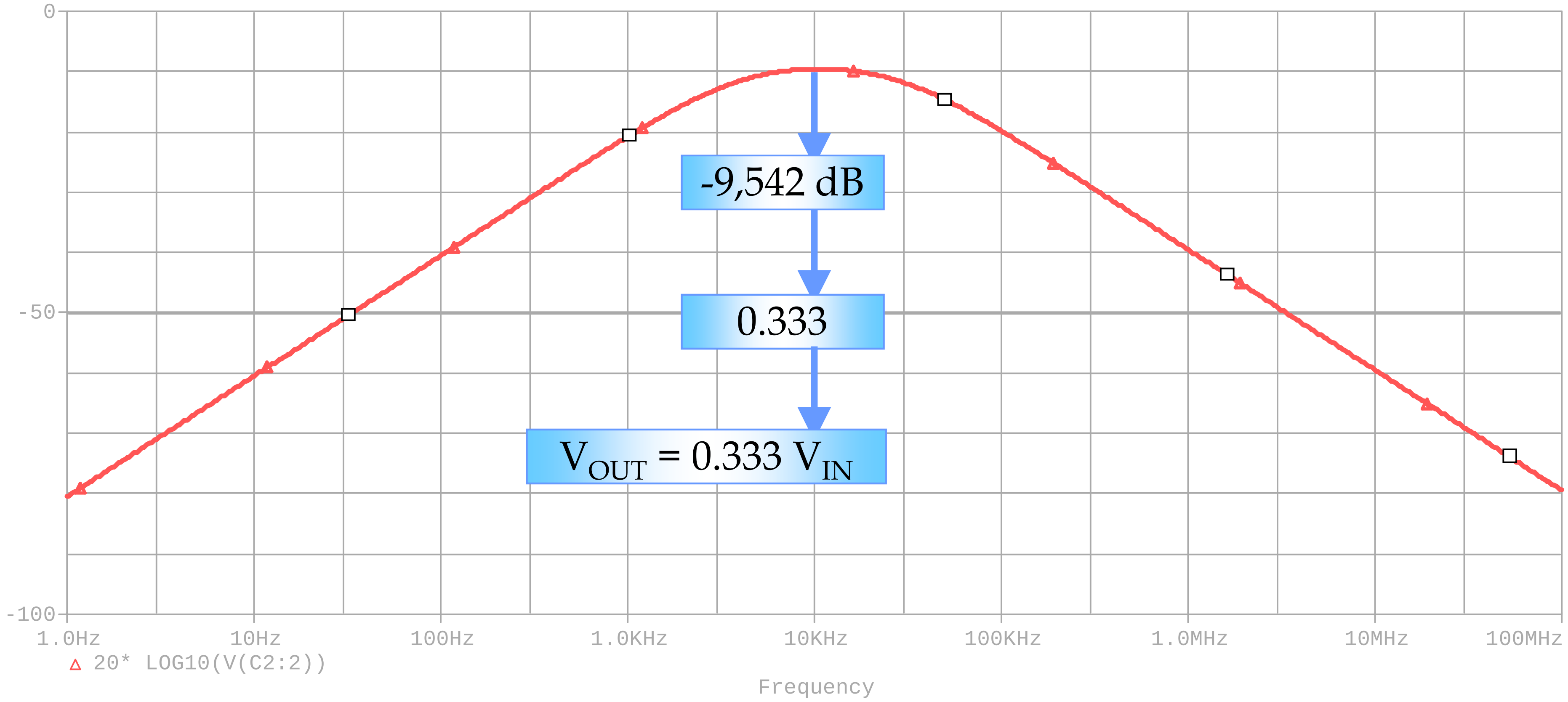


Qualitative analysis (Phase)



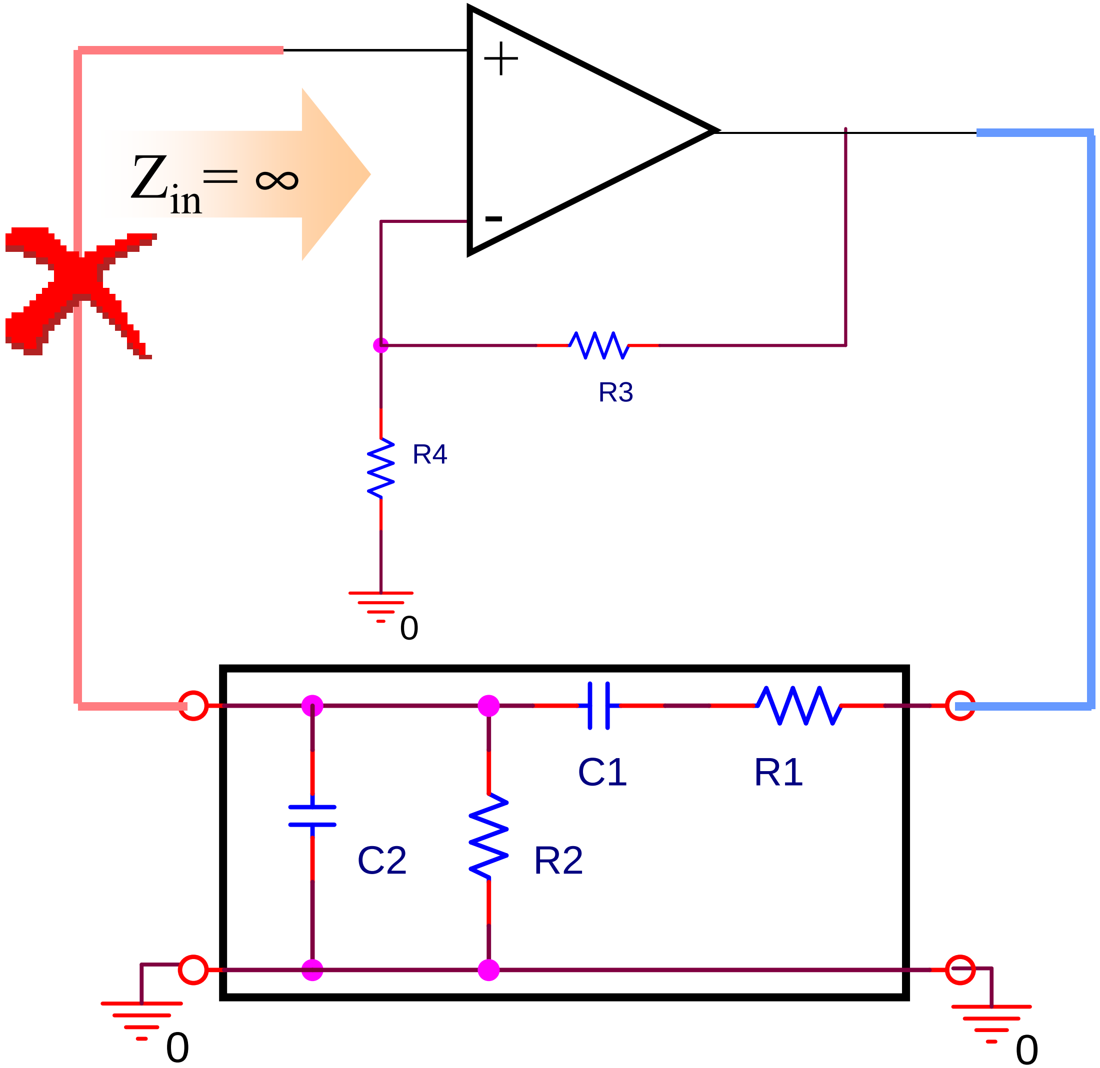
Requires NON-INVERTING AMP

Qualitative analysis (Gain)

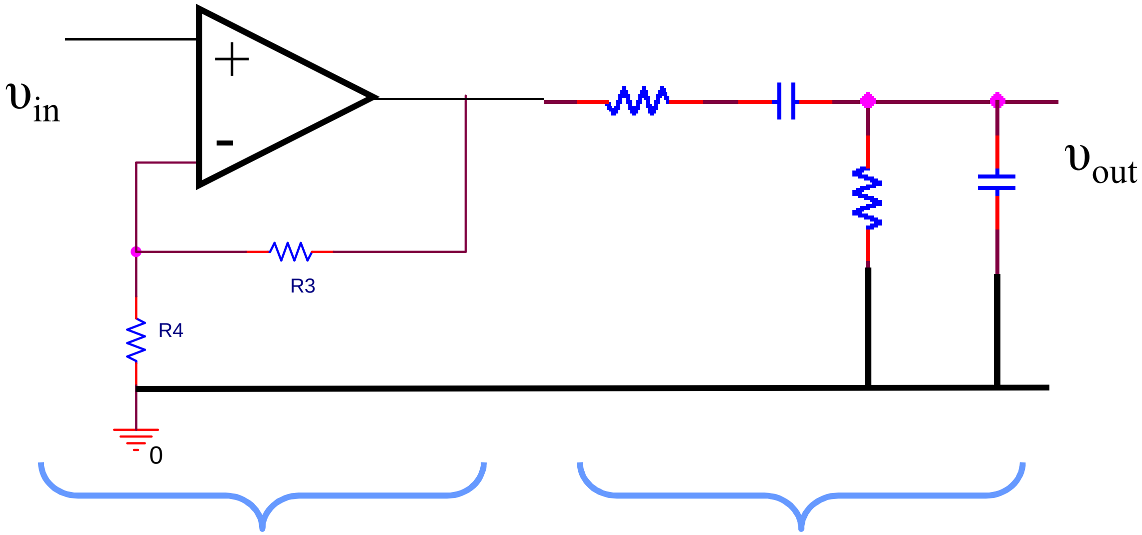


Feedback Network Attenuation level β = 3 !!

Oscillator Configuration



Loop Gain Calculation



$$A = 1 + \frac{R_3}{R_4}$$

$$\beta = \frac{sRC}{(sRC)^2 + 3(sRC) + 1}$$

$$A\beta = \left(1 + \frac{R_3}{R_4}\right)\frac{sRC}{(sRC)^2 + 3(sRC) + 1}\Bigg|_{s=j\omega} = 1$$

Conditions for Oscillation

$$j\omega RC\left(1+\frac{R_3}{R_4}\right)=-(\omega RC)^2+j3(\omega RC)+1$$

Phase $-(\omega RC)^2+1=0$ → $\omega_0=\frac{1}{RC}$

Gain $\left(1+\frac{R_3}{R_4}\right)=3$ → $A=3$

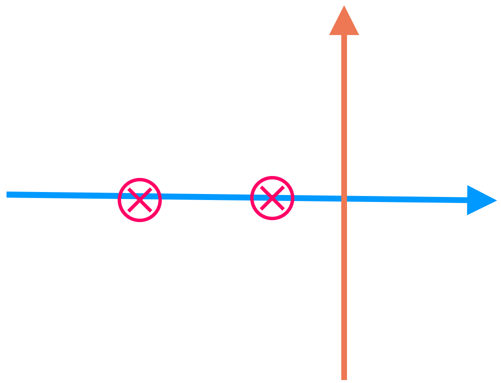
Root Locus

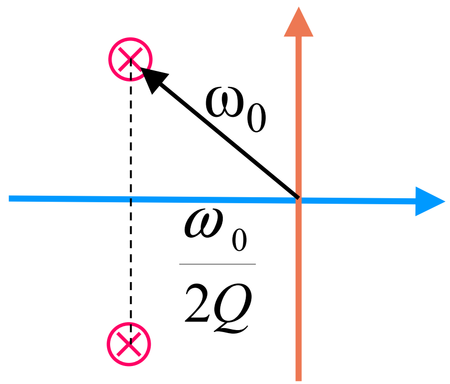
Solve the denominator of the TF, $1-A(s)\beta(s)=0$

Which results, $(sRC)^2+(3-A)(sRC)+1=0$

A second order system, $s^2+s\frac{\omega_0}{Q}+\omega_0^2=0$

$$\omega_0=\frac{1}{RC} \qquad Q=\frac{1}{3-A}$$

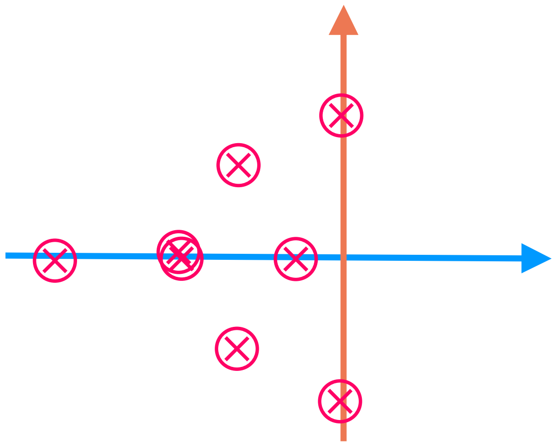




Root locus in terms of AMP GAIN

The poles of the second order system result . . .

. . . . two real poles	IF	$Q < 0.5 \longrightarrow A < 1$
. . . . two complex conjugate	IF	$Q > 0.5 \longrightarrow A > 1$
. . . . In the imaginary axis	IF	$Q = \infty \longrightarrow A = 3$



Some results

Wien Bridge Oscillator without Amplitude Control.

With A = 3

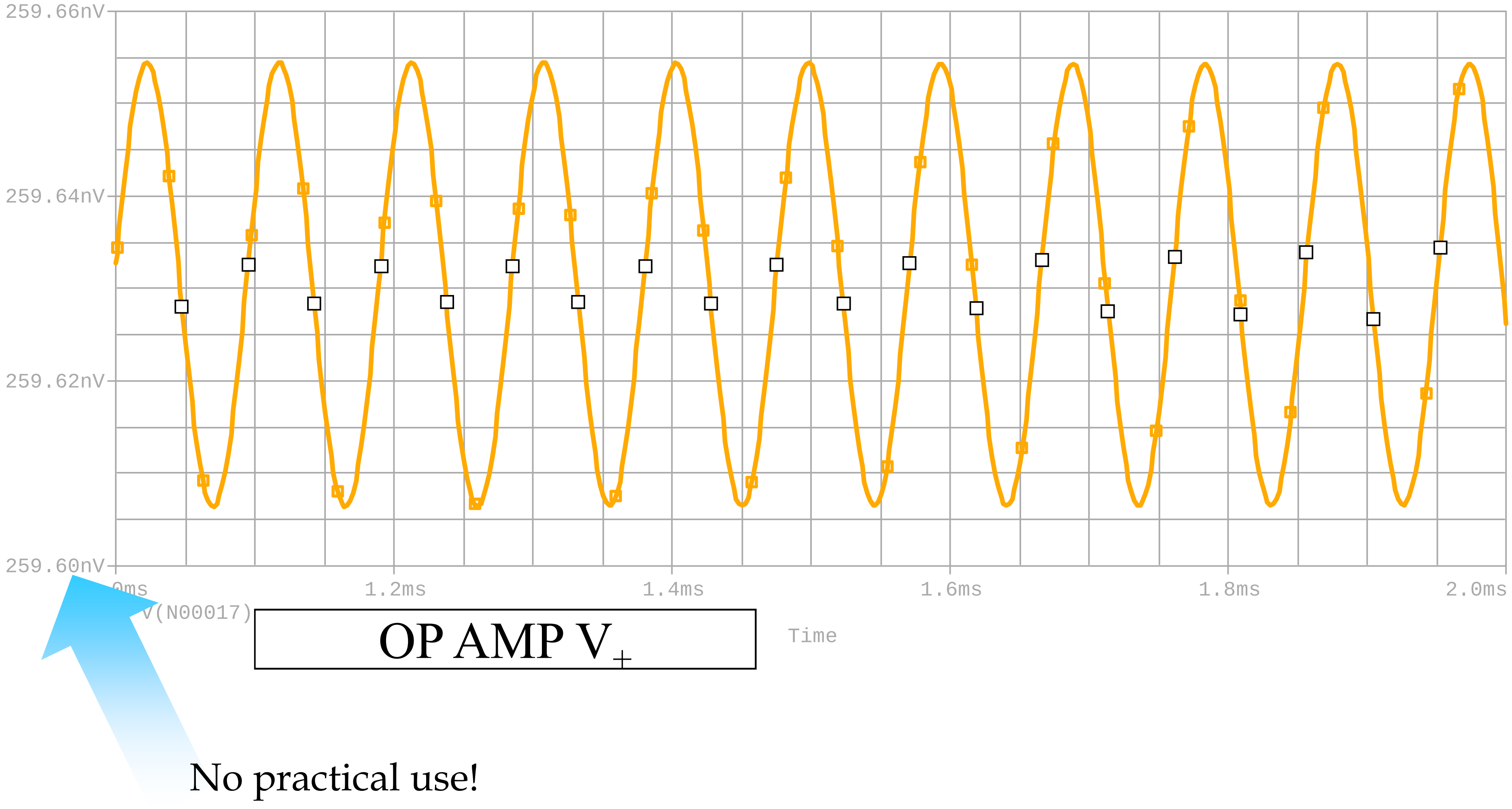
With A = 3.2

Wien Bridge Oscillator wit Amplitude Control

with Light Bulb

Ohm region FET

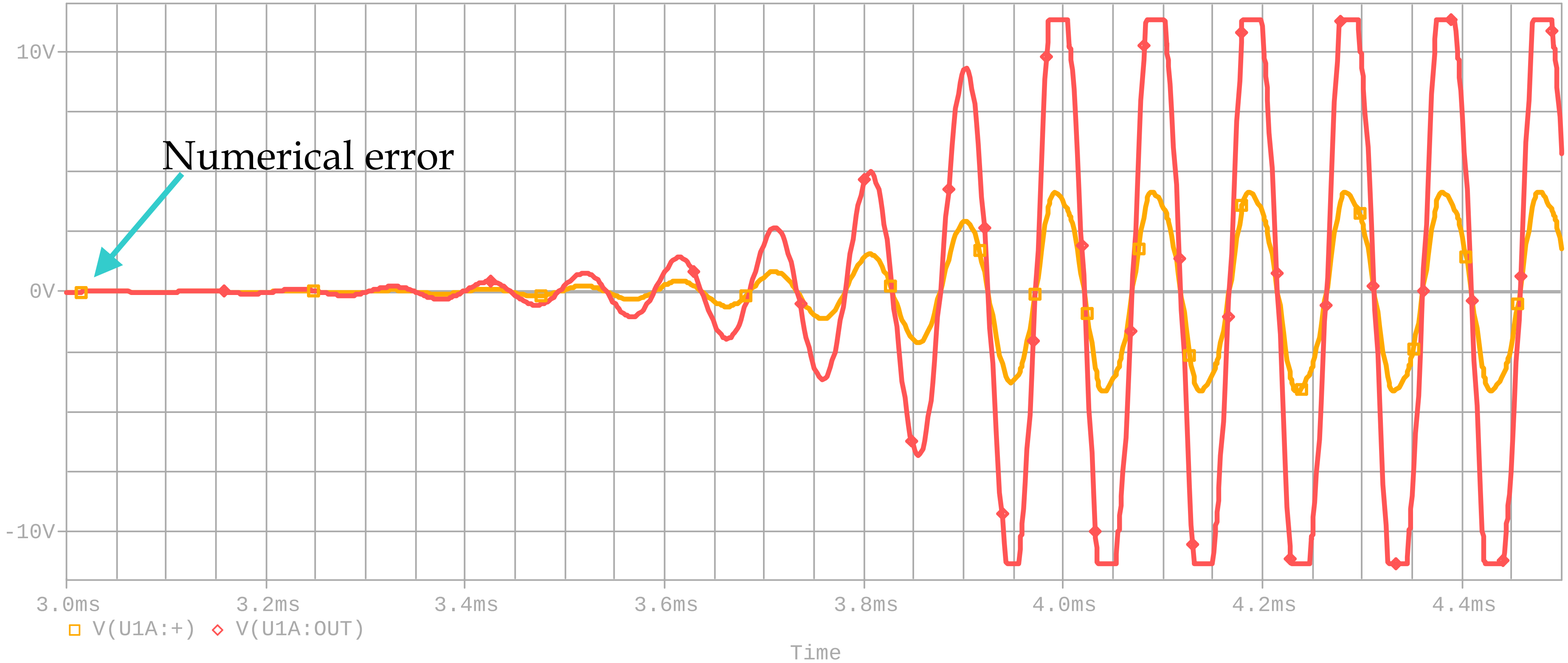
Spice analysis with A = 3



No practical use!

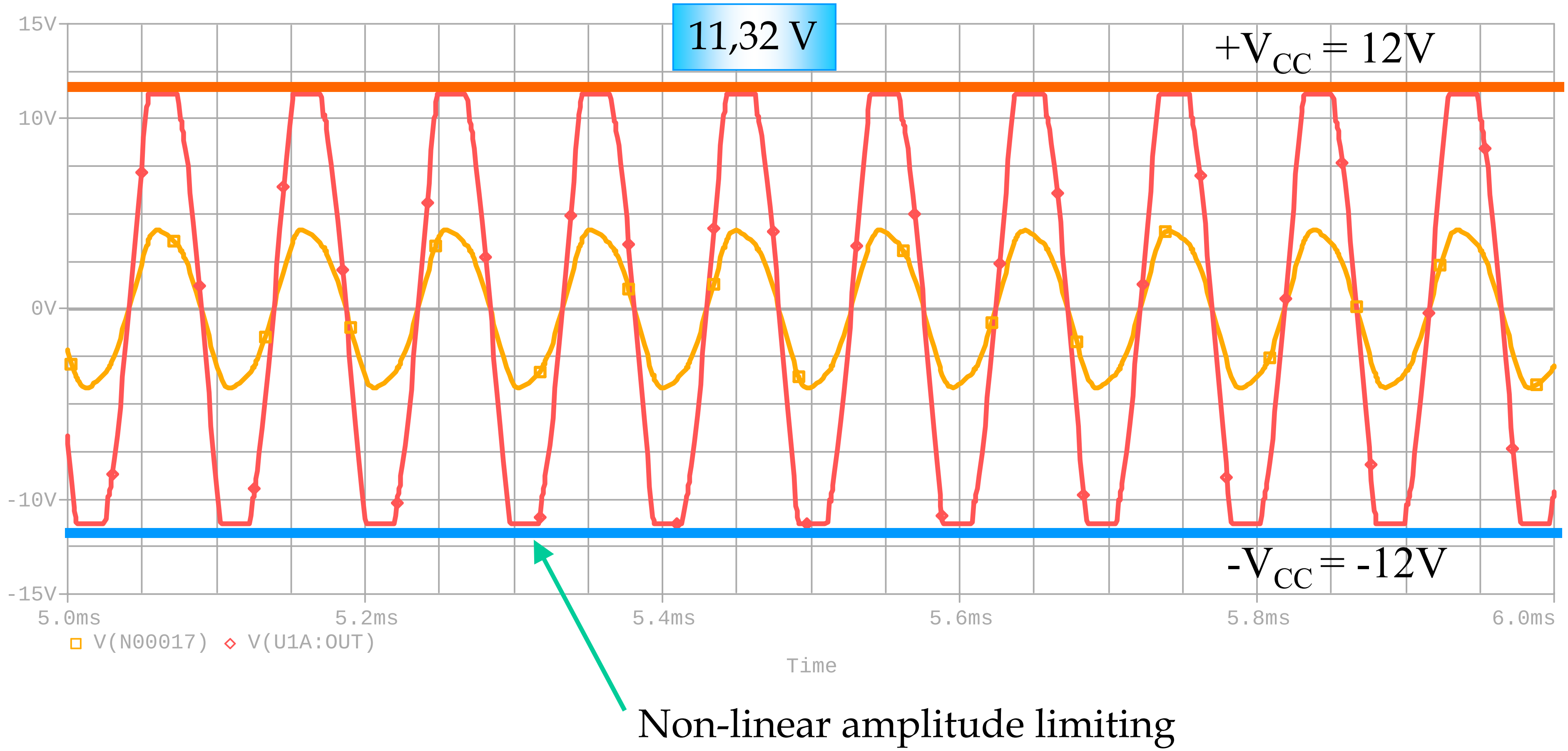
Spice analysis with A = 3,2

Start up.



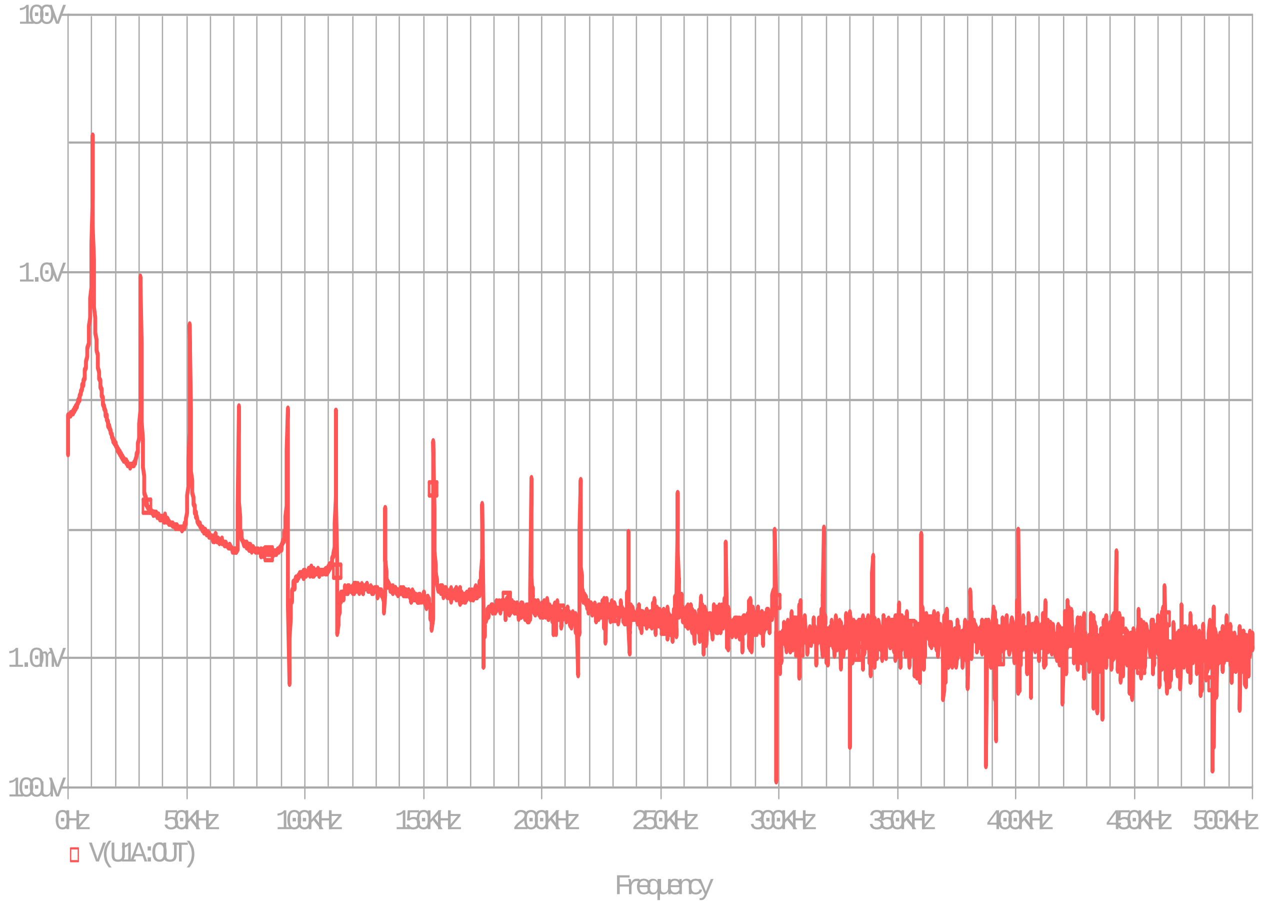
Spice analysis with A = 3,2

CW oscillation



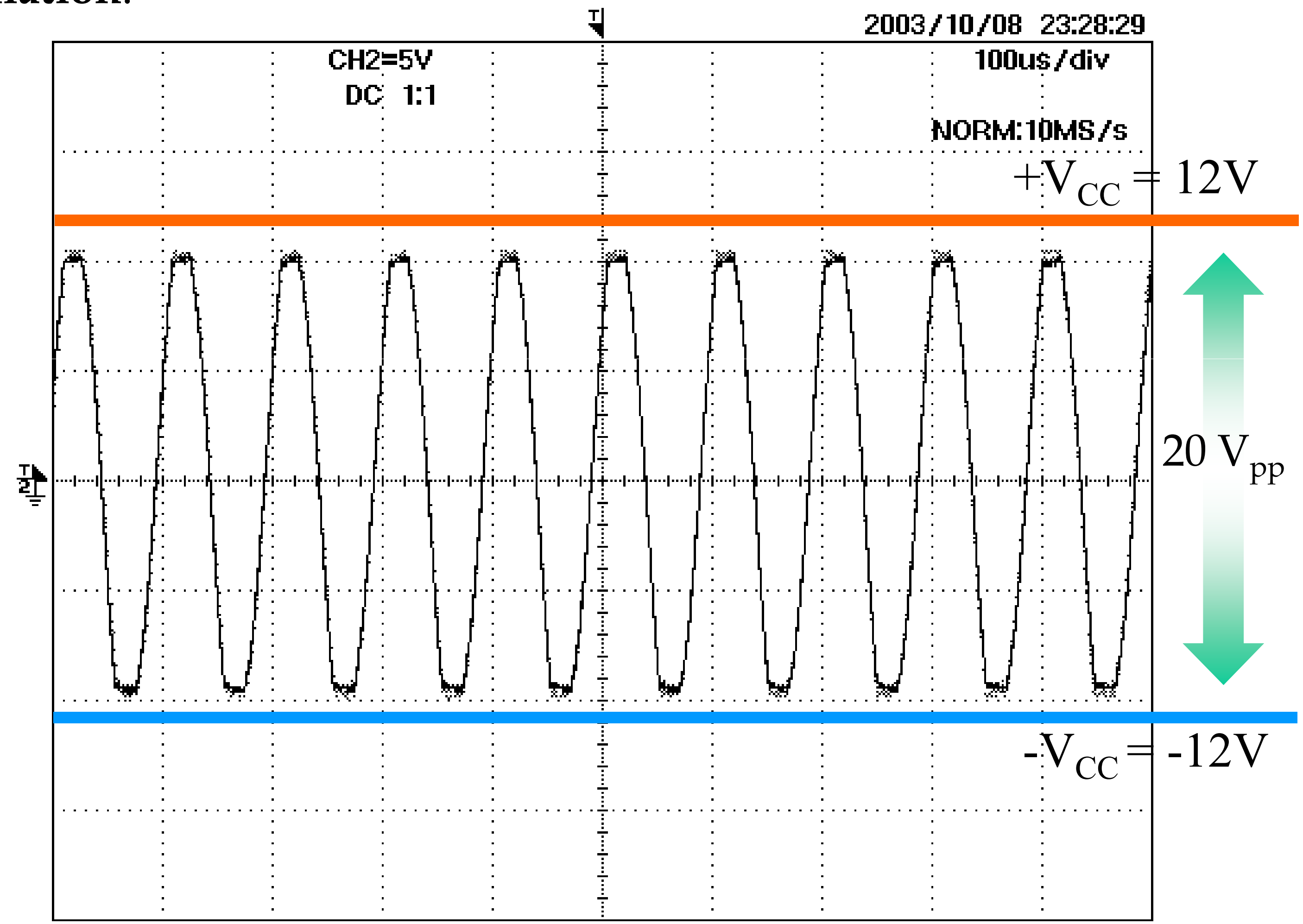
Spice analysis with A = 3,2

Fourier picture of the oscillation.



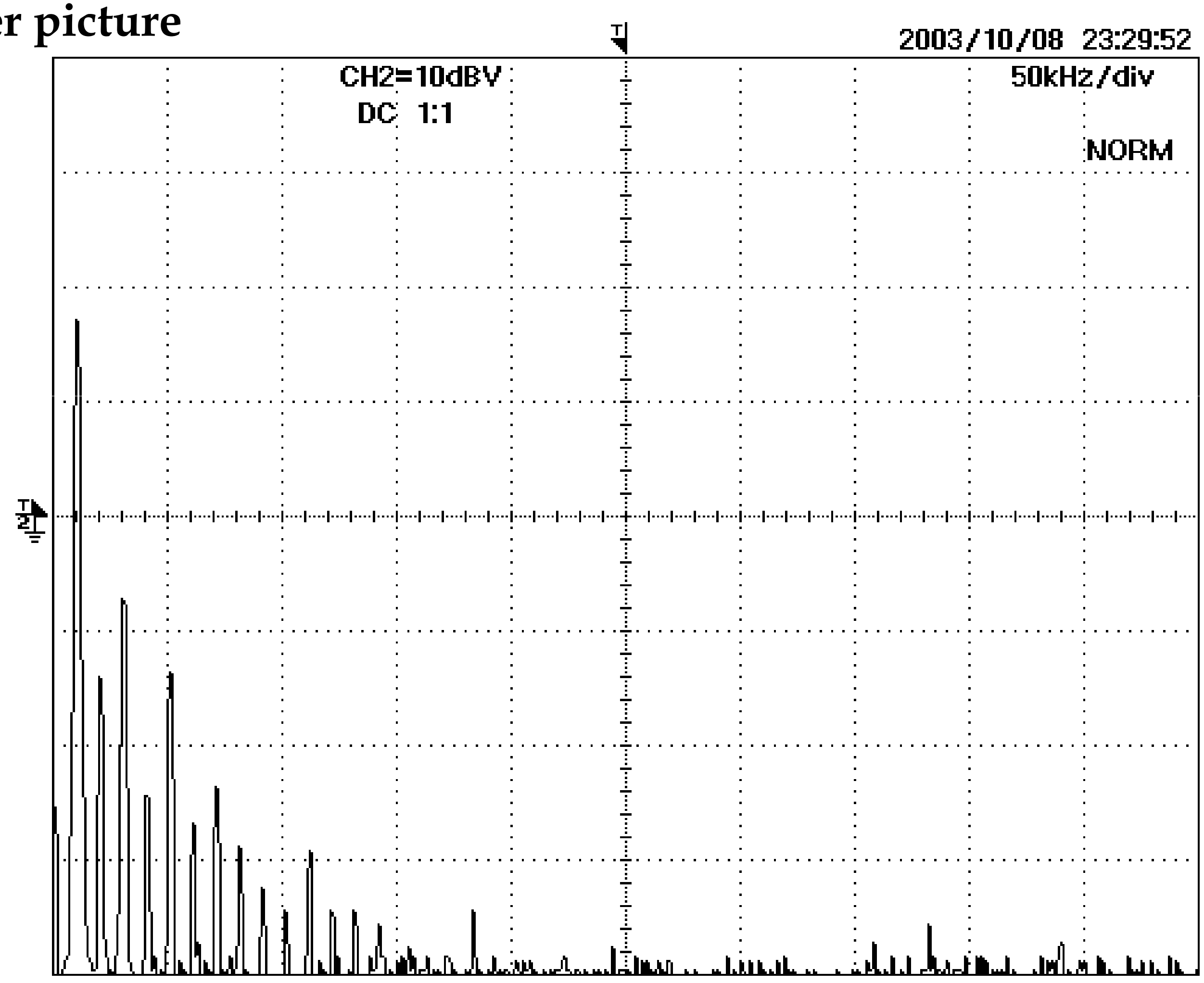
The real thing with A = 3,2

CW oscillation.

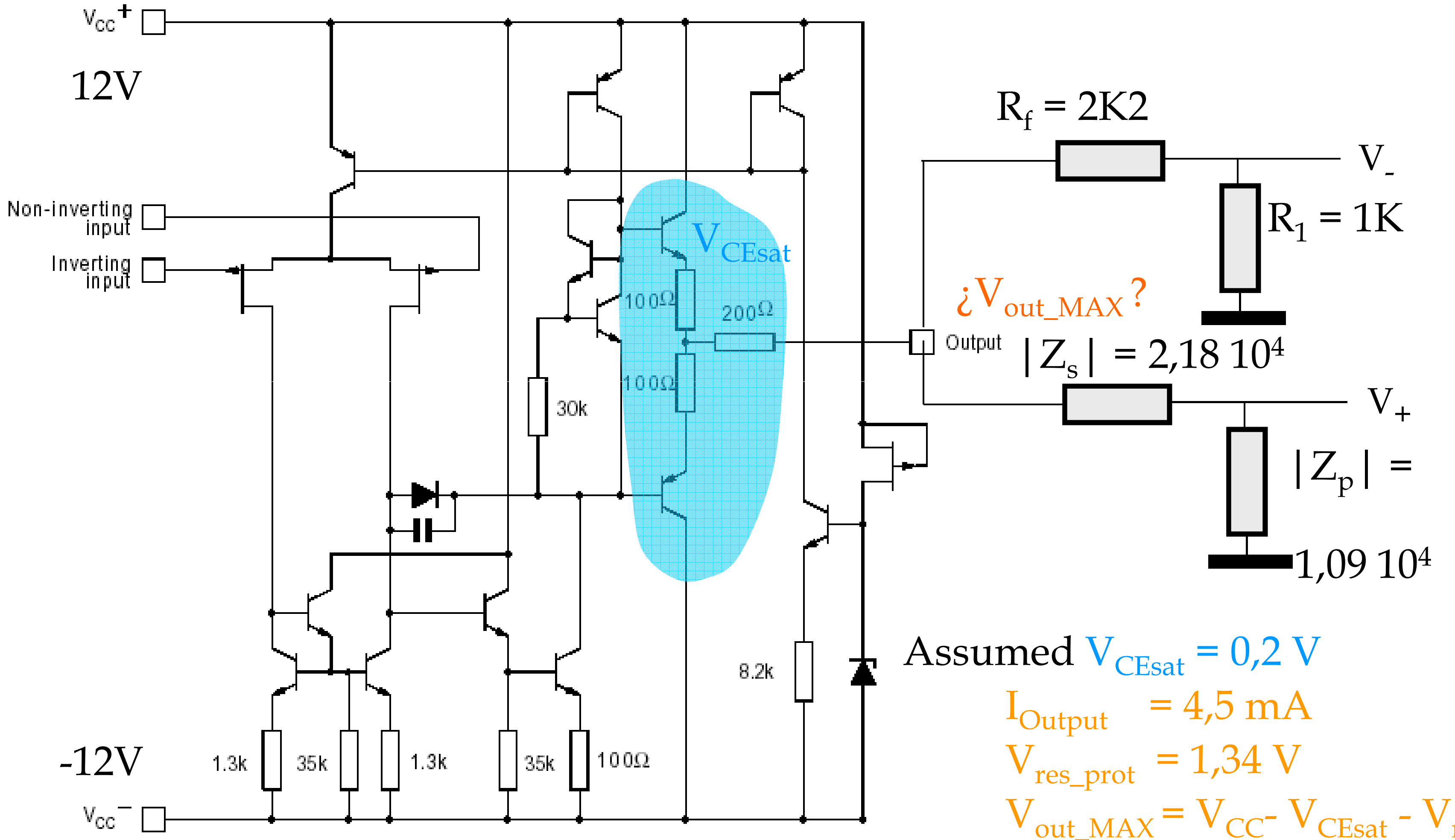


The real thing with A = 3,2

Fourier picture



Non-linear amplitude limitation



Assumed $V_{CEsat} = 0{,}2\ V$

$I_{Output} = 4{,}5\ mA$

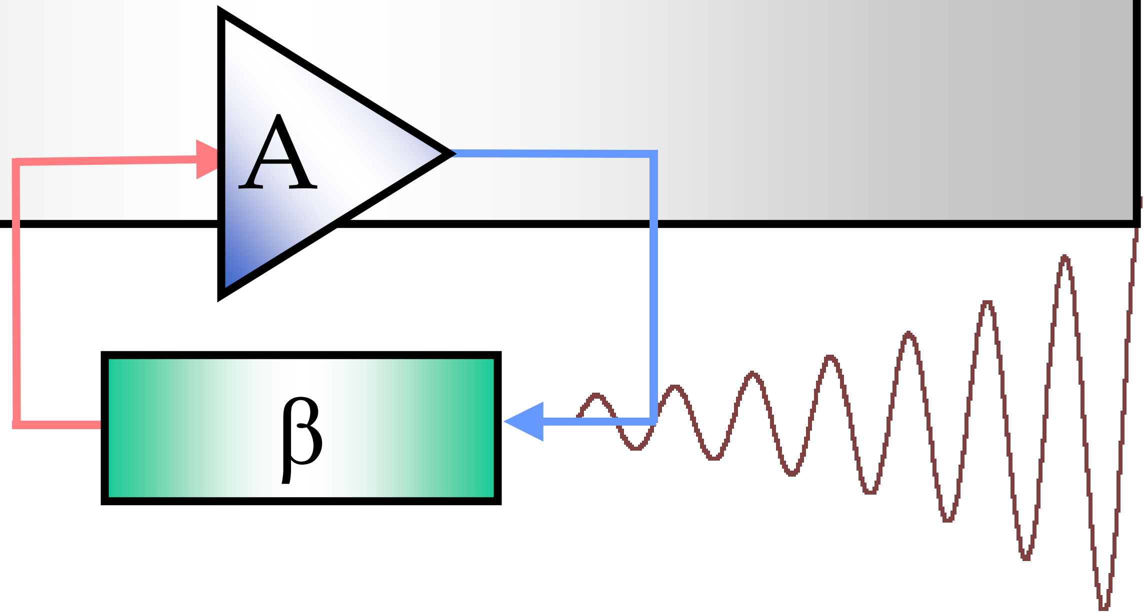
$V_{res\_prot} = 1{,}34\ V$

$V_{out\_MAX} = V_{CC} - V_{CEsat} - V_{res\_prot}$

$= 10{,}3\ V$

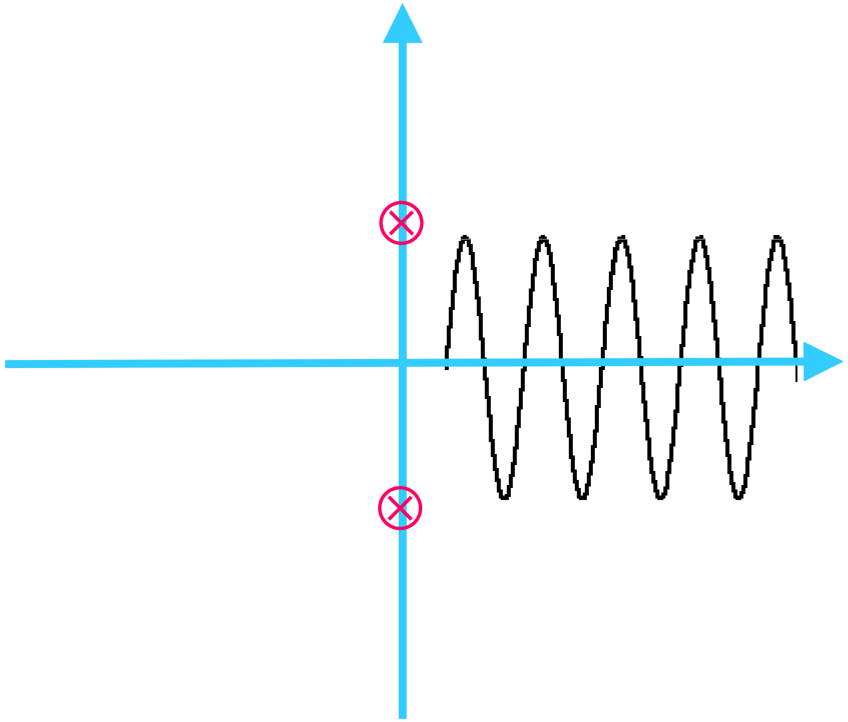
OSCILLATOR AMPLITUDE CONTROL

Wien Bridge Example



What we do know

For an oscillator to operate properly, requires $|A\beta|=1$ (PRECISE)

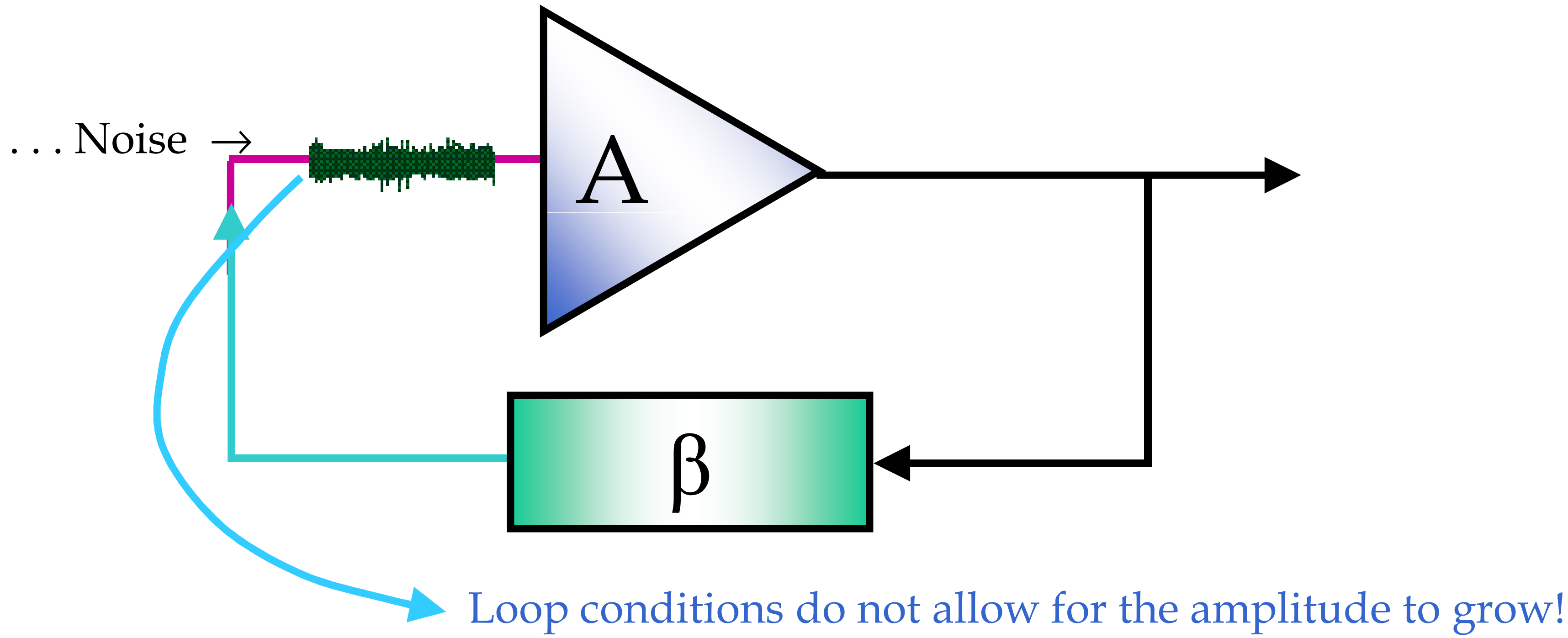


A precise adjustment of the Amplifier gain to exactly compensate for the feedback network losses in the loop.

Precise adjustment of amplifier gain → Use of feedback.

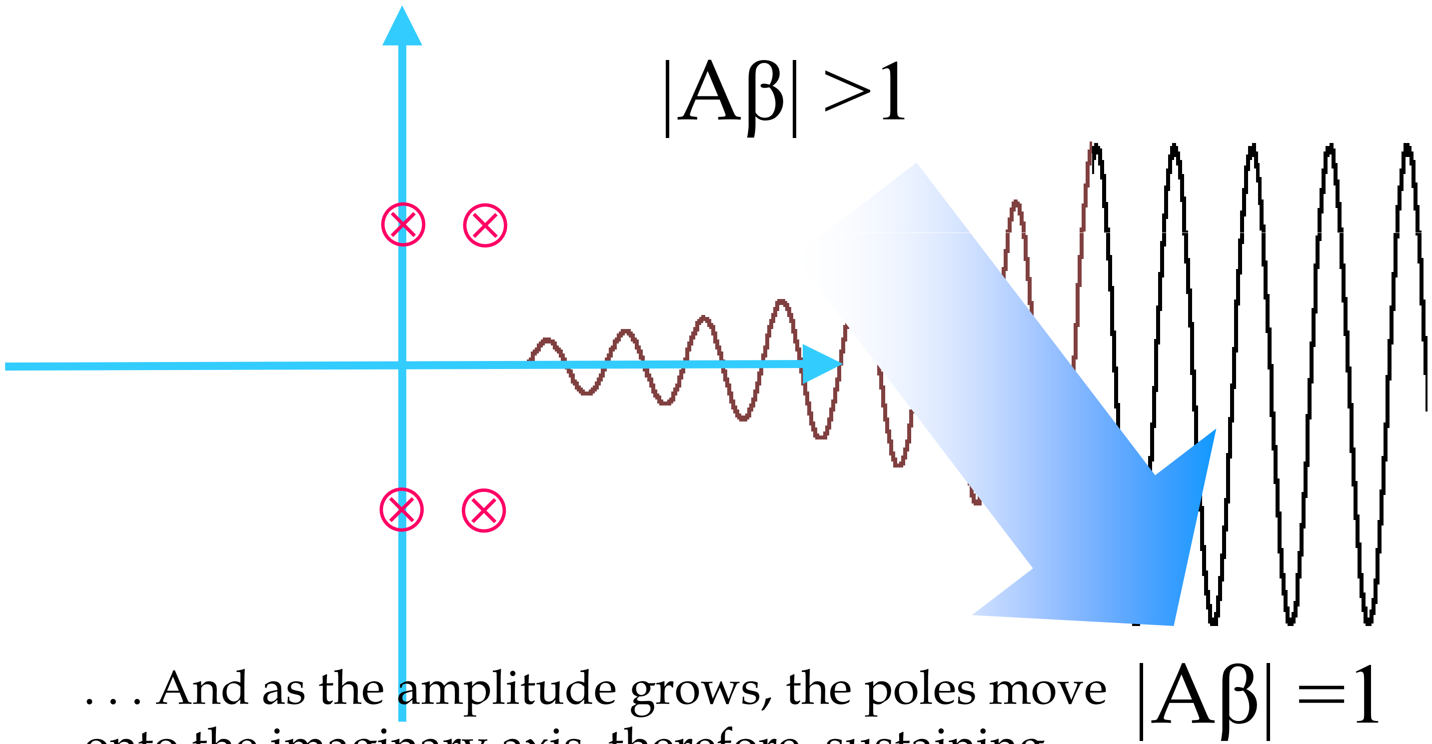
Oscillation turn-on

Gain = Loss means poles are on the imaginary axis, which allows to sustain oscillation. However, at turn-on time, the oscillation amplitude is given by noise



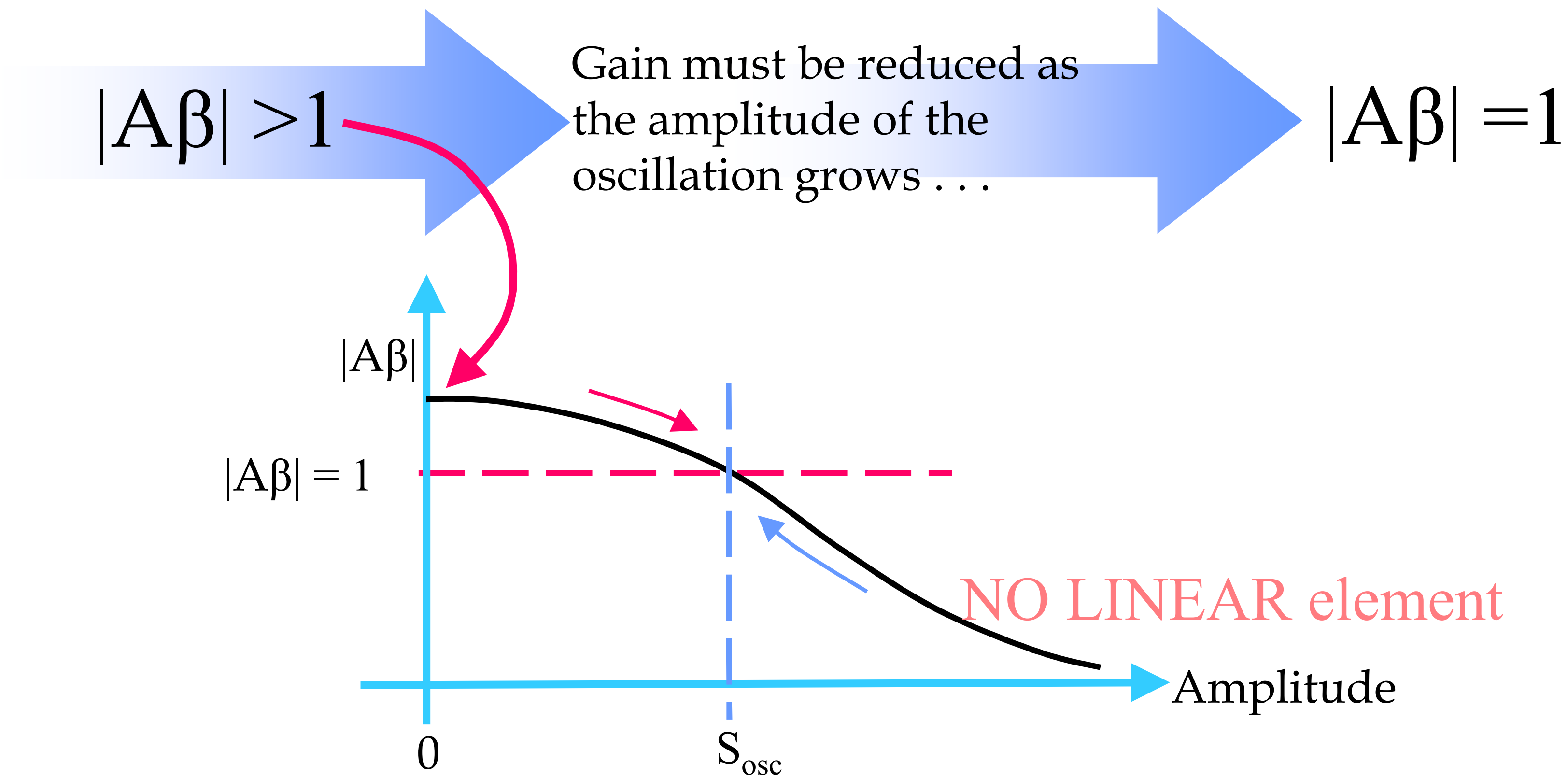
Oscillation turn-on

We need to build in a system that when the oscillation amplitude is low, locates the system poles on the right hand side . . .



. . . And as the amplitude grows, the poles move onto the imaginary axis, therefore, sustaining the oscillation at a desired amplitude level.

Automatic Gain Control (AGC) system



Elementos necesarios de un oscilador (y II)

- **Amplificador Básico, . . .**

  que proporciona **GANANCIA** (con un desfase).

- **Red de realimentación, . . .**

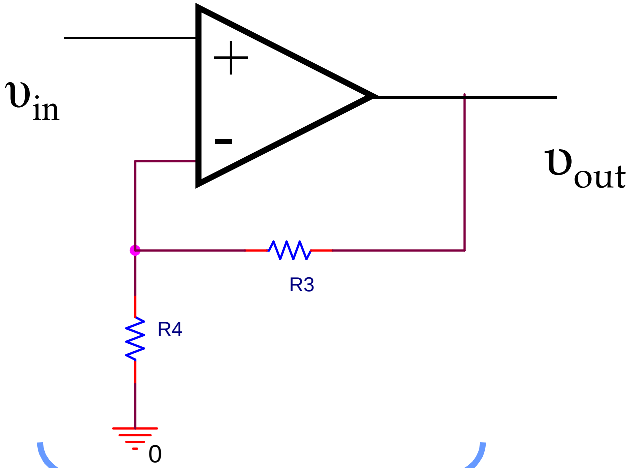
  SELECTIVA EN FRECUENCIA para determinar la frecuencia de oscilación, y que además introduce **PÉRDIDAS.**

- **Control no lineal de la ganancia, . . .**

  que permite **ARRANCAR** al oscilador a partir del ruido.

Control de la amplitud. Bases

Fijada inicialmente (cuando $\upsilon_{out} = 0$) $|A\beta| > 1$, . . .



. . . buscamos un medio para reducir la ganancia del amplificador a medida que aumenta υ_{out}.

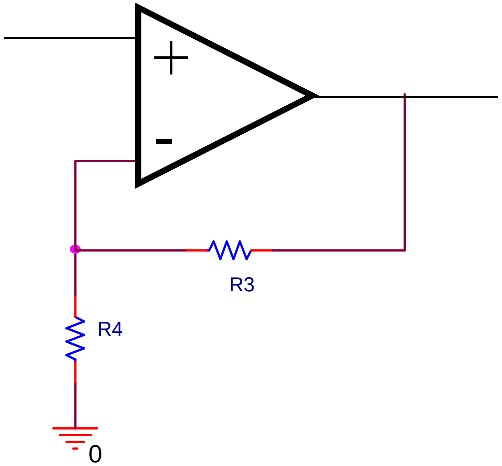
$$A = 1 + \frac{R_3}{R_4}$$

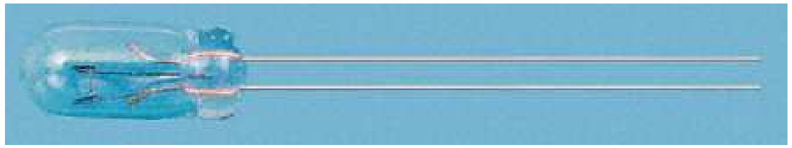
$R_3 \downarrow$ cuando $\upsilon_{out} \uparrow$ (**NTC**)

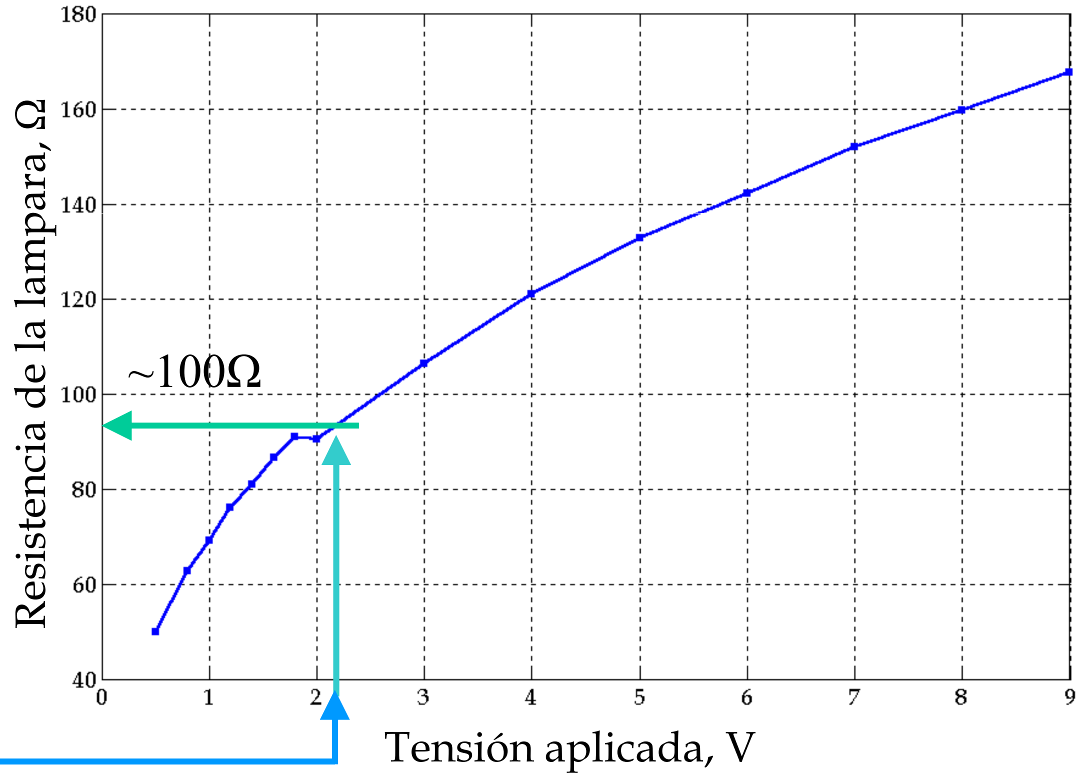
$R_4 \uparrow$ cuando $\upsilon_{out} \uparrow$ (**PTC**)

IMPORTANTE: La constante de tiempo de variación de la resistencia $\tau >>> T_{osc}$

Control de la amplitud con lampara incandescente (I)



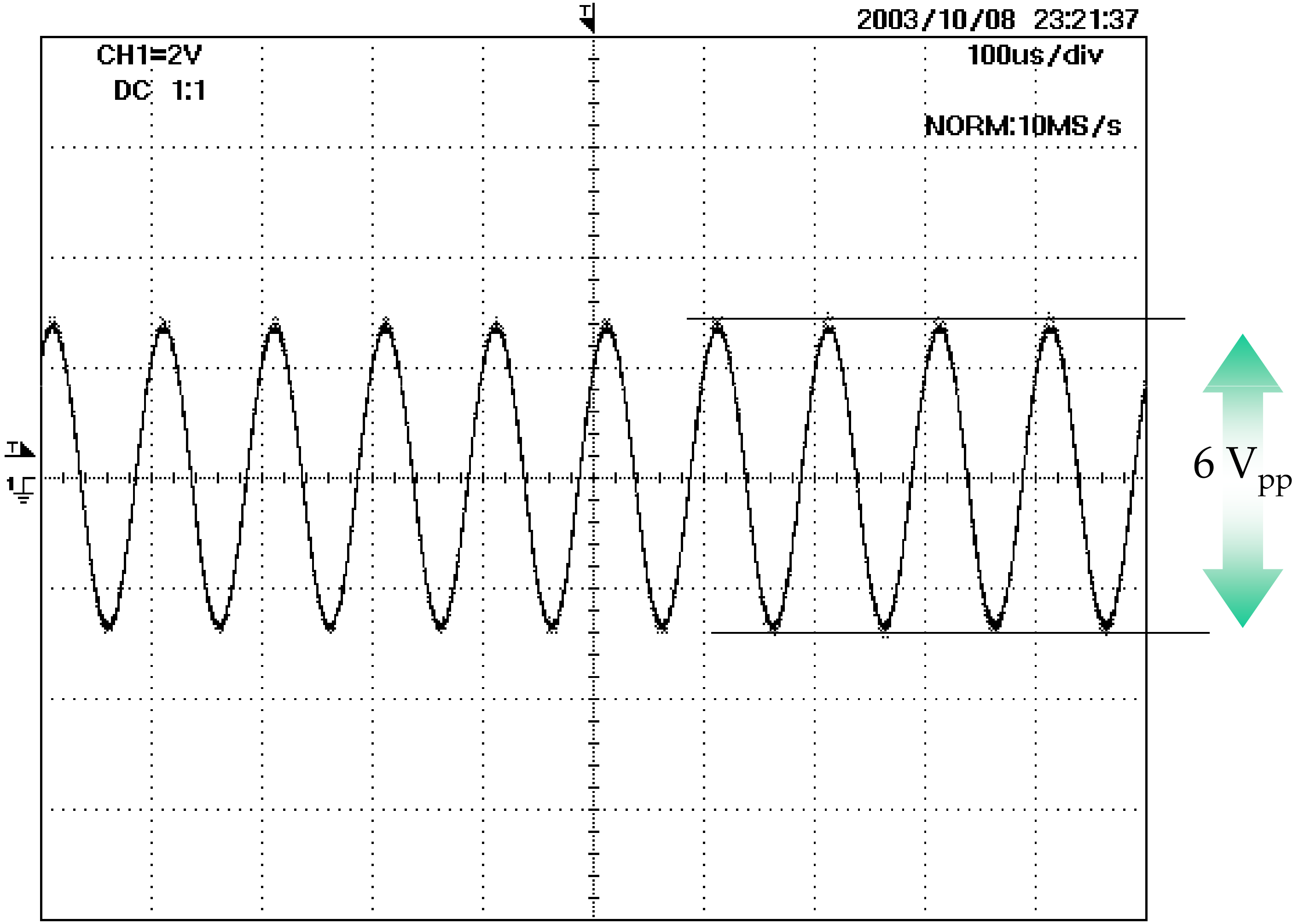




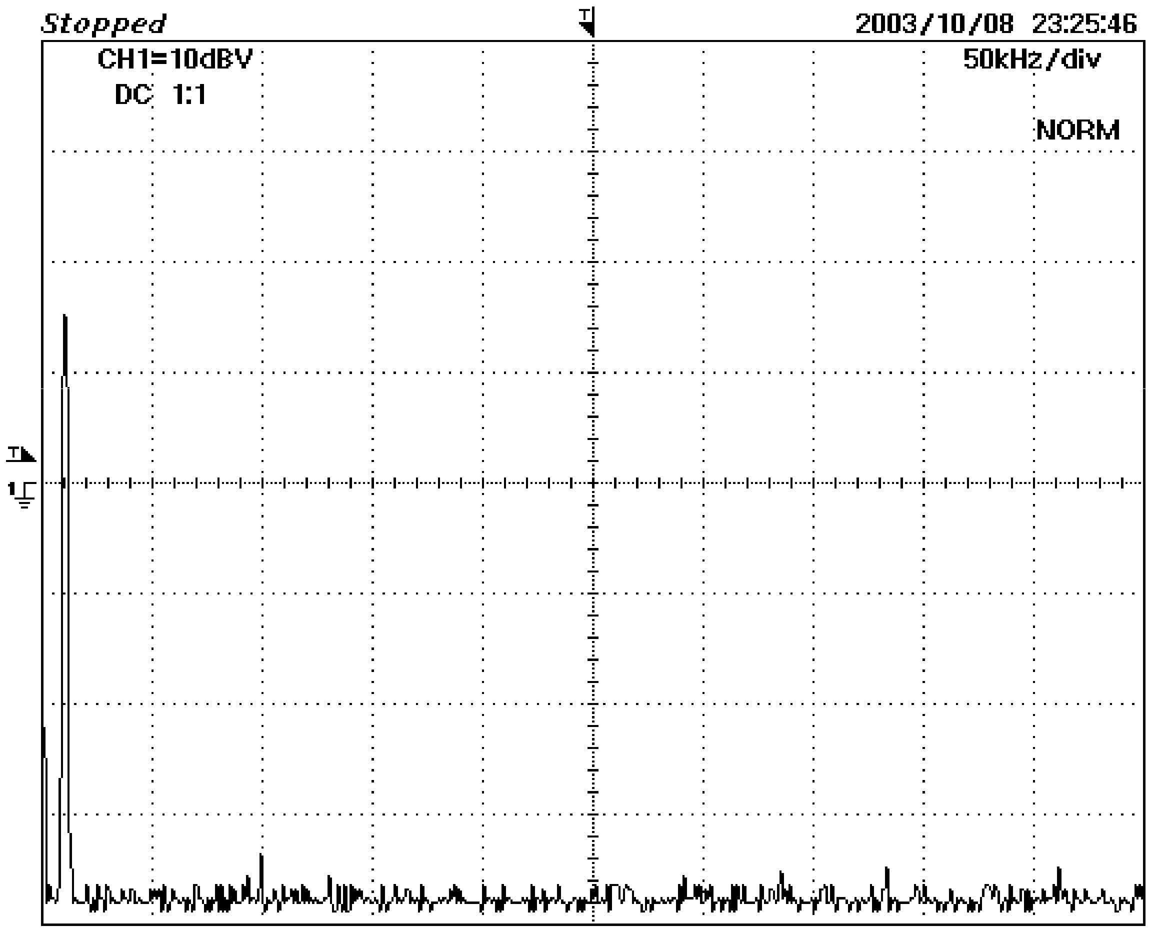
$V_{OUT} = 3$ V

$V_{OUT\_rms} = 2.12$ V

Control de la amplitud con lampara incandescente (II)

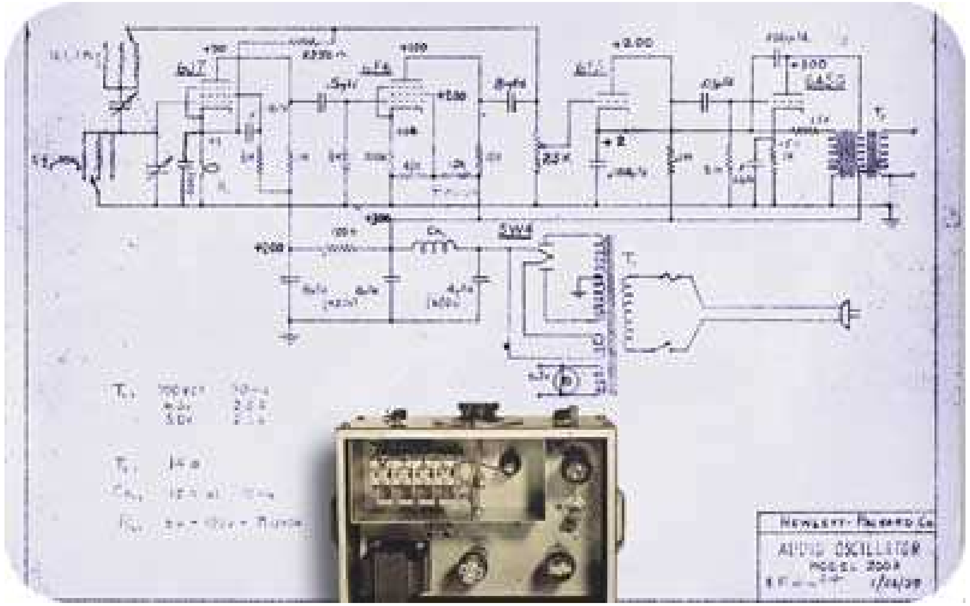


Control de la amplitud con lampara incandescente (III)



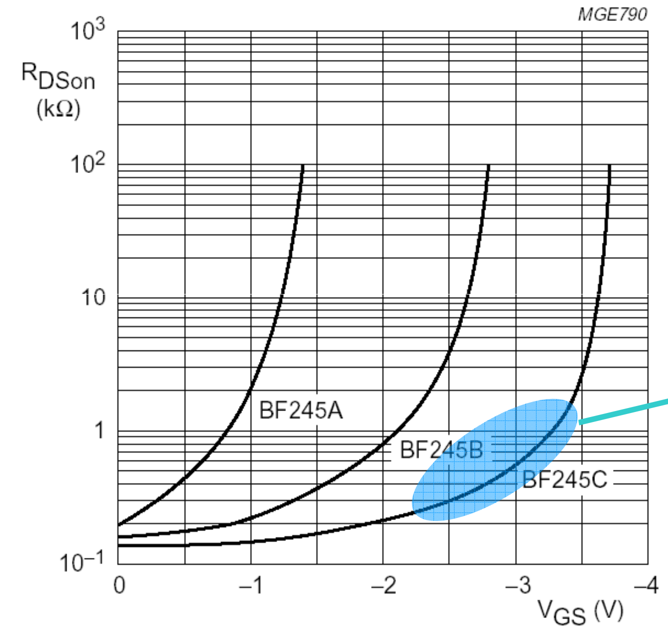
Control de la amplitud, Bill Hewlett y HP

En Enero del 2002, HP celebró el 60th aniversario de la patente de Bill Hewlett sobre el oscilador de audio HP 200A.



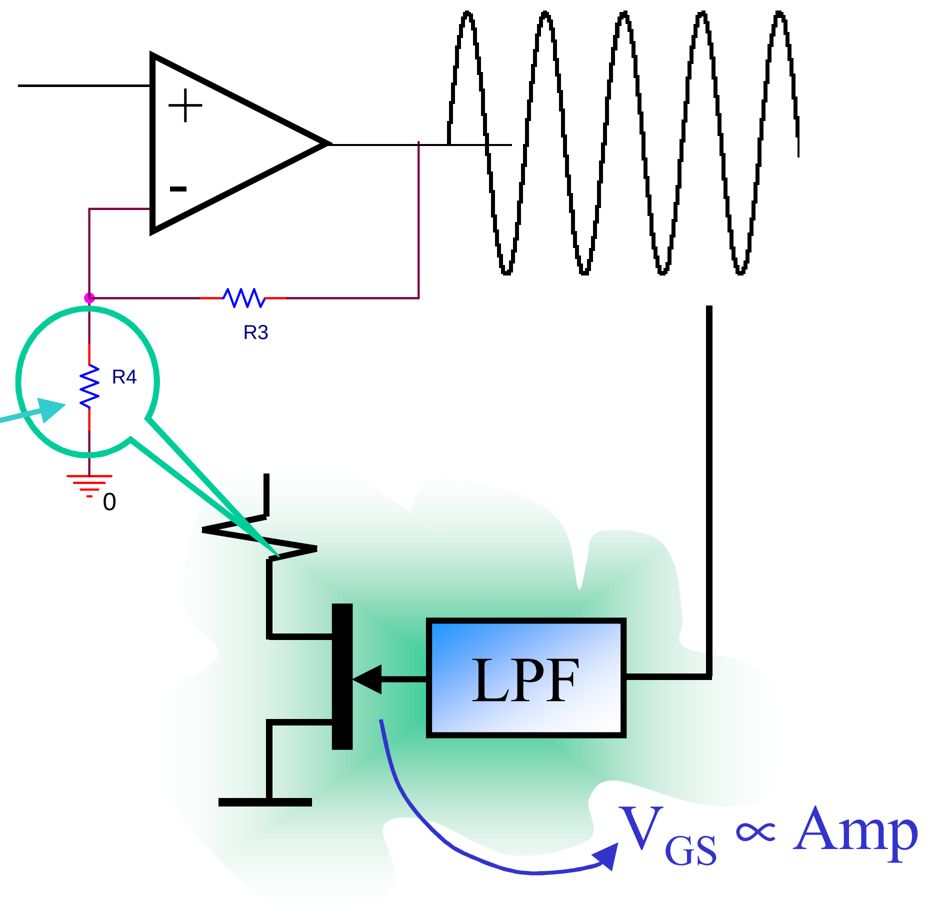
Control de la amplitud con FET en zona Ohmica

Resistencia variable del FET (V_{ds} <<)

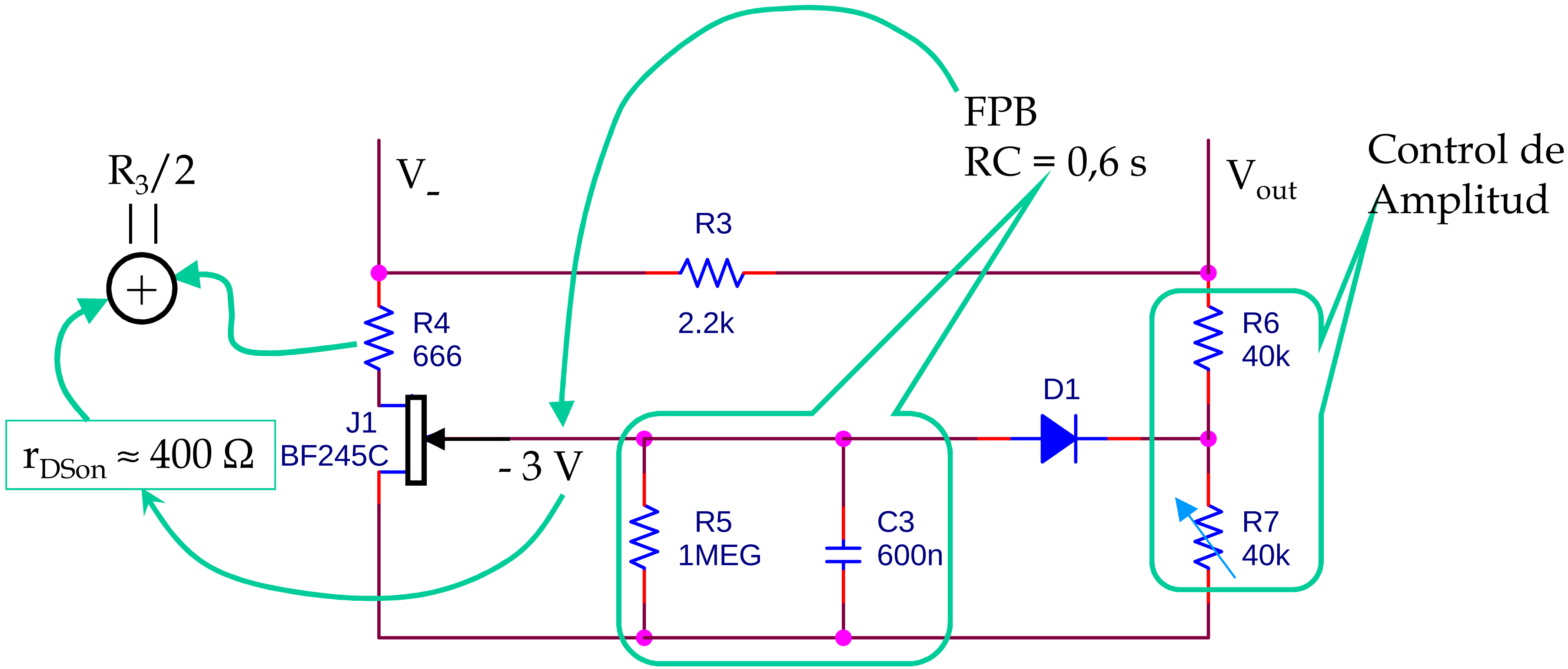


$V_{DS} = 0$; f = 1 kHz; T_{amb} = 25 °C.

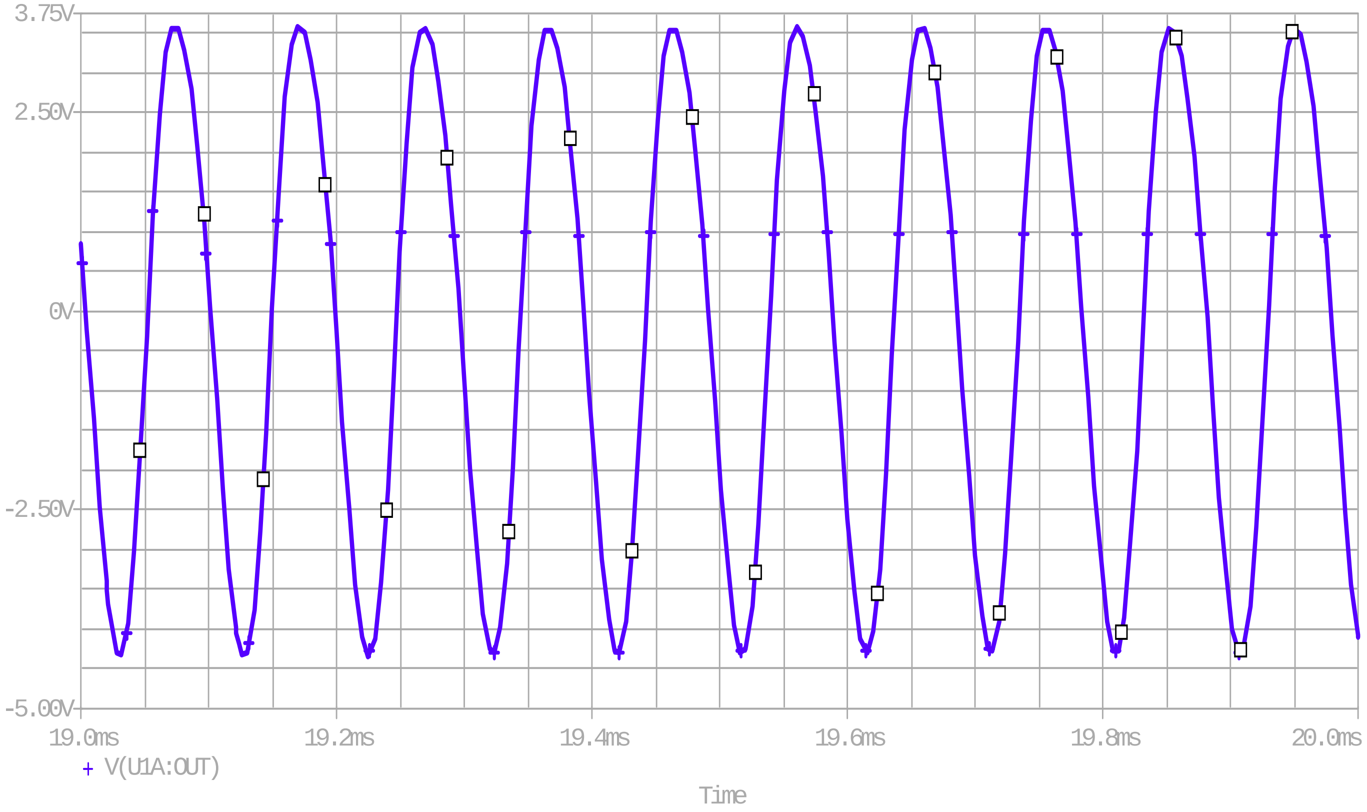
Fig.20 Drain-source on-state resistance as a function of gate-source voltage; typical values.



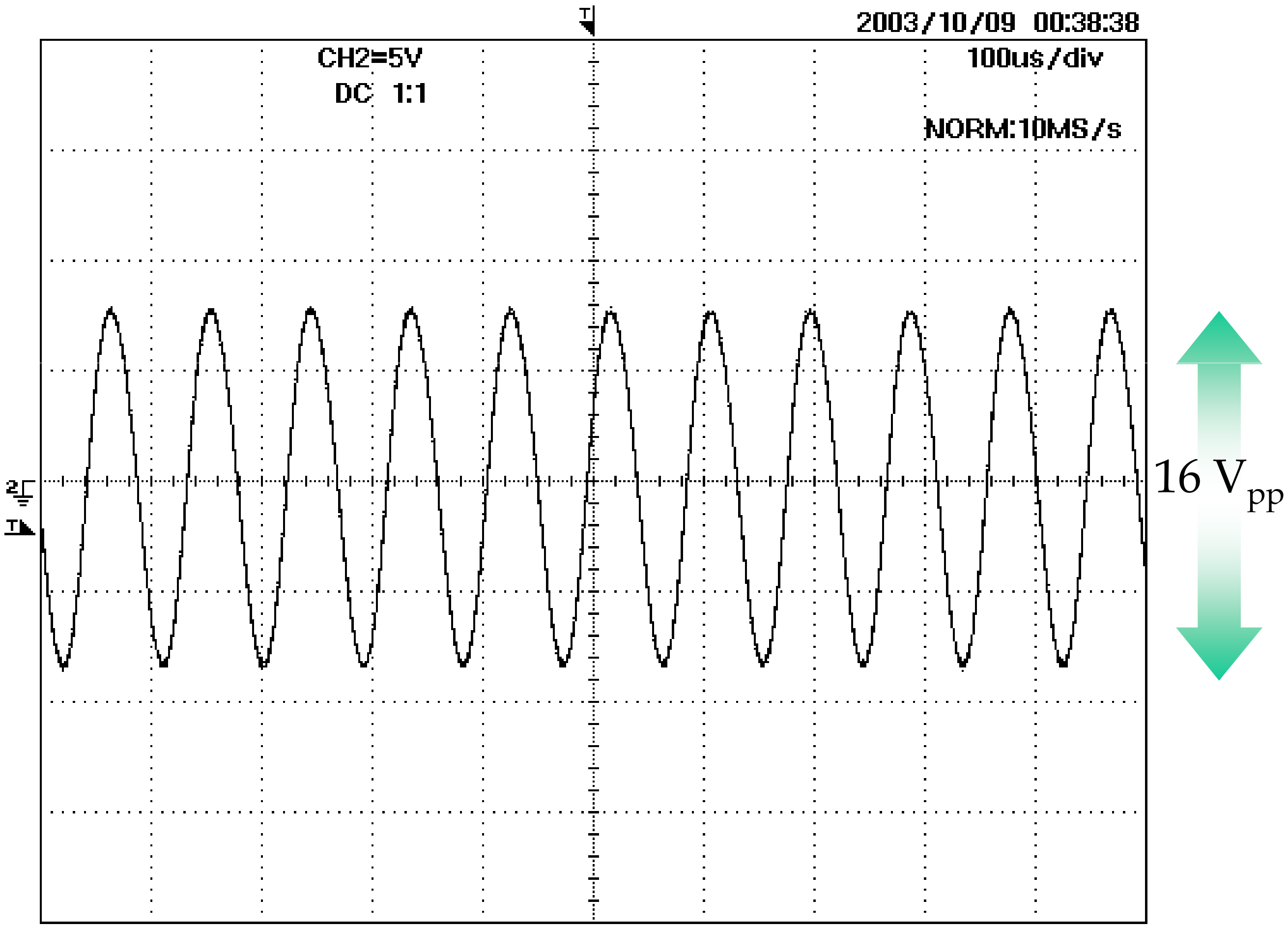
Control de la amplitud con FET en zona Ohmica



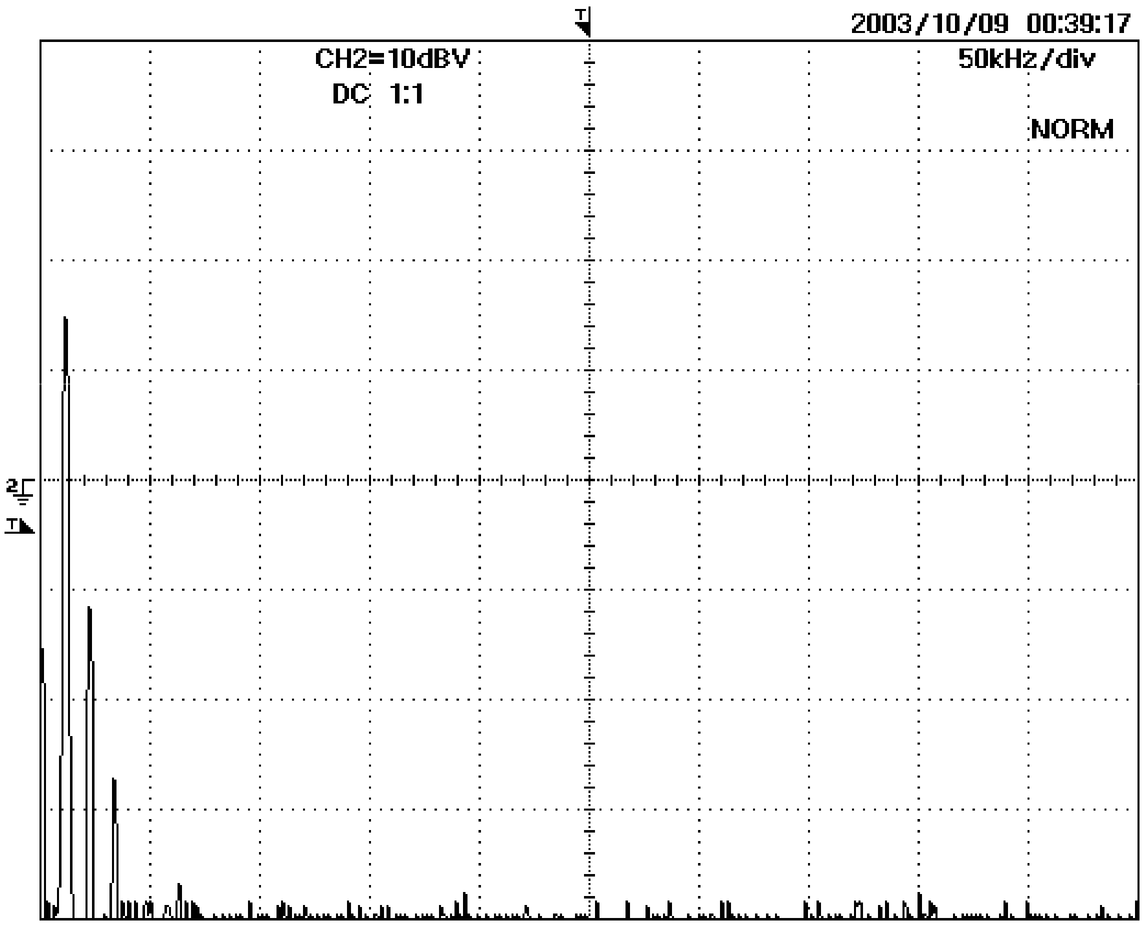
Control de la amplitud con FET en zona Ohmica



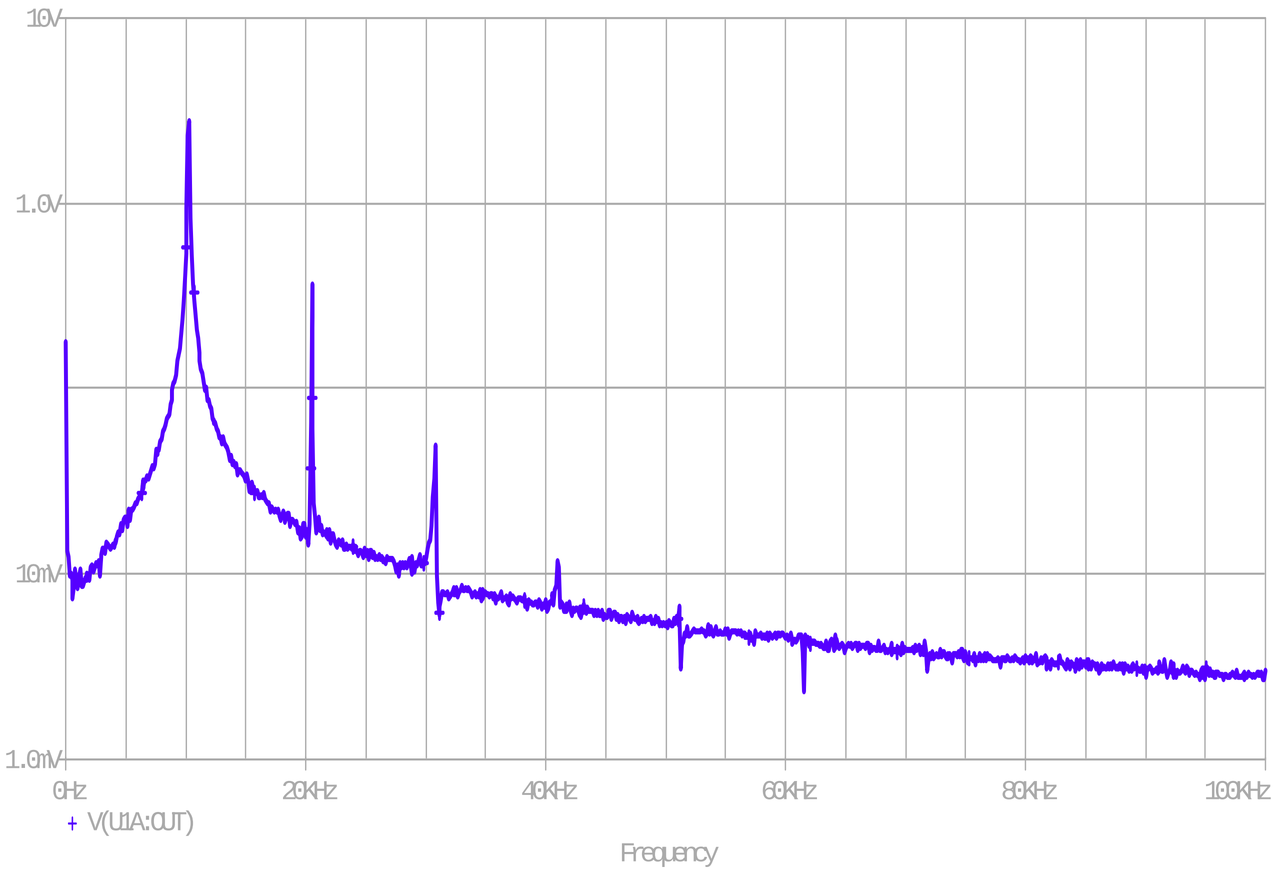
Control de la amplitud con FET en zona Ohmica



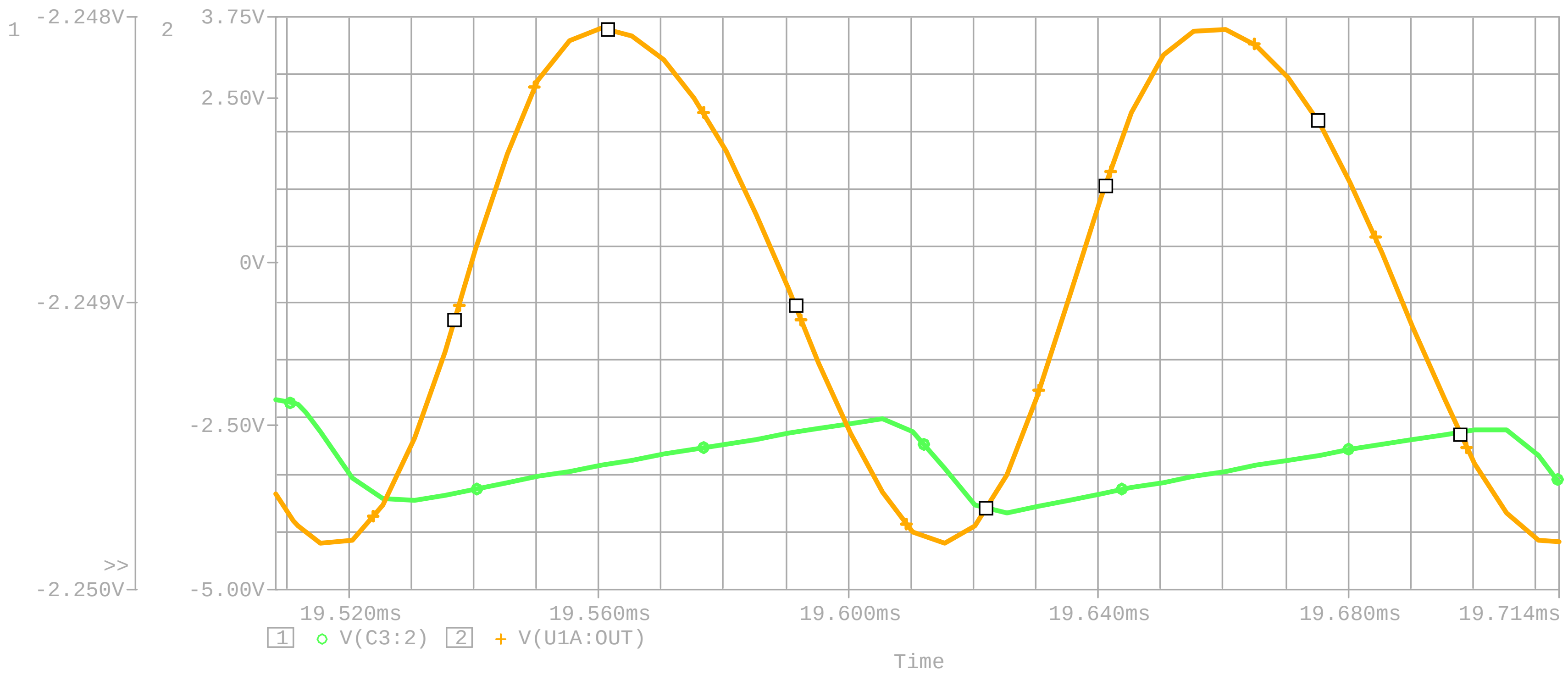
Control de la amplitud con FET en zona Ohmica



Control de la amplitud con FET en zona Ohmica

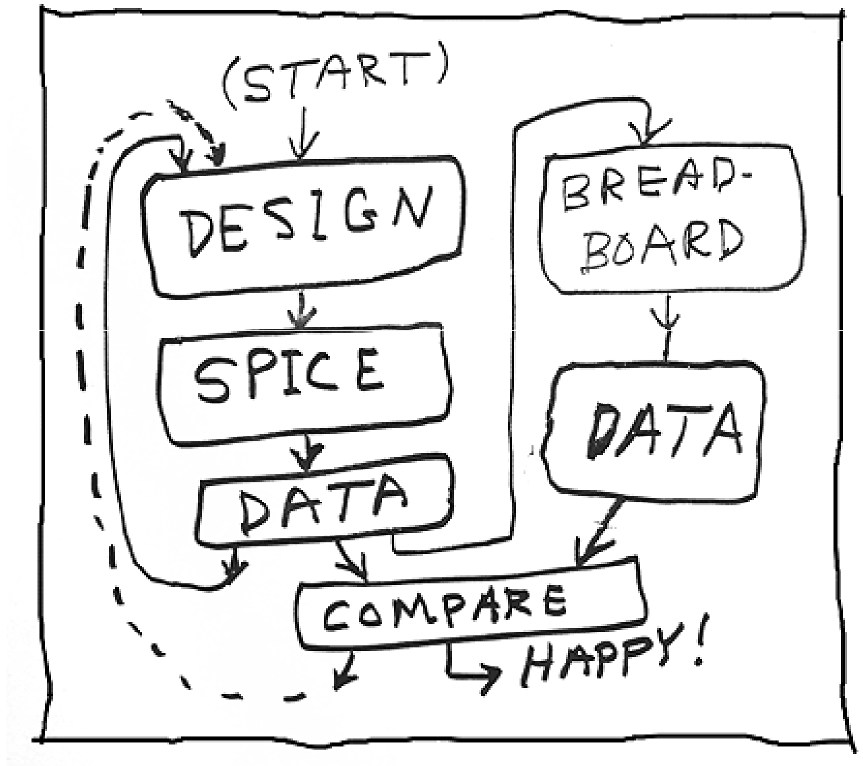


Control de la amplitud con FET en zona Ohmica



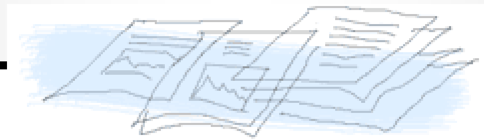
C_3 se carga sólo en periodos negativos, debido al diodo.
Los procesos de carga y descarga son asimétricos en cada semiperiodo de la oscilación, y esta es por tanto, asimétrica.

Pease y SPICE



What's All This Spicey Stuff (Part I)," Electronic Design, November 22, 1990, p. 127
What's All This Spicey Stuff (Part II)," Electronic Design, December 13, 1990, p. 87

CONCLUSIONES



Conclusión

Importancia de la fase en el lazo de realimentación.

Importancia de la red de realimentación:

Determina la frecuencia de osciladión

Determina la ganancia necesaria del amplificador.

Importancia del control de amplitud

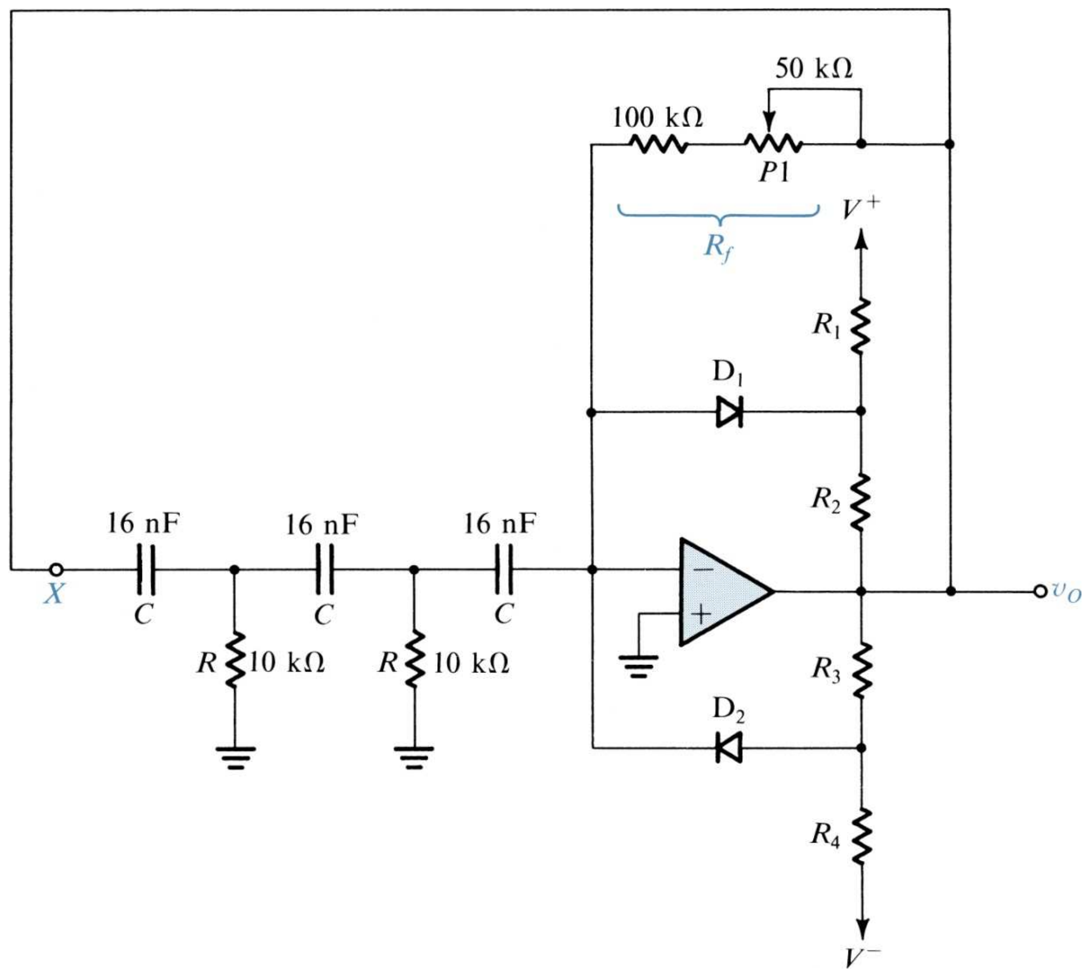
Pasos (iterativos):

1. Analítico
2. Simulación
3. Implementación.

Atención a los efectos del operacional: “Slew Rate” y GxBW

ANÁLISIS DE UN OSCILADOR

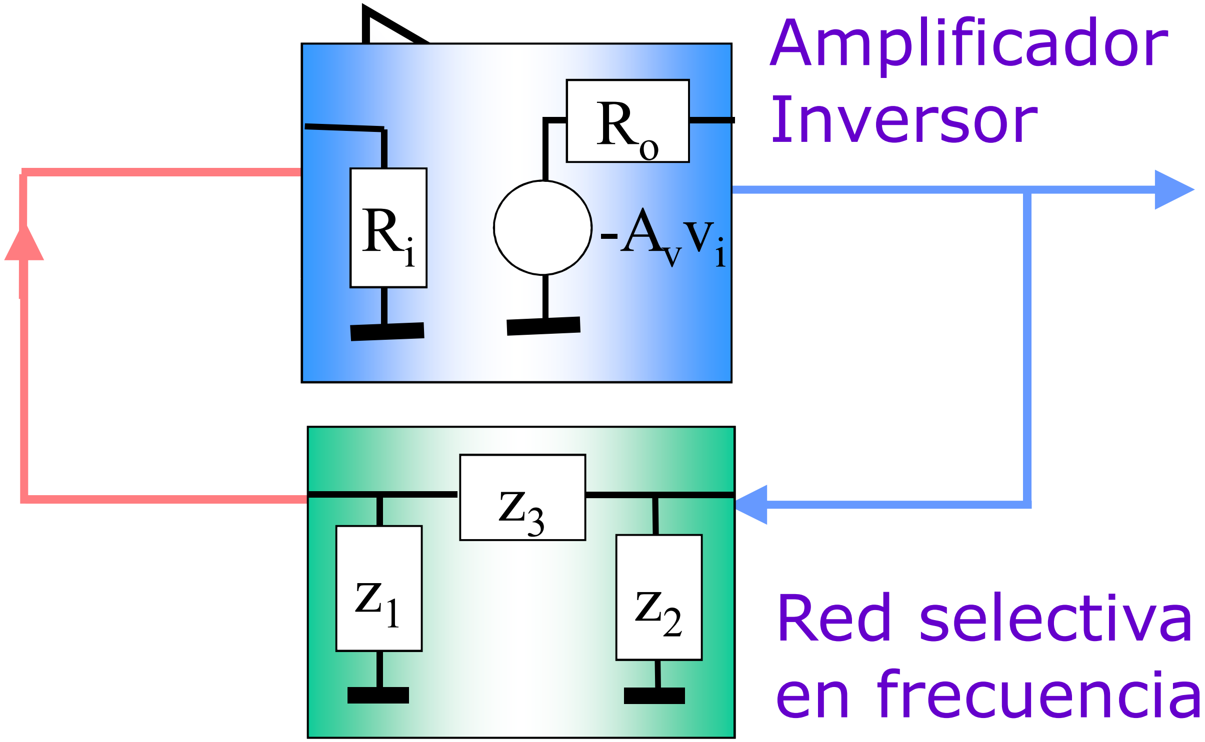
Oscilador RC por desplazamiento de fase


50 kΩ
100 kΩ
P1
R_f
V^+
R_1
D_1
R_2
16 nF
16 nF
16 nF
X
C
C
C
R
10 kΩ
R
10 kΩ
v_O
R_3
D_2
R_4
V^-

ANÁLISIS DE UN OSCILADOR

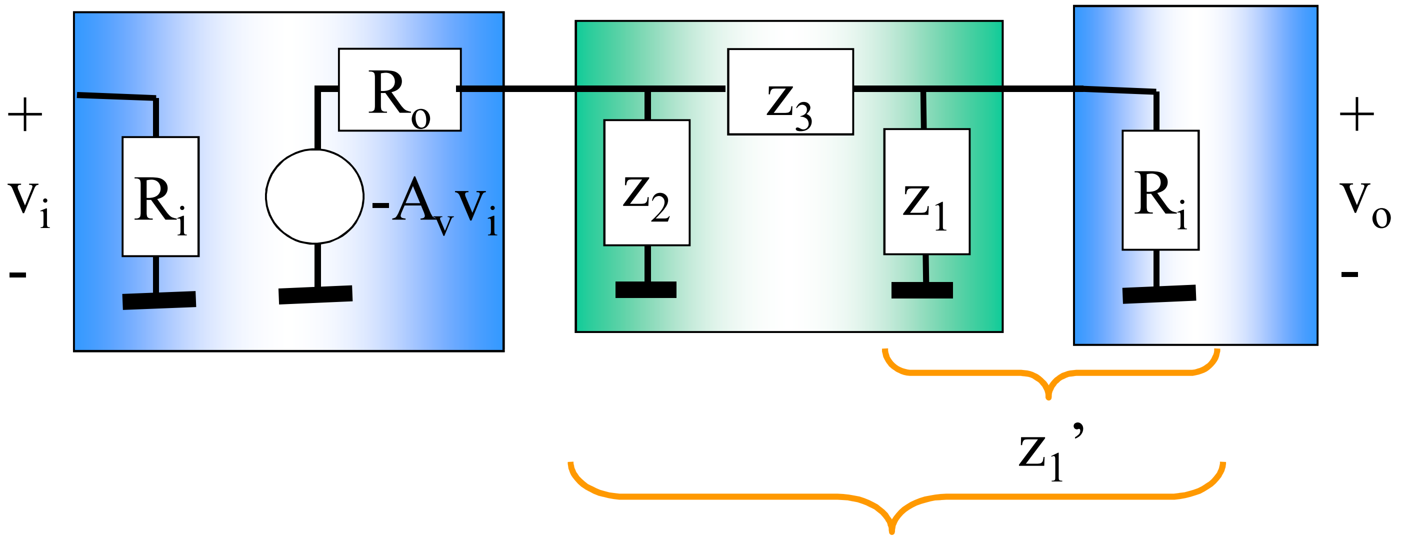
Oscilador LC

Topología



Amplificador Inversor
R_o
R_i
$-A_v v_i$
z_3
z_1
z_2
Red selectiva en frecuencia

Análisis del Oscilador



$$z_2 \,||\, [z_3 + (z_1 \,||\, R_i)]$$

$$A\beta = v_o/v_i = -A_v \frac{z_2 \cdot (z_1 \,||\, R_i)}{R_o\,[(z_1 \,||\, R_i) + z_2 + z_3] + z_2[z_3 + (z_1 \,||\, R_i)]}$$

Condiciones de Oscilación

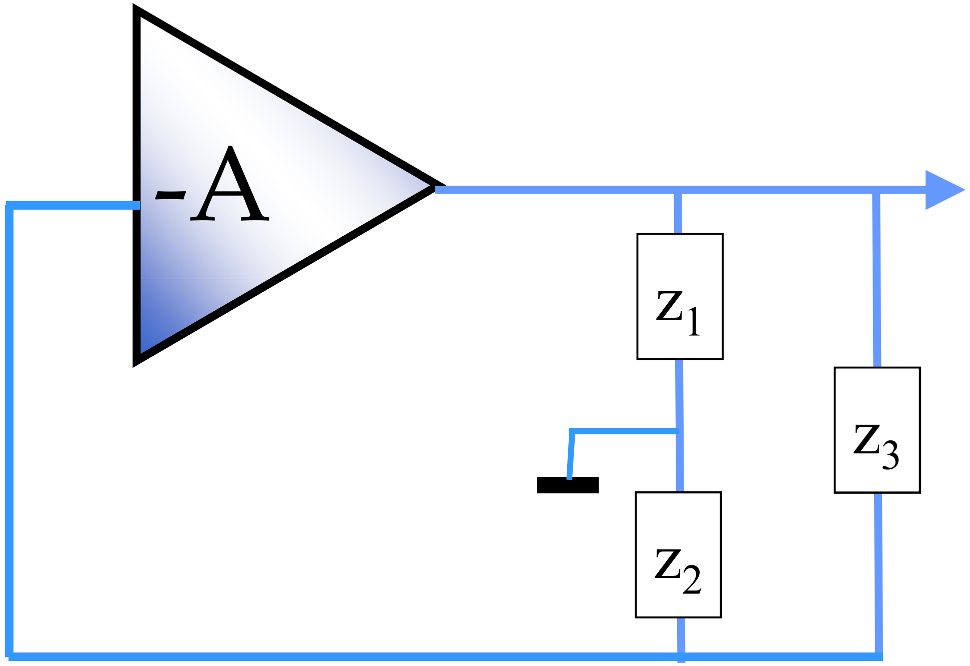
Una impedancia, z, proviene de un

Condensador $Z_C = 1/(j\omega C) = -j/(\omega C) = j\,[-1/(\omega C)] = jX_C$

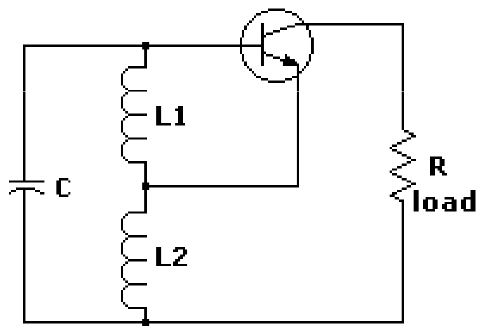
Bobina $Z_L = \quad j\omega L = j\,[\omega L] = jX_L$

$$A\beta = v_o/v_i = -A_v \frac{-\,X_2 \cdot X_1}{j\,R_o\,[\,X_1 + X_2 + X_3\,] - X_2[\,X_3 + X_1\,]}$$

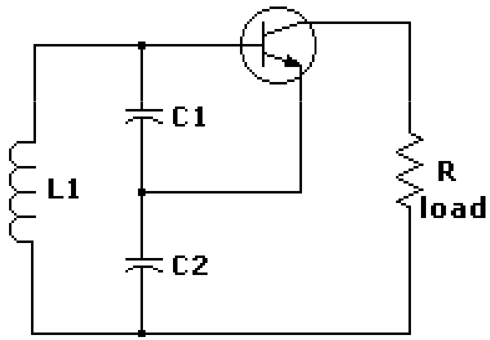
Topología Plegada



Hartley



Colpitts



Atención! Red de polarización del TRT NO representada, pero necesaria.

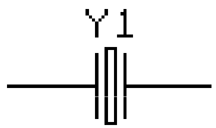
ANÁLISIS DE UN OSCILADOR

Oscilador de Cristal de Cuarzo

Componente basado en efecto piezoeléctrico:

Ante una presión, el cristal genera una tensión en bornas de los conectores.

Ante una tensión aplicada, genera fuerzar mecánicas que alteran la forma del cristal. **Cuando la tensión aplicada varía con el tiempo, el cristal vibra**, y la ampitud de la vibración es máxima cuando la frecuencia de la señal aplicada tiene un determinado valor (**resonancia**)

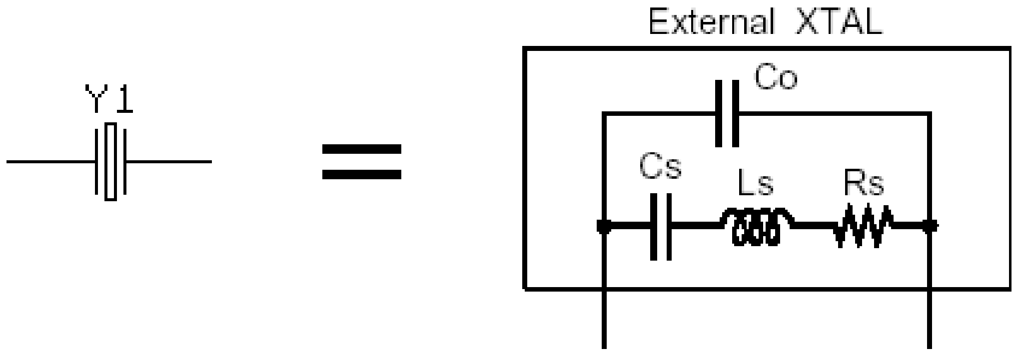


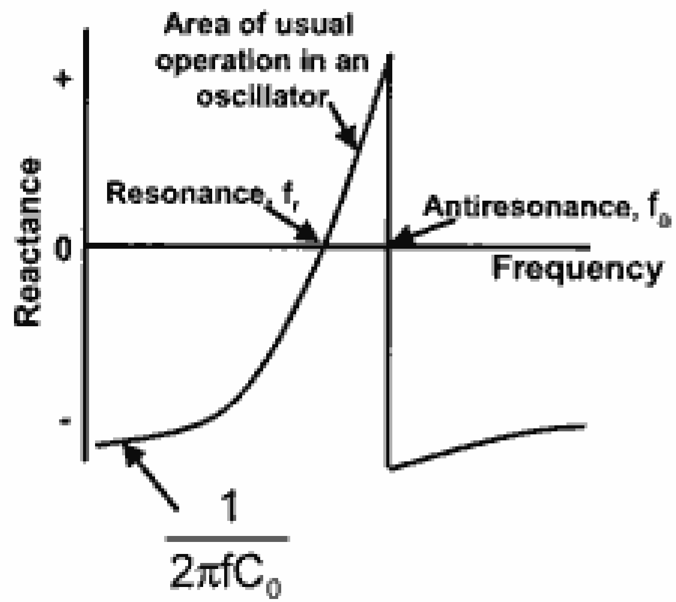
Los cristales permiten fijar una frecuencia de oscilación.

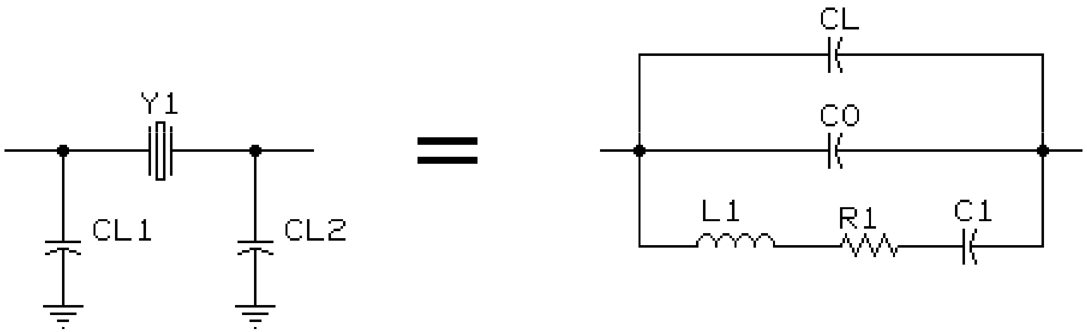
Esta frecuencia se especifica en partes por millón. Por ejemplo, un cristal de 32,768 Hz con tolerancia de ±20 ppm a 25°C, la frecuencia de resonancia puede encontrarse entre:

32.768 +32.768*(20/1000000) = 32.76865536 Hz

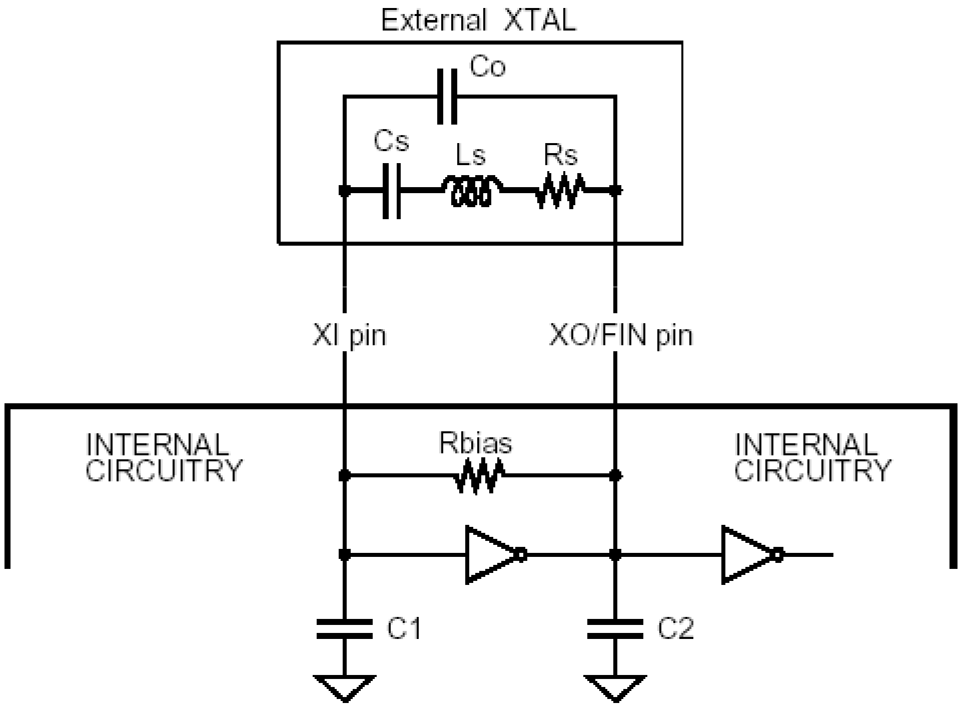
32.768 - 32.768*(20/1000000) = 32.76734464 Hz


Y1
External XTAL
Co
Cs
Ls
Rs


Area of usual operation in an oscillator
Resonance, f_r
Antiresonance, f_a
Reactance
+
0
-
Frequency
$\frac{1}{2\pi f C_0}$



$$Fp = Fs\sqrt{1 + \frac{C1}{Co + CL}}$$


External XTAL
Co
Cs
Ls
Rs
XI pin
XO/FIN pin
INTERNAL CIRCUITRY
Rbias
INTERNAL CIRCUITRY
C1
C2

Nota histórica

1911 – 1912 Fritz Lowenstein,
Laboratorios en Nassau St. (N.Y.)
Primer uso del audión de De Forest como amplificador
Primer oscilador operativo.

1912 Van Etten
Descubre el hecho de que al realimentar un audión se producen oscilaciones **(HOWLING, SINGING)**

1912-1913 E.H. Armstron (USA), A. Meissner (DE)
Uso de la realimentación positiva → Detector regenerativo.

El fenómeno de 'regeneración'

AMPLIFICADOR CON REALIMENTACIÓN POSITIVA

Cuando se **realimentaba suficiente señal**, el amplificador operaba como un oscilador estable, perfecto para los transmisores de radio.

Reduciendo el nivel de señal, el amplificador operaba como un receptor de señal con una sensibilidad que superaba a todos los dispositivos de la época.