SEMINARIO:
Prototipos de circuitos de RF

FCyT
Sede Concepción del Uruguay

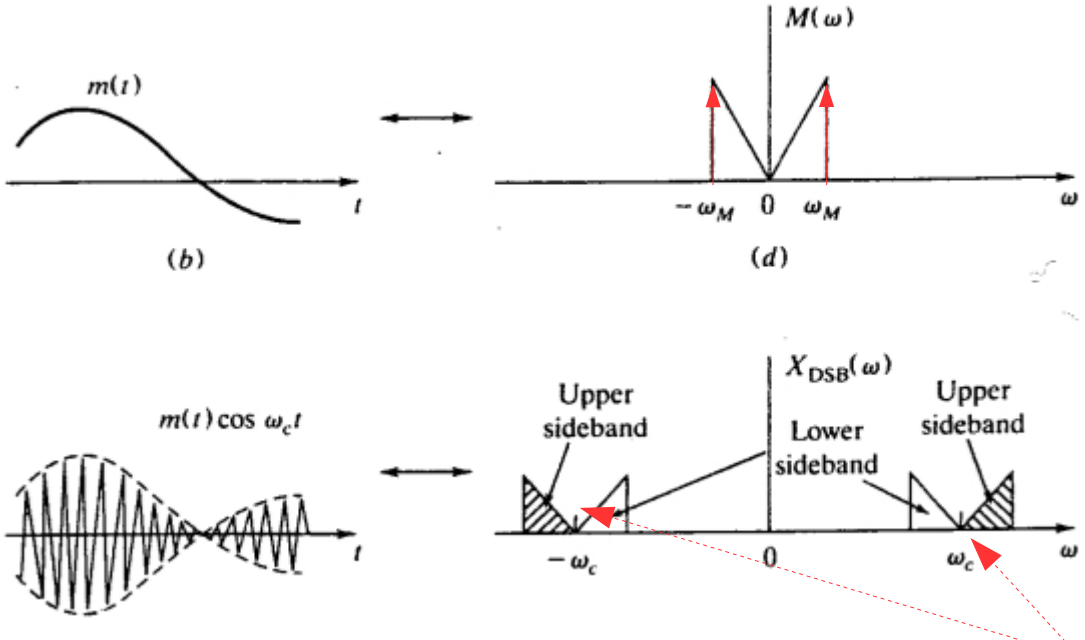
Temario :

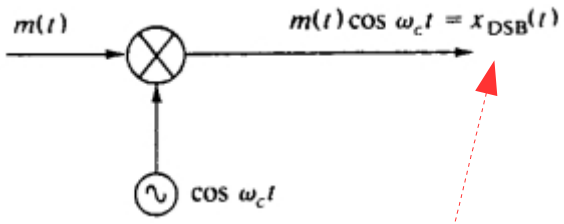
- Modulación de AM. Espectros de señal.
- Circuito didáctico de un modulador de AM:
  Análisis y construcción de prototipos experimentales.
  Introducción a Amplificadores clase *A, AB, C. Polarizaciones. Oscilogramas.*
- *Circuitos resonantes. Diseño y mediciones de inductores.*
- Amplificador como Multiplicador de frecuencia.
- Mediciones con instrumentos de laboratorio, osciloscopio y analizador de espectros.

Experimentos - Mediciones :

- Resonancia de circuito LC. Medición de L y Q.
- Amplificador clase A, AB, C. Oscilogramas.
- Mediciones de Ancho de banda del Modulador:
  -con generador y OSC.
  -con SA.
- Espectros de frecuencia con SA.
- Amplificador de audio con OpAmp.
- Mezclador de frecuencias (2da opción).

Modulación de Amplitud - Doble Banda Lateral Portadora Suprimida (DSB.SC):

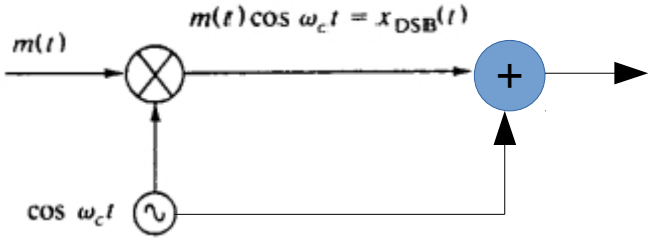




$$X_{DSB}(\omega) = \tfrac{1}{2}M(\omega - \omega_c) + \tfrac{1}{2}M(\omega + \omega_c)$$

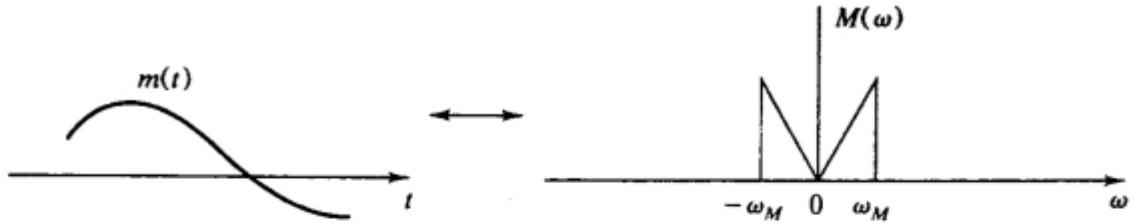
portadora suprimida

Modulación de Amplitud - Doble Banda Lateral con Portadora (DSB.FC) :

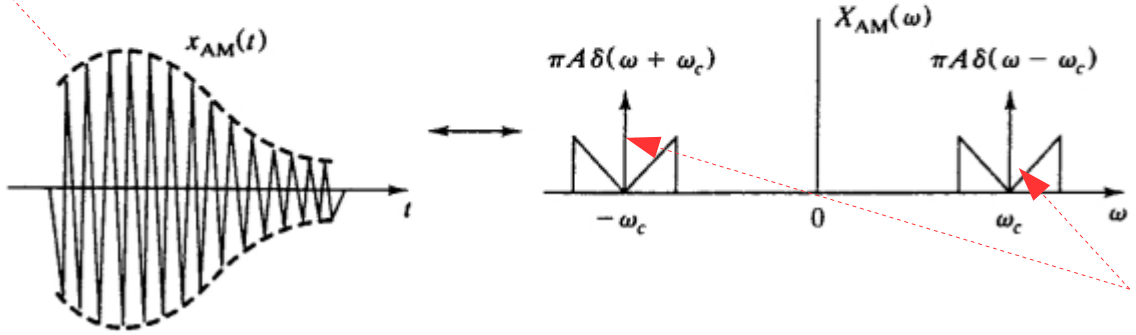


$$x_{AM}(t) = m(t)\cos\ \omega_c t + A\cos\omega_c t = [A + m(t)]\cos\omega_c t$$

$$X_{AM}(\omega) = \tfrac{1}{2}M(\omega - \omega_c) + \tfrac{1}{2}M(\omega + \omega_c) + \pi A[\delta(\omega - \omega_c) + \delta(\omega + \omega_c)]$$



Envolvente



Portadora

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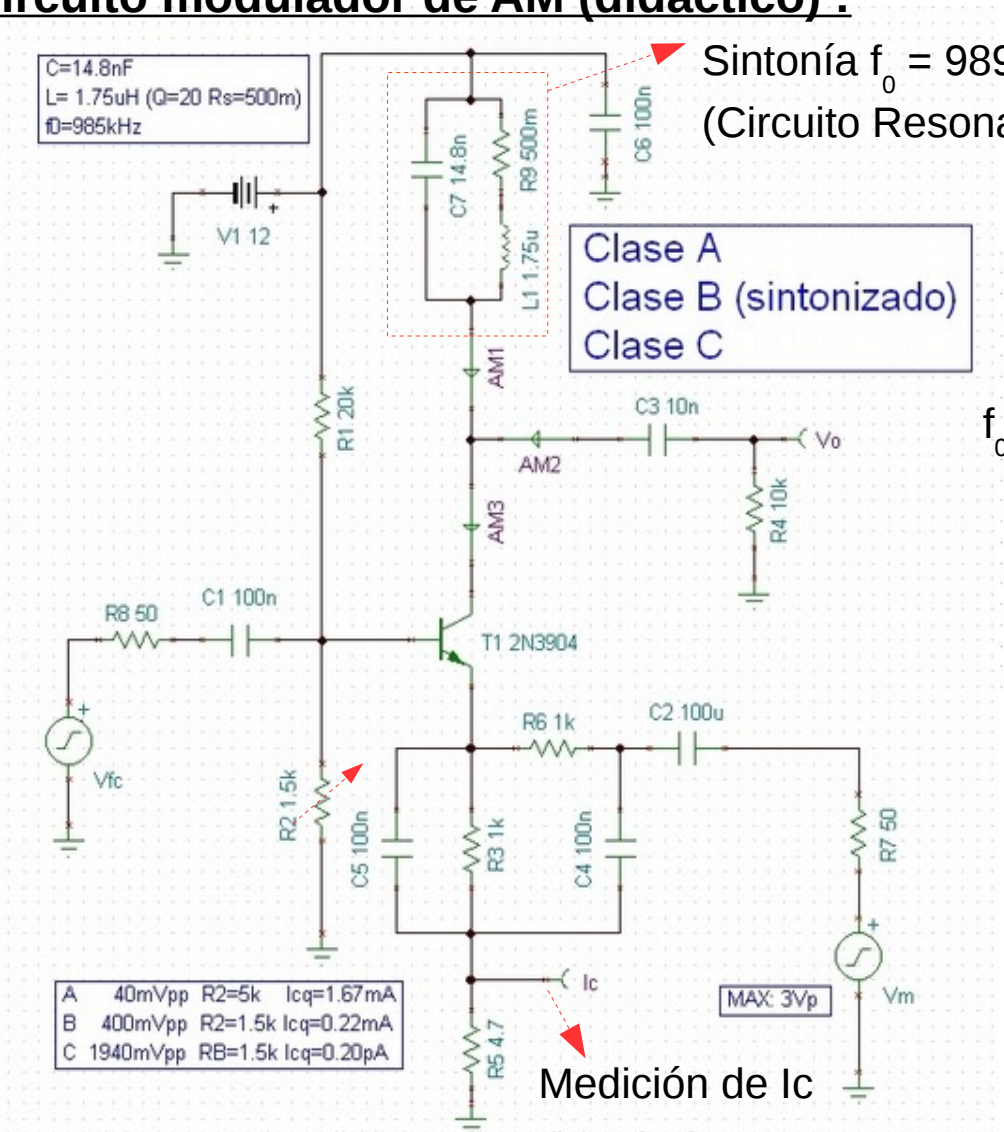
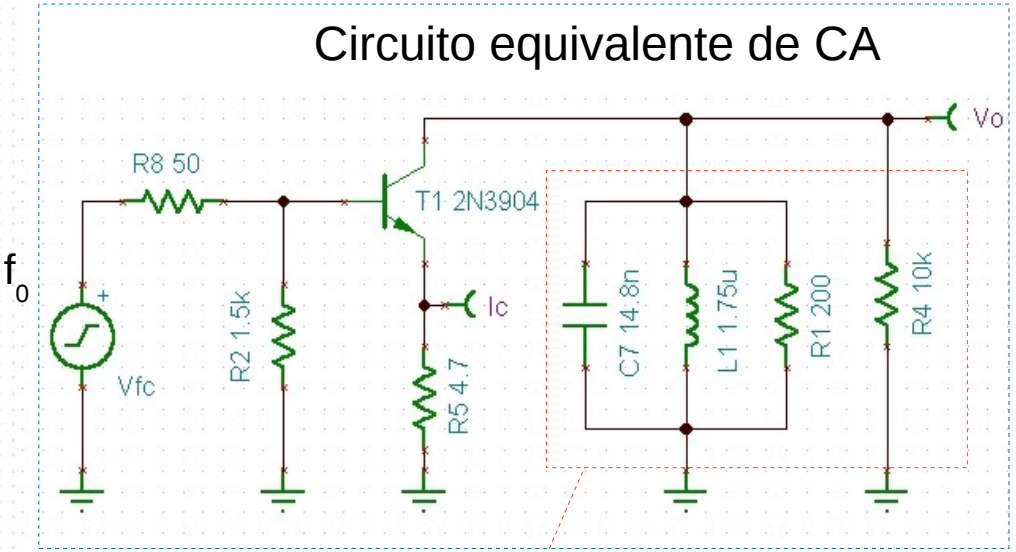
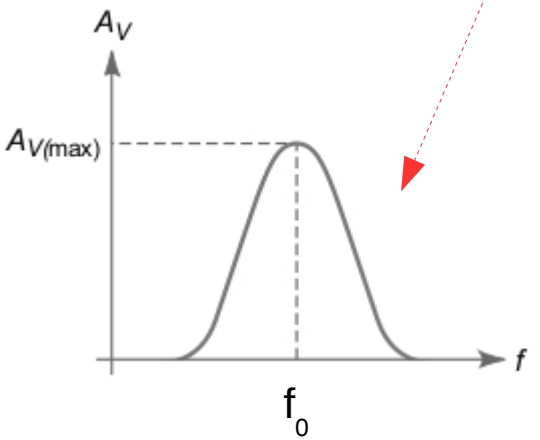
Circuito modulador de AM (didáctico) :



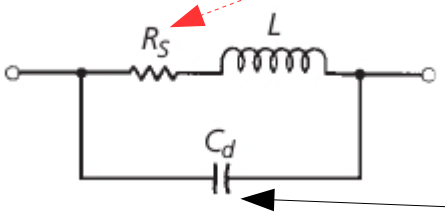
Sintonía f_0 = 989,5kHz con L=1,75uH y C=14,8nF
(Circuito Resonante)

Circuito equivalente de CA





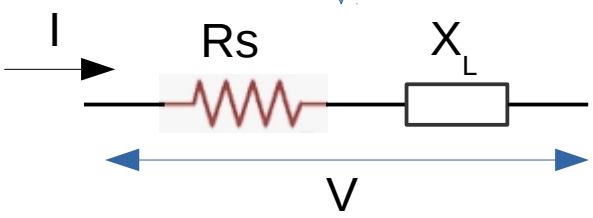
Circuito equivalente de inductores :

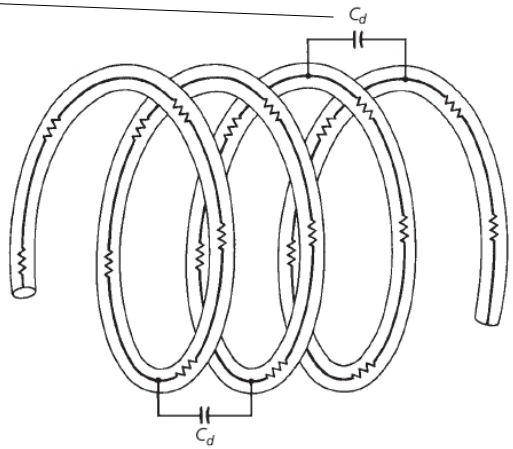


-> en caso de inductores con nucleo de aire
Rs representa las perdidas por efecto Joule del conductor. (I^2R)
Rs ≠ R_{DC}, Rs depende de la frecuencia por efecto pelicular.

-> en caso de inductores con núcleo ferromagnético
Rs además representa las perdidas por efecto Foucault y por histéresis en el nucleo

Modelo serie





$$Q = \frac{X_L}{R_s}$$

Factor de calidad (depende de f) → Conociendo Q y L (y la frecuencia de medición) puede calcularse Rs

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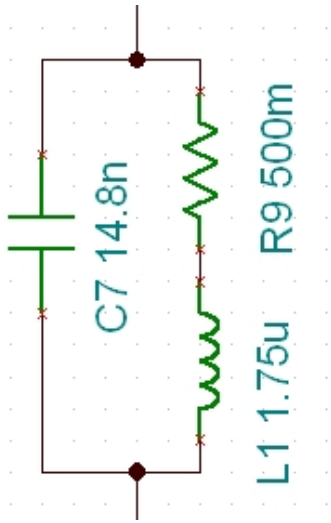
Transformación serie-paralelo de impedancias :

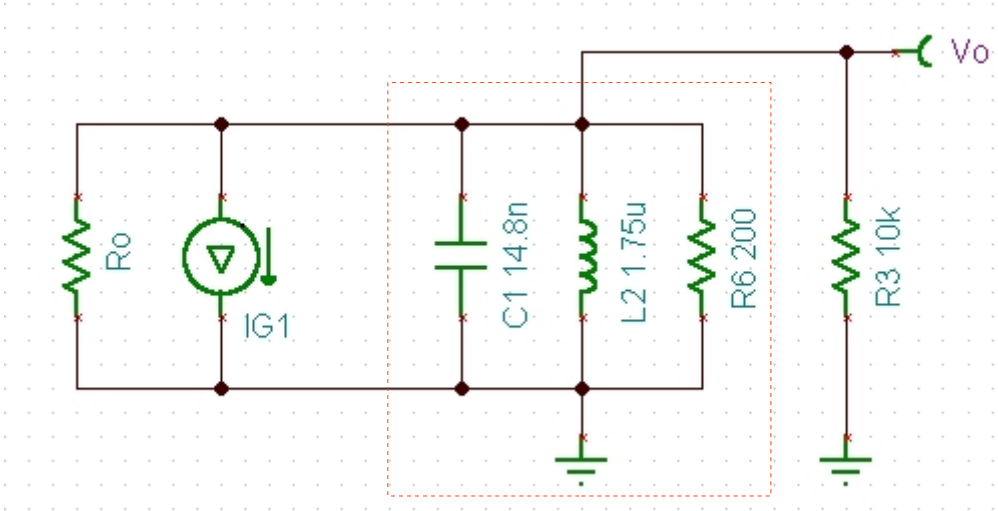
f = 985 Khz
L = 1,72 uH
Q ≈ 20

$$R_s = \frac{X_L}{Q} = \frac{2\pi . f . L}{Q} = 530 m\Omega$$



Si $Q \geq 10$ entonces:

$R_P \approx Q^2 R_S$
$X_P = X_S$



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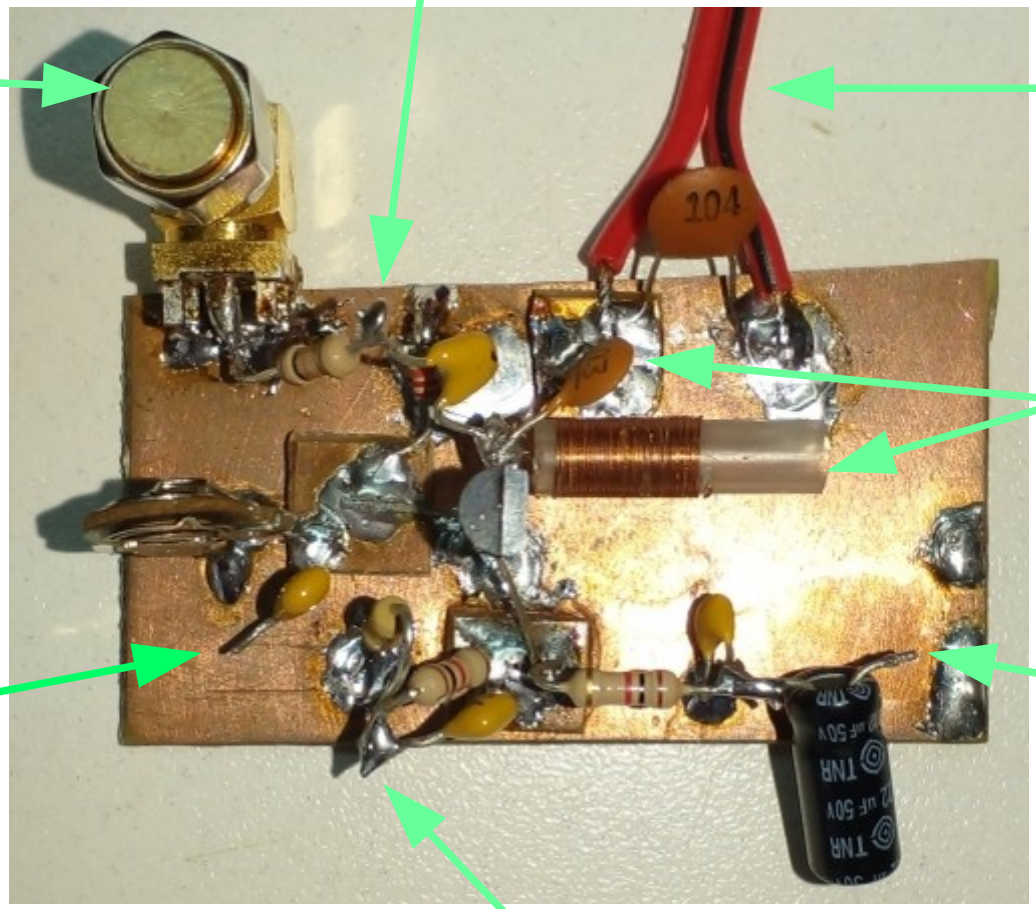
Detalle I/O Prototipo :



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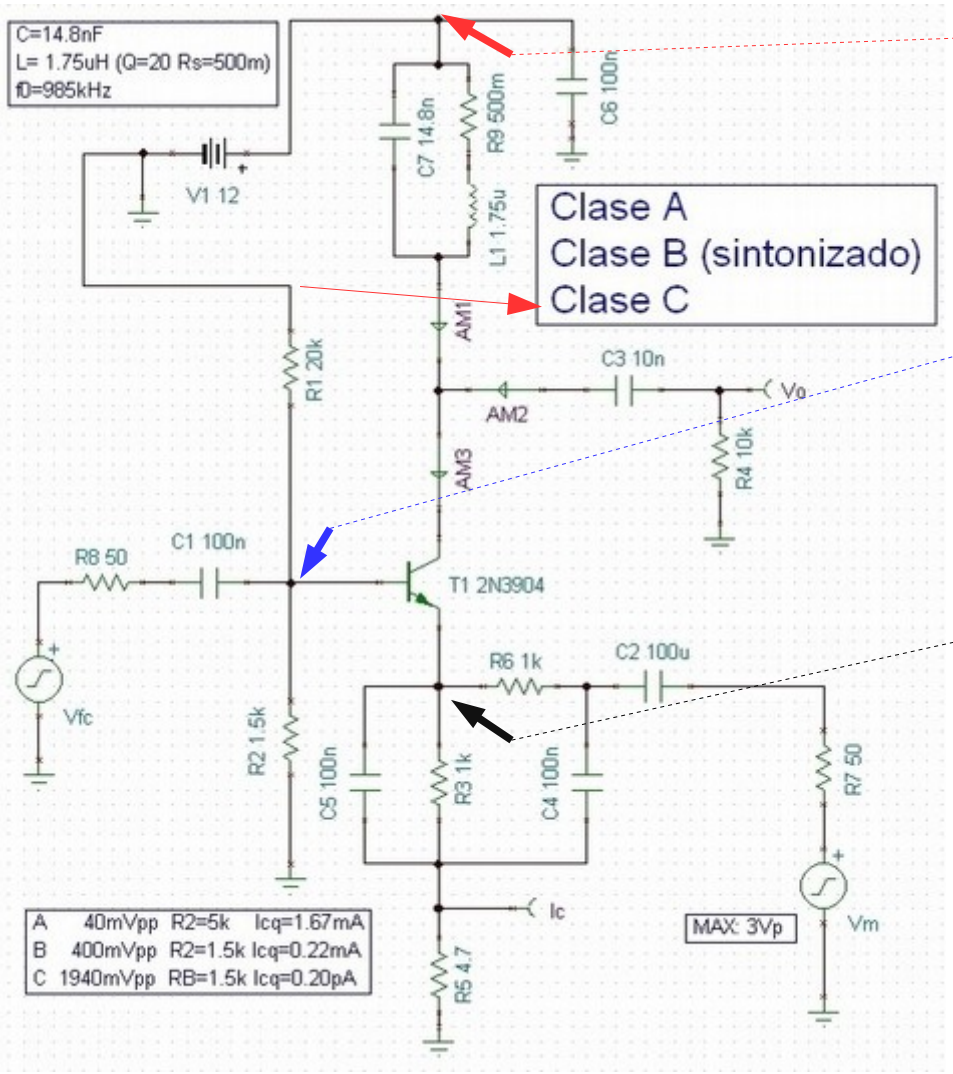
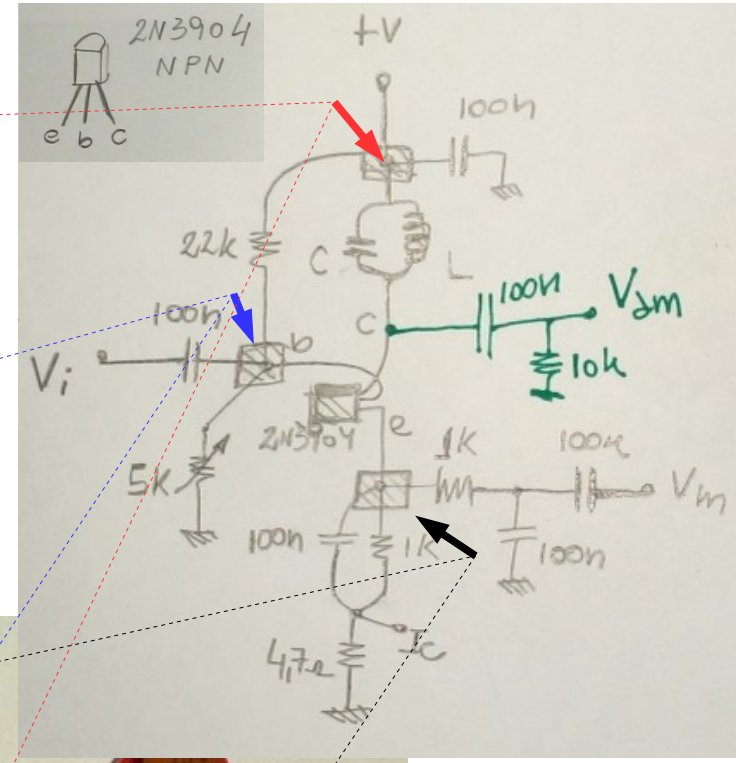
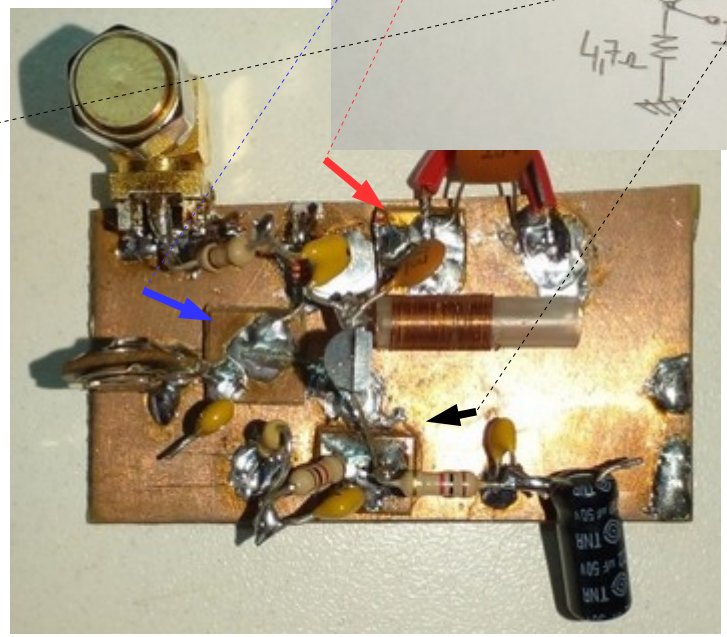
Del circuito al prototipo:







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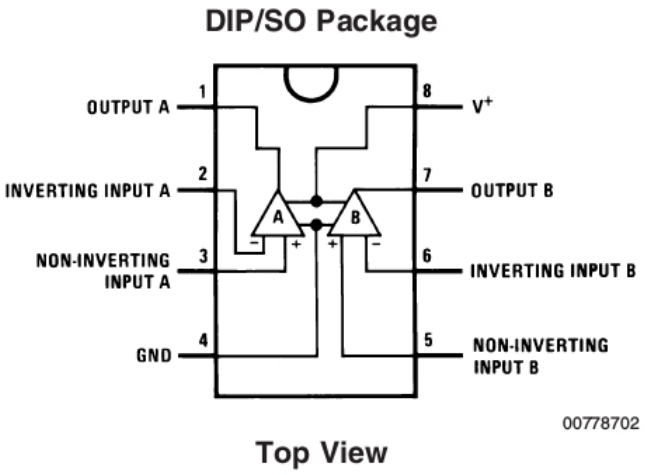
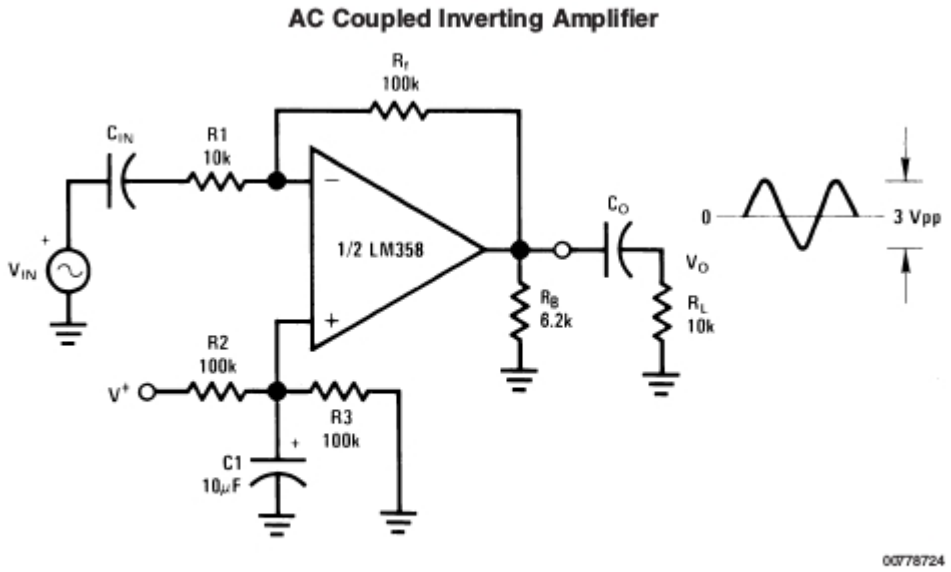
Amplificador de audio :





$A_V = \frac{R_f}{R1}$ (As shown, $A_V = 10$)

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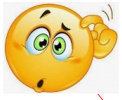
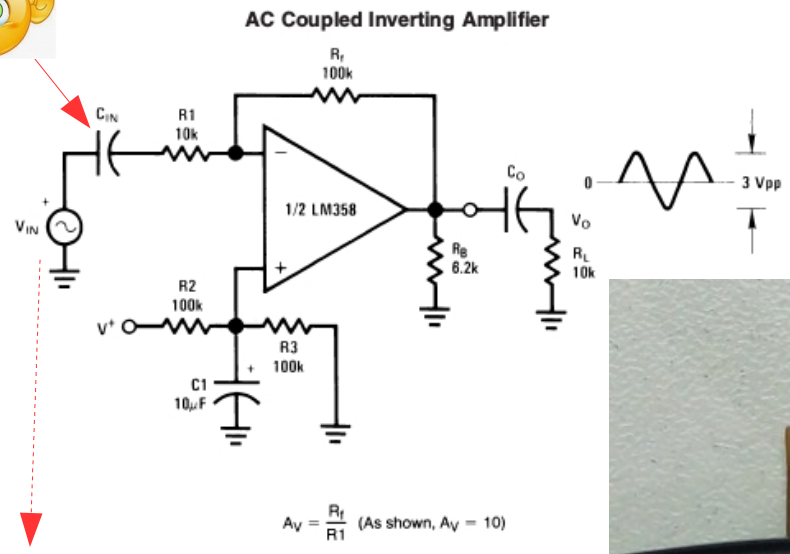
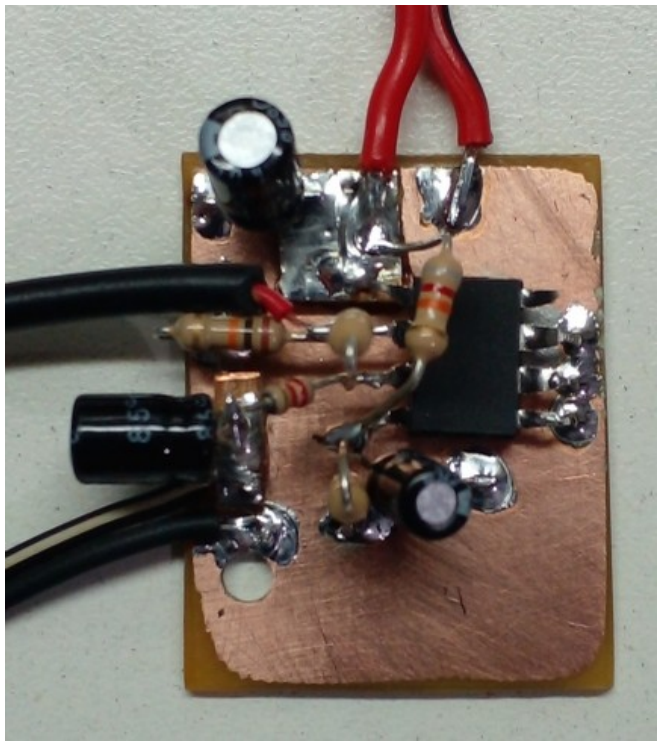
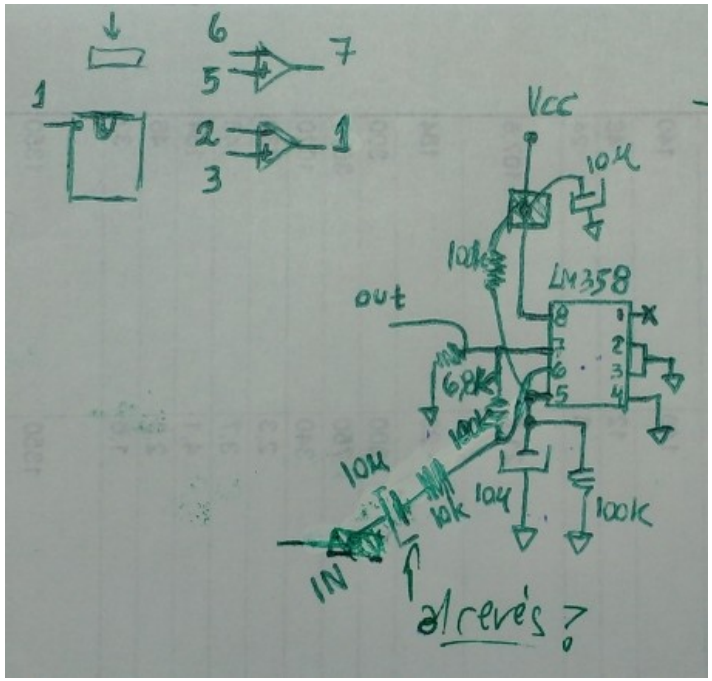
Amplificador de audio :





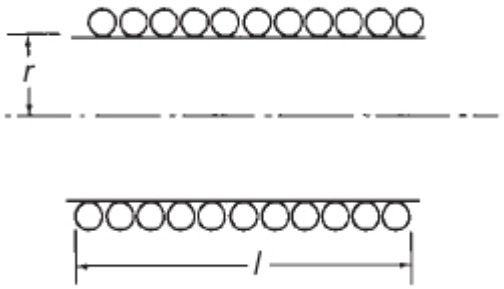
Keuwlsoft Function Generator





Inductores con nucleo de aire :

Fórmula de Wheeler :



$r =$ the coil radius in cm,

$l =$ the coil length in cm,

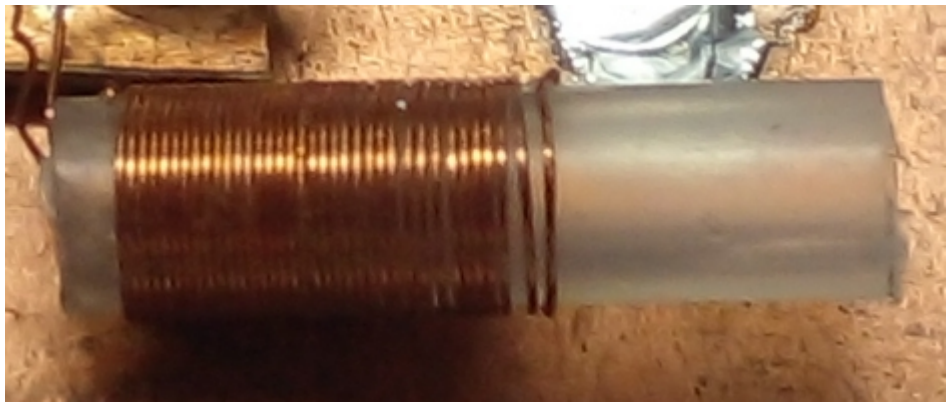
$L =$ the inductance in microhenries.

$l > 0.67r$

$$L = \frac{0.394r^2N^2}{9r + 10l}\ \mu Hy$$

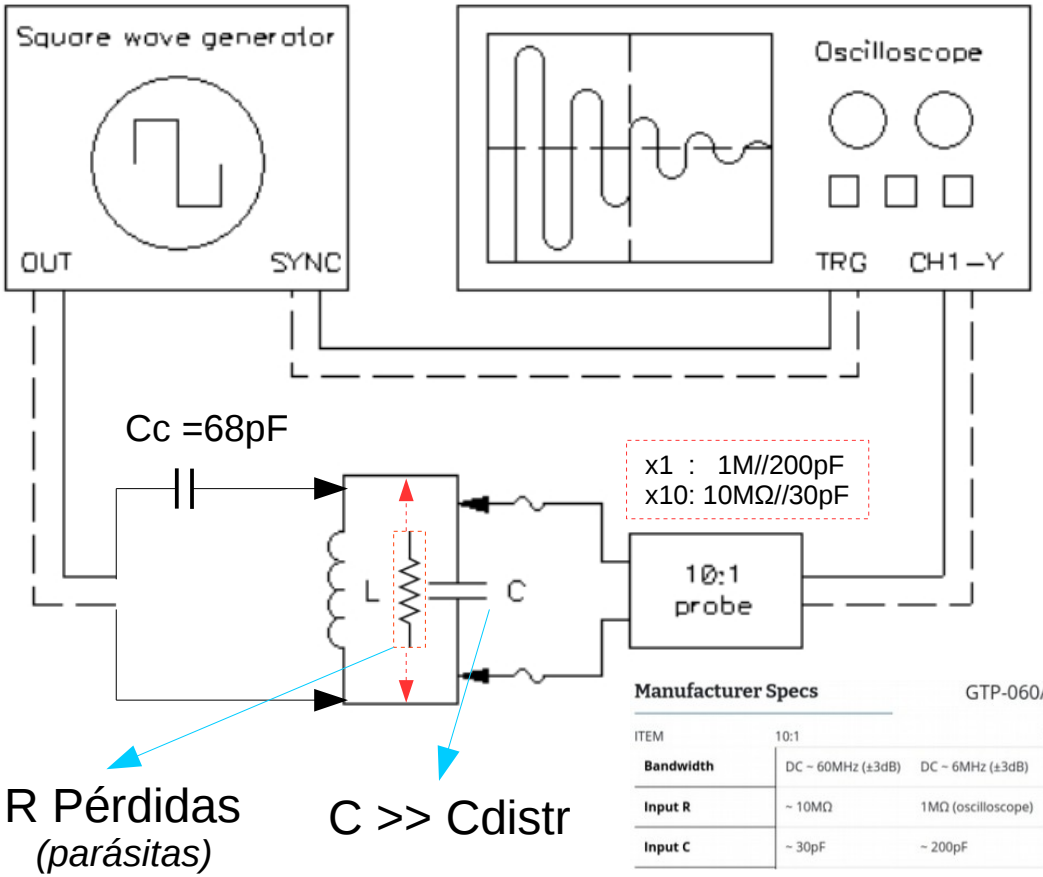
Ejemplo de cálculo:

r = 0,2 cm
l = 1 cm
N = 36 vueltas



$$L = \frac{0.394x(0.2)^2(36)^2}{9x0.2+10} = 1.73\mu Hy$$

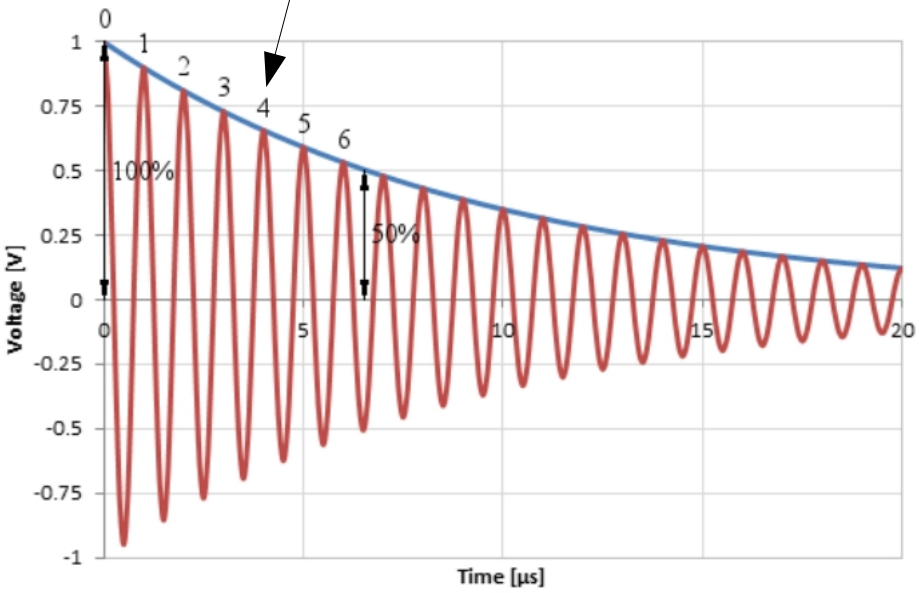
Método de medición de L y Q (ring-down):



Manufacturer Specs GTP-060A-4

ITEM	10:1	1:1
Bandwidth	DC ~ 60MHz (±3dB)	DC ~ 6MHz (±3dB)
Input R	~ 10MΩ	1MΩ (oscilloscope)
Input C	~ 30pF	~ 200pF

Q ≈ **6,5** x 4,53 ≈ 30



$$f_o = \frac{1}{2\pi.\sqrt{L.C}}$$

$$L = \frac{1}{(2\pi.f_o)^2.C}$$

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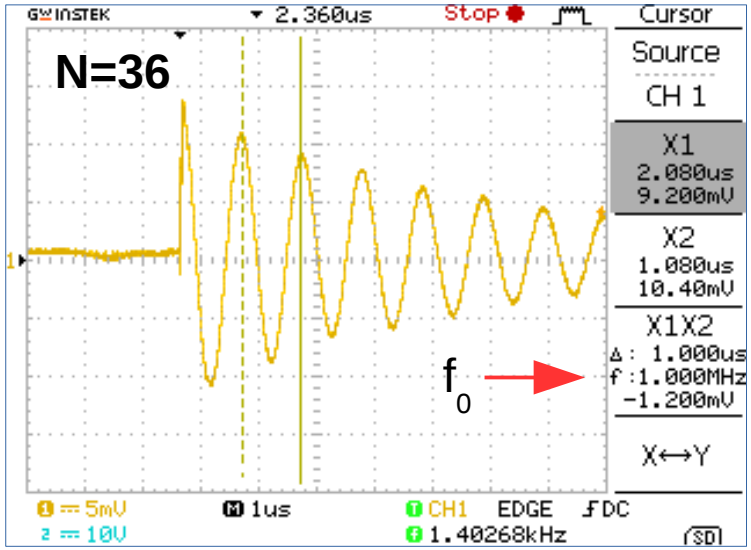
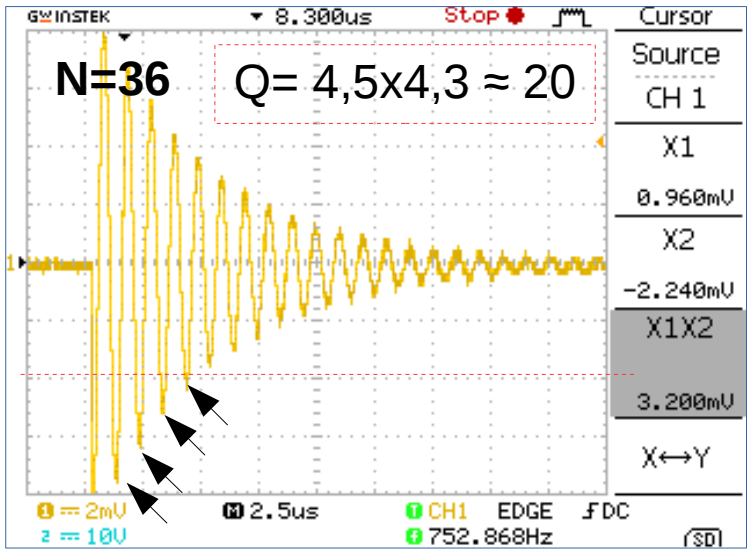
Mediciones L (nucleo aire):

C = 14,8nF *(10nF)*

$$L = \frac{1}{(2\pi.f_o)^2.C}$$

$$L = \frac{1}{(2\pi.1.10^6)^2.148e{-}10} = 1.72\mu Hy$$





Inductores con nucleo toroidal :

A_L Factor de Inductancia

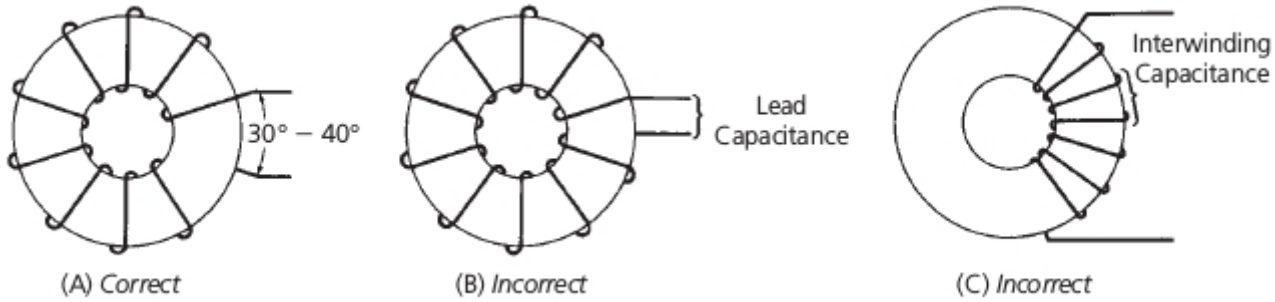
$$L = \frac{0.4\pi N^2 \mu_1 A_c \times 10^{-2}}{l_e}$$

$$L = N^2 A_L \text{ nanohenries}$$

$$N = \sqrt{\frac{L}{A_L}}$$

L = the inductance in nanohenries,
N = the number of turns,
μ_i = initial permeability,
A_c = the cross-sectional area of the core in cm^2,
l_e = the effective length of the core in cm.

A_L = the inductance index in nanohenries/$turn^2$.



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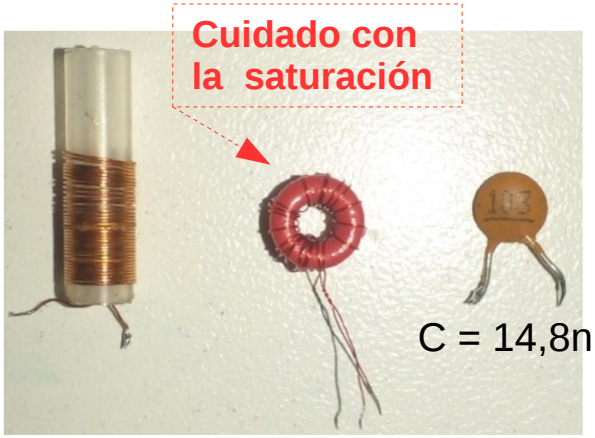
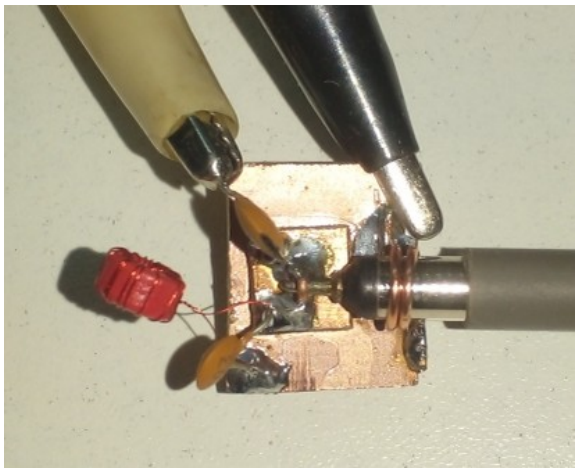
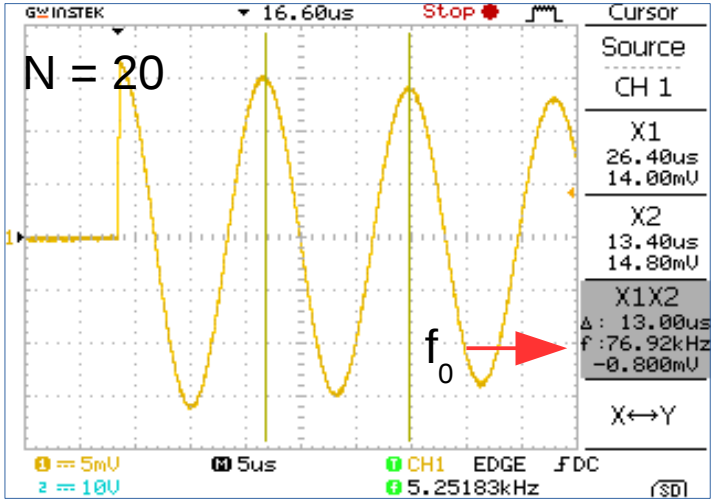
Medicion de L toroidal (nucleo ferrite) :

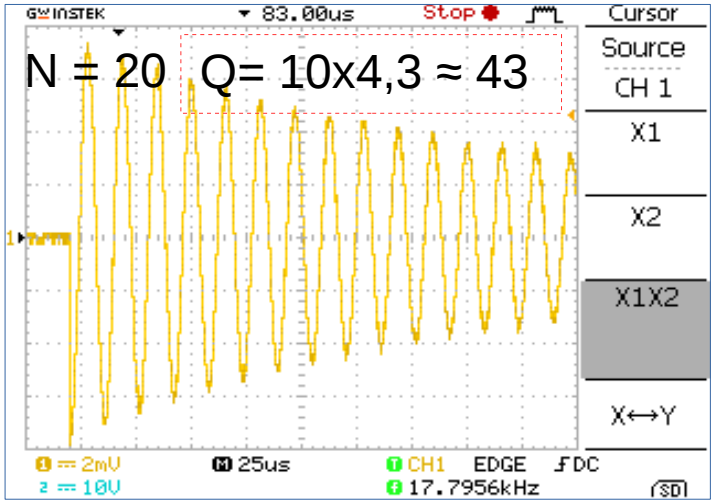




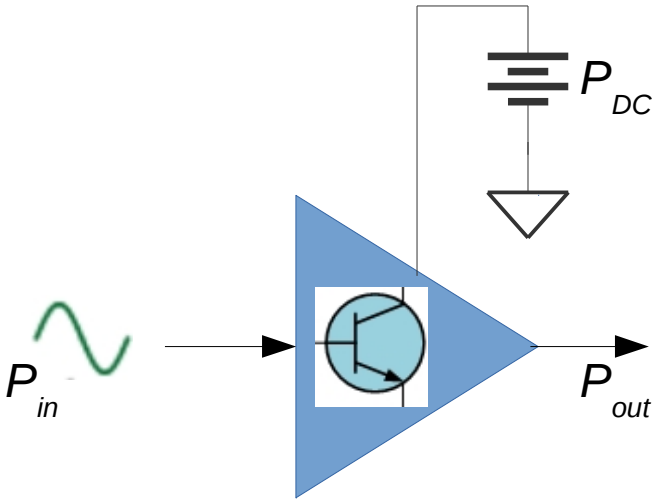


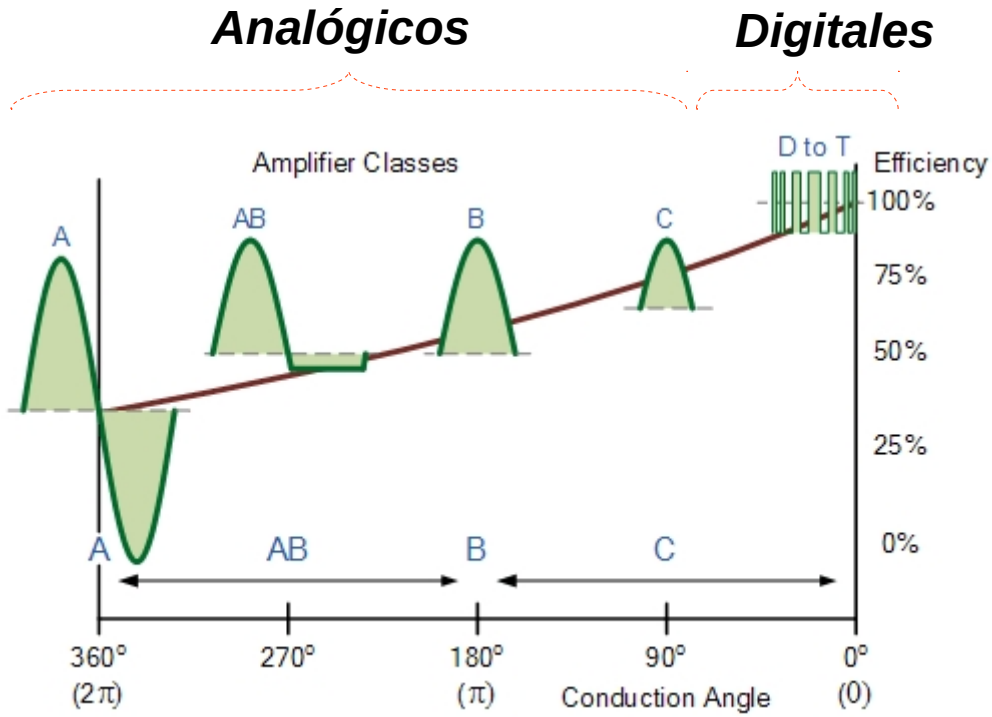
N	f0 [Khz]	L [uH]	Q	AL [nH/N²]
3	435	9,1	6,5	1006
4	384,6	11,6	8,6	724
8	167	61,4	26,7	960
12	114	131,8	34,4	915
15	89,3	214,8	38,7	955
20	76,9	289,7	43	724

$$N = \sqrt{\frac{L}{A_L}}$$



Clasificación de amplificadores de potencia de RF :





Clase	η Teórica	η Real
A	50%	25%-30%
B	78,5%	50%-60%
C	100%	80%-90%

$$\text{Eficiencia } \eta = \frac{P_{out}}{P_{DC}}$$

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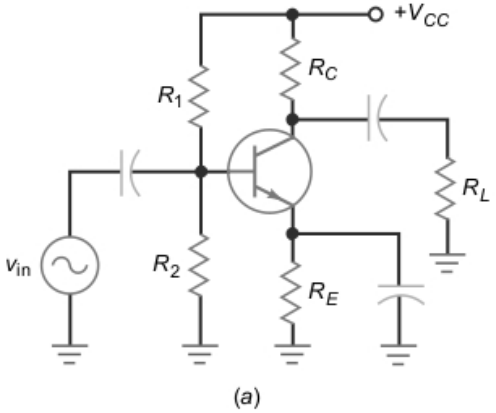
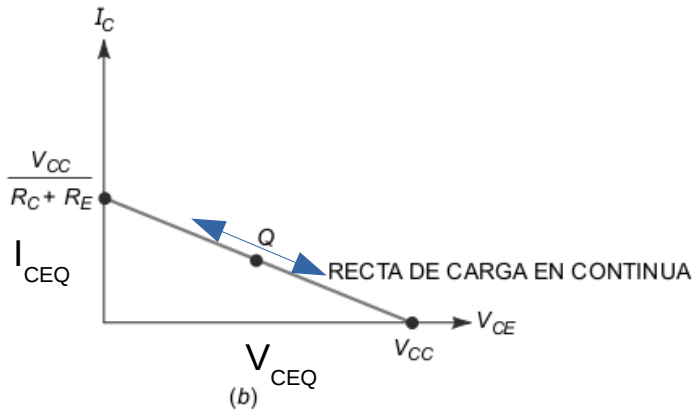
Punto “Q” de polarización (Quiescent = reposo):

Recta de carga en C.Contínua y Recta de carga en C.Alterna

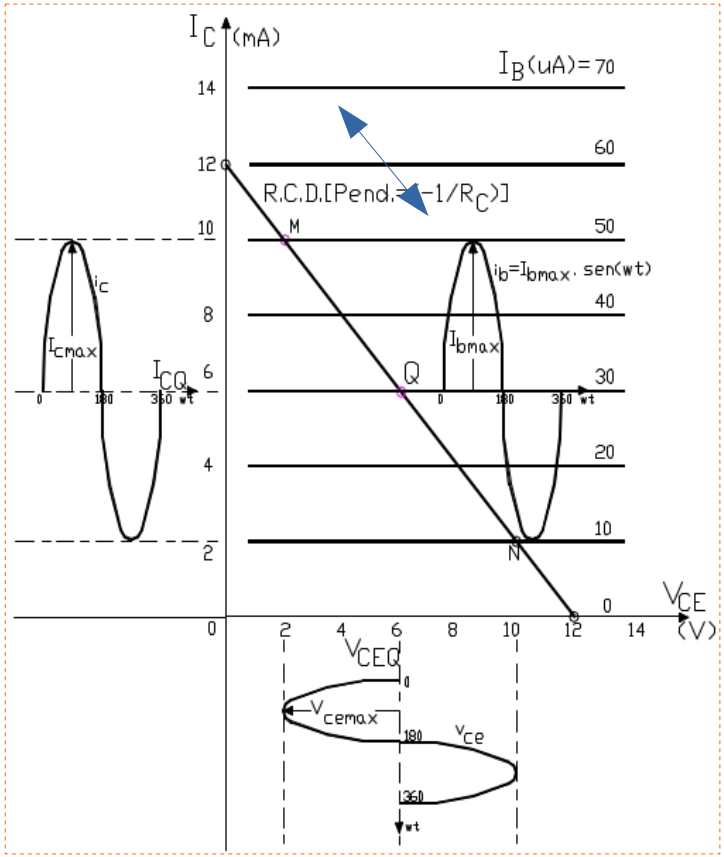


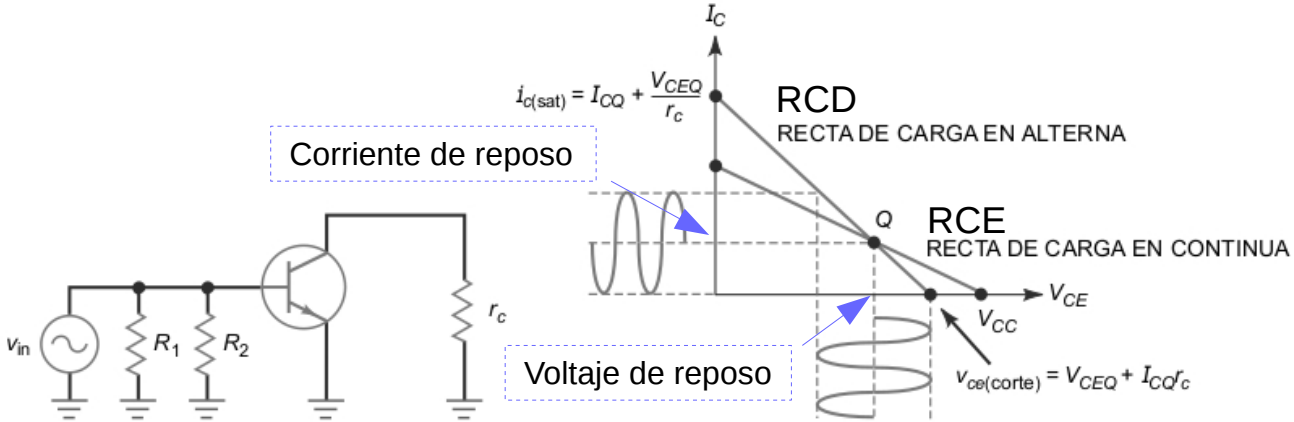
(a)



(b)

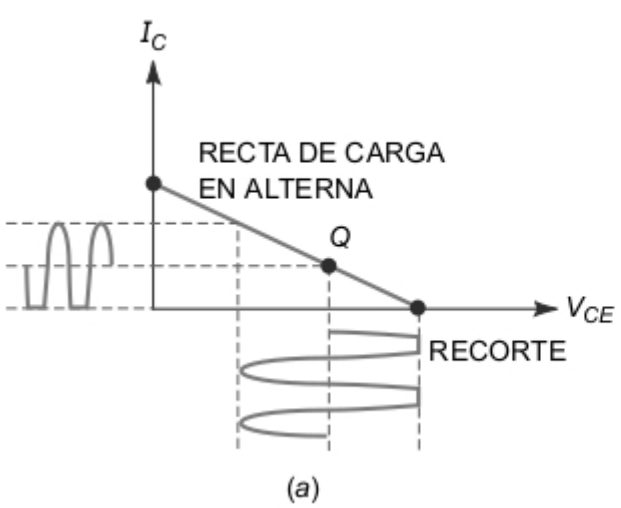
La Ic “copia” a la Ib

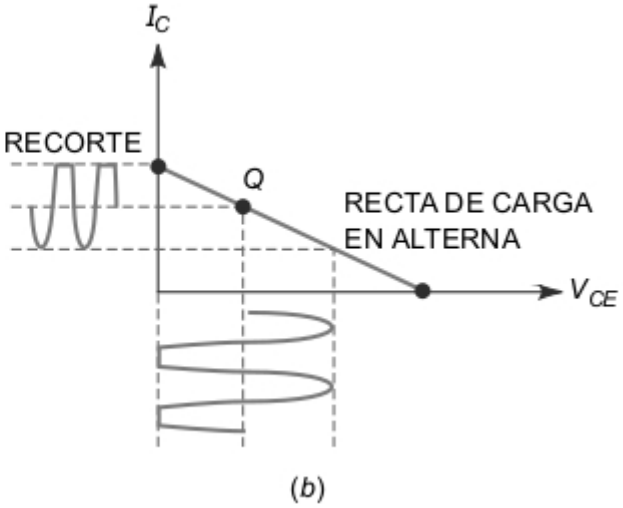




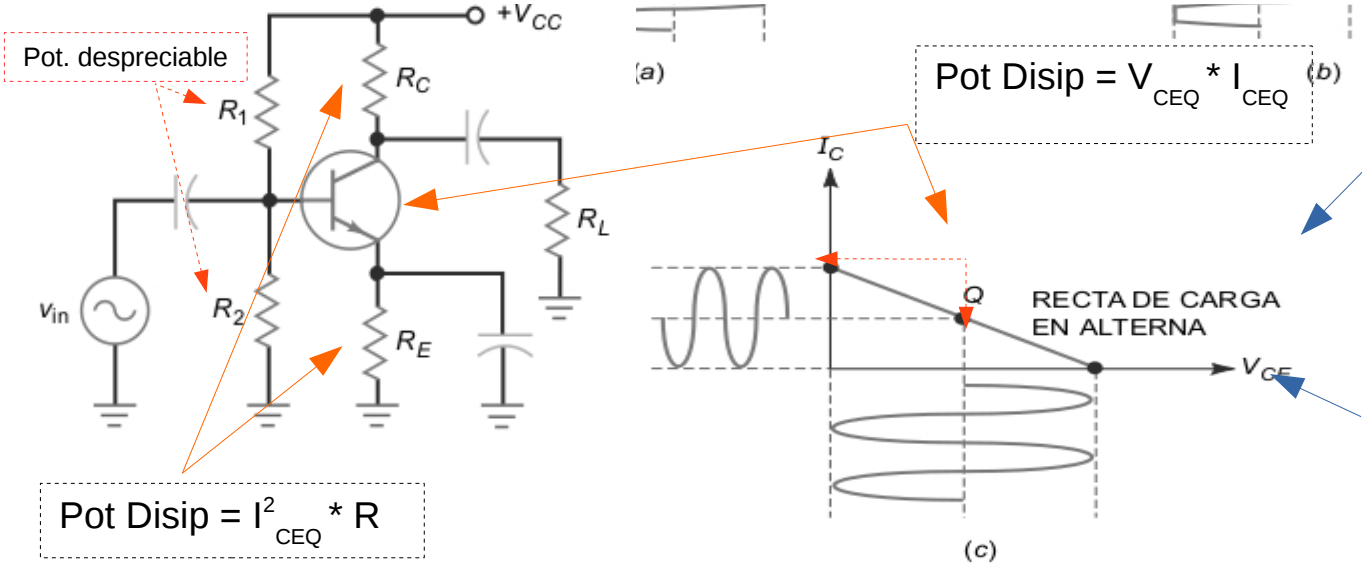
(c) (d)

Punto “Q” de polarización (Quiescent current):





La **clase** de operación se selecciona moviendo el punto Q



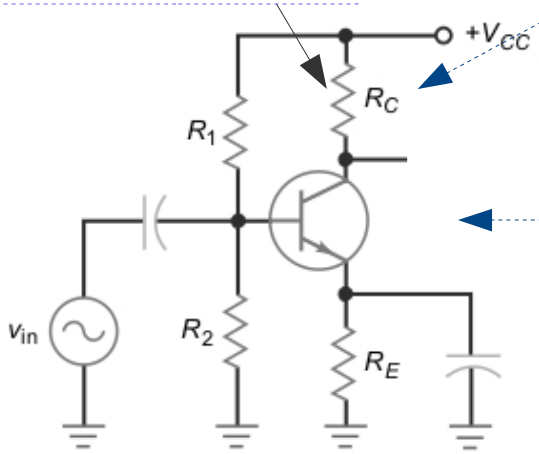
Clase A con Q a la mitad de recta de carga permite máxima excursión de señal

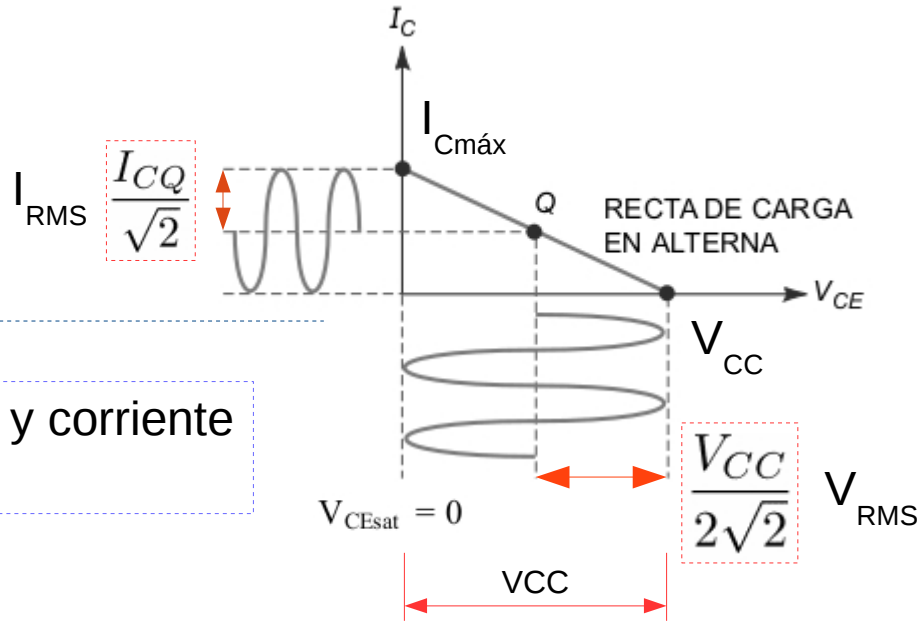
PROBLEMA!! Disipación sin señal útil

Eficiencia de Amplificador clase A (RCD = RCE) :

Se podría usar una fuente de corriente con Z alta

Carga RC





Ondas de voltaje y corriente en la carga

$$P_{out} = \frac{V_{CC}}{2\sqrt{2}} . \frac{I_{CQ}}{\sqrt{2}} = \frac{V_{CC} . I_{CQ}}{4}$$

$$P_{DC} = V_{CC} . I_{CQ}$$

$$\eta = \frac{P_{out}}{P_{DC}} = \frac{1}{4} \Leftrightarrow 25\%$$

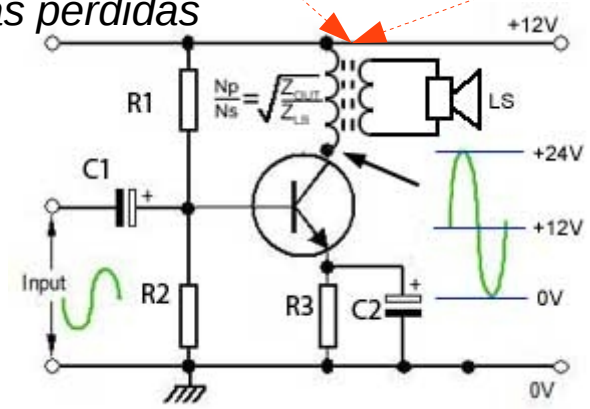
(en este caso) Si la carga RL estuviese acoplada capacitivamente el η sería menor a 25%

Amplificador clase A acoplamiento a transformador:

- **Clase A** Buena linealidad (muy poca distorsión de señal)
- Mala eficiencia energética < 25%

- El **acoplamiento a transformador** mejora la eficiencia

Atención con el Ancho de Banda y las perdidas

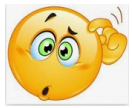


AC → $Z_P = Z_{LS} (N_P/N_S)^2$

DC → R ≈ 0

Cálculo de N = *Np/Ns*

$Zp_{(óptimo)} = V_{cc}/I_{CQMáx} = N^2.Zs$



$$P_{out} = \frac{2.V_{CC}}{2\sqrt{2}} \cdot \frac{I_{CQ}}{\sqrt{2}} = \frac{V_{CC}.I_{CQ}}{2}$$

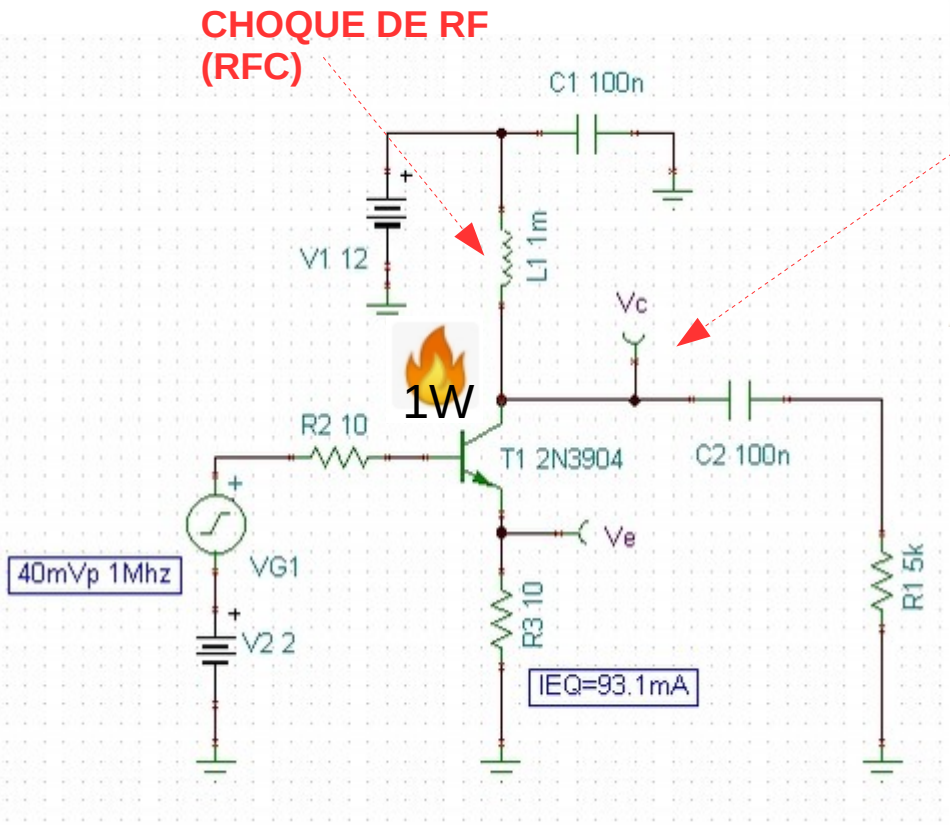
$$P_{DC} = V_{CC}.I_{CQ}$$

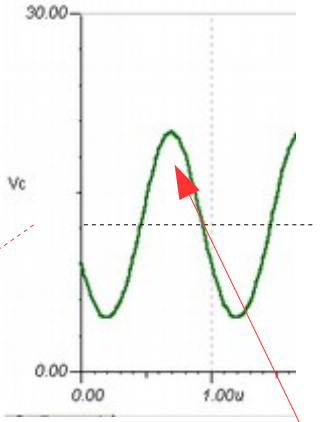
$$\eta = \frac{P_{out}}{P_{DC}} = \frac{1}{2} \Leftrightarrow 50\%$$

- El transformador desacopla la CC por la carga
- El "efecto transformador" permite que el colector vea una carga Zp ≠ Zs y que sobre ella se desarrolle un valor de tensión de pico a pico de 2.VCC.

El **η real** *es menor a 50% ya que no se tuvo en cuenta la* V_{CEsat} *y las perdidas en el transformador. (ni en R1 y R2)*

Clase A con L de “choque” en colector :





12V DC

20 Vp !!!!
(ó más)

➡ Veamos la “Ie y Vc” en el simulador

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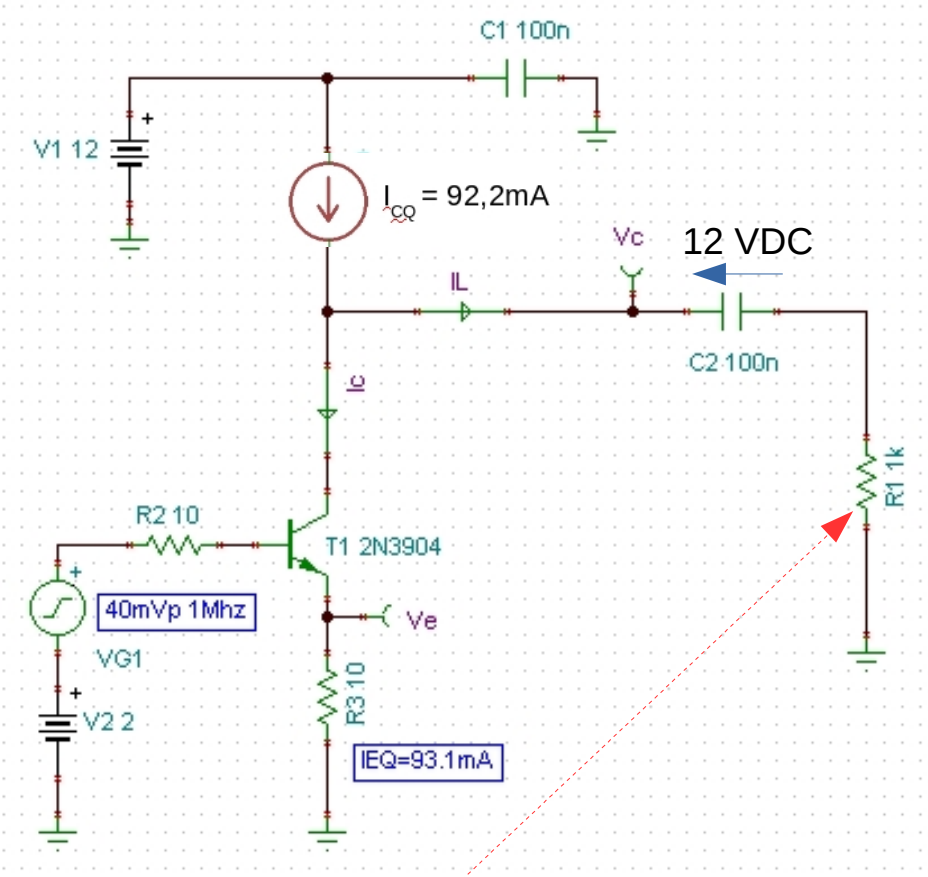
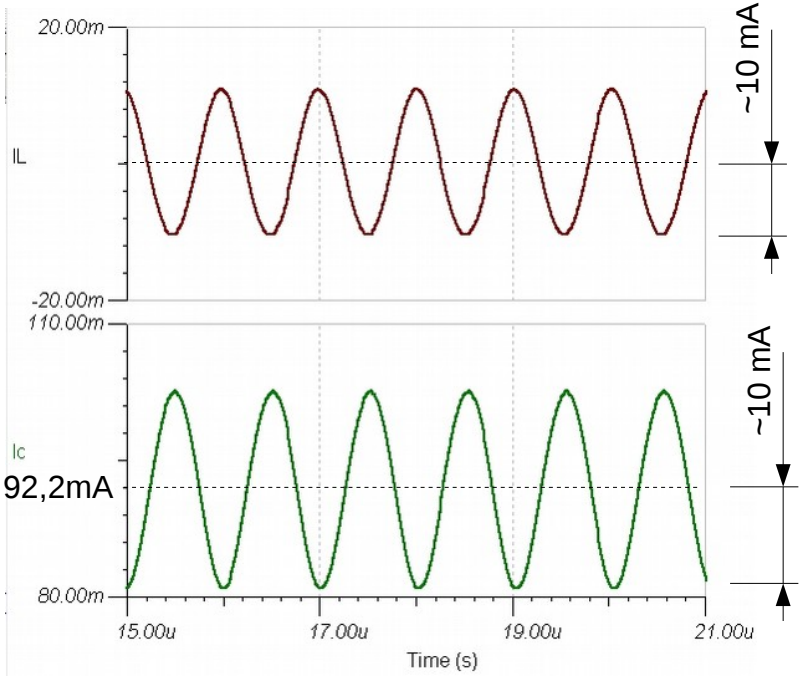
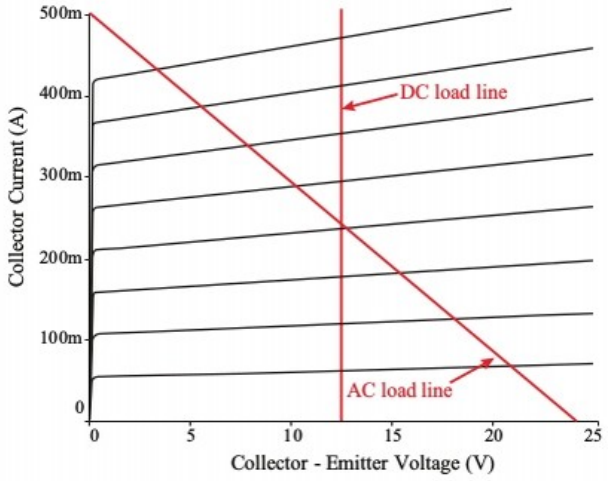
Clase A con L de “choque” en colector :



$R_{L(óptima)} = VCC/ICQ$





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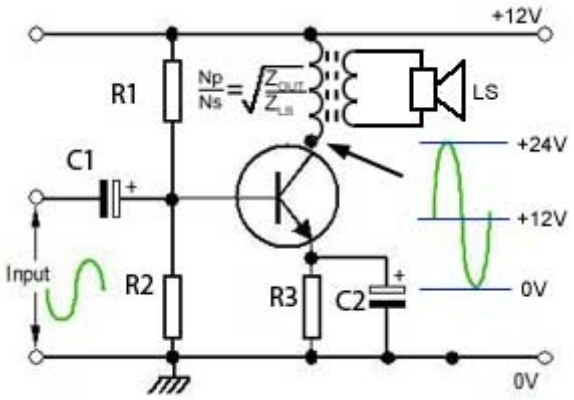
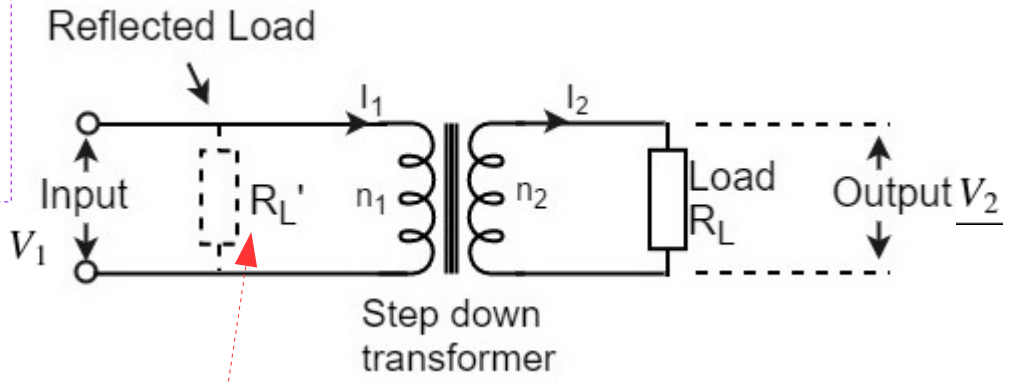
Clase A con Acoplamiento a transformador:

- No circula corriente continua por la carga
- Se logra la condición de MTP (adaptación)
- Necesidad de usar transformador de RF



$$n = \frac{number\ of\ turns\ in\ primary}{number\ of\ turns\ in\ secondary} = \frac{n_1}{n_2}$$



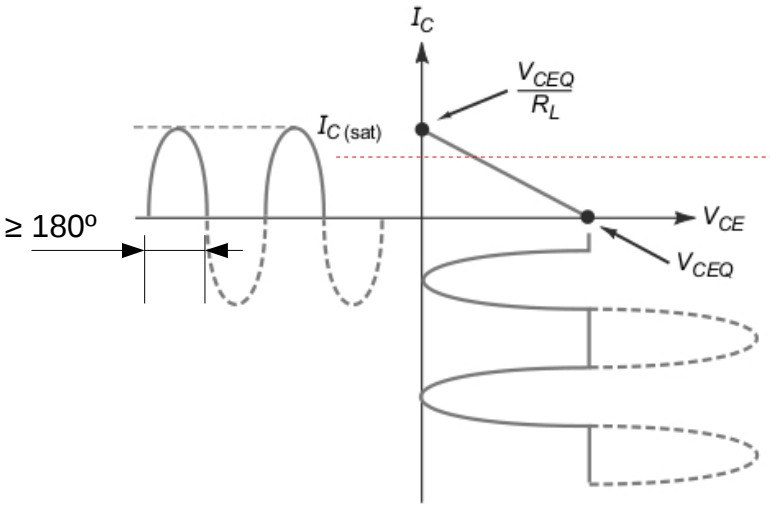
$$R_L' = \left(\frac{n_1}{n_2}\right)^2 R_L = n^2 R_L$$

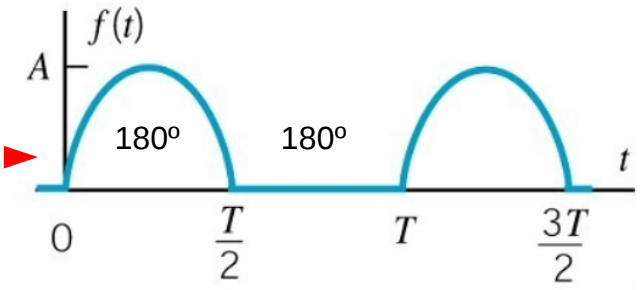
$$\frac{V_1}{V_2} = \frac{n_1}{n_2} \text{ and } \frac{I_1}{I_2} = \frac{n_1}{n_2}$$

$$V_1 = \frac{n_1}{n_2} V_2 \text{ and } I_1 = \frac{n_1}{n_2} I_2$$

$$\frac{V_1}{I_1} = \left(\frac{n_1}{n_2}\right)^2 \frac{V_2}{I_2}$$

Amplificador clase B:





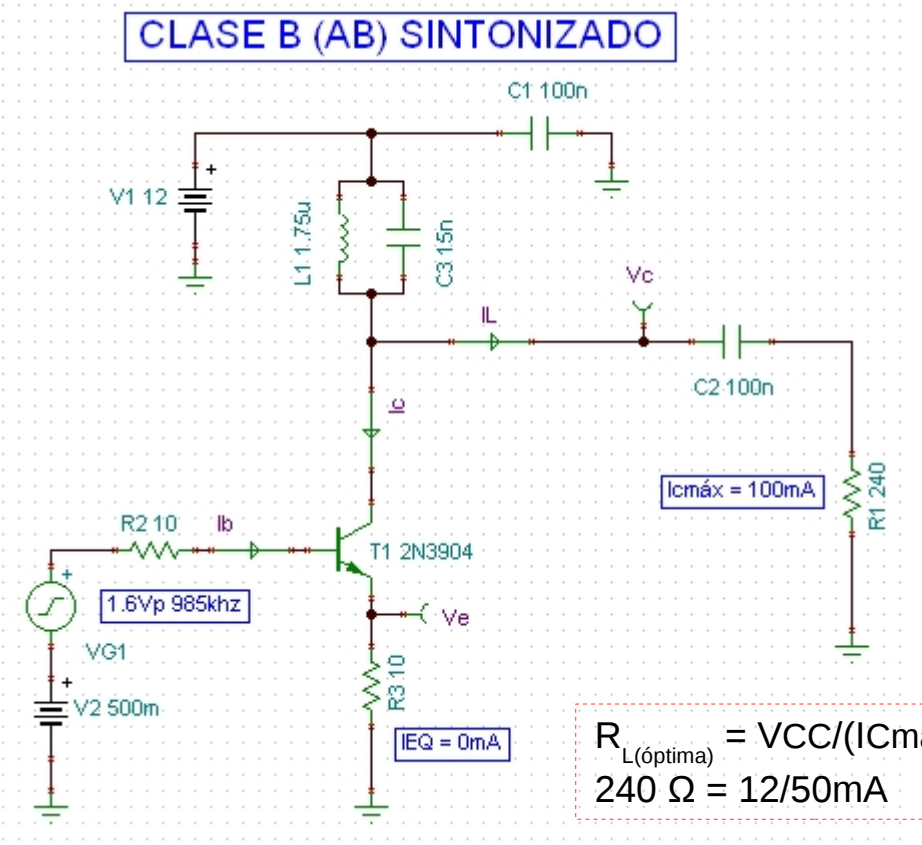
Half wave rectified sine wave: $\omega_0 = \frac{2\pi}{T}$

$$f(t) = \frac{A}{\pi} + \frac{A}{2}\sin\omega_0 t - \frac{2A}{\pi}\sum_{n=1}^{\infty}\frac{\cos(2n\omega_0 t)}{4n^2-1}$$

DC

1er armónico

Amplificador clase B (sintonizado):

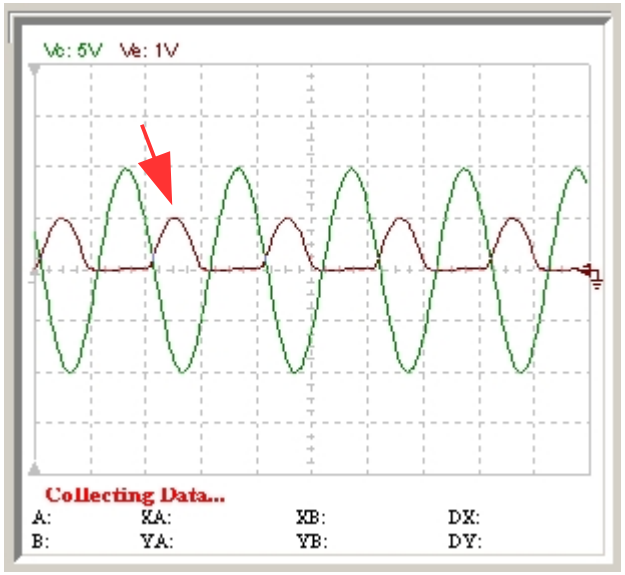


$R_{L(\text{óptima})}$ = VCC/(ICmax/2)
240 Ω = 12/50mA

$$P_{out} = \frac{V_P}{\sqrt{2}} \cdot \frac{I_P}{\sqrt{2}} = \frac{V_{CC}}{\sqrt{2}} \cdot \frac{\frac{I_{Cmax}}{2}}{\sqrt{2}} = V_{CC} \cdot \frac{I_{Cmax}}{4}$$

$$P_{DC} = V_{CC} \cdot \frac{I_{Cmax}}{\pi}$$

$$\eta = \frac{P_{out}}{P_{DC}} = \frac{\pi}{4} = 0.785 \quad 78{,}5\%$$



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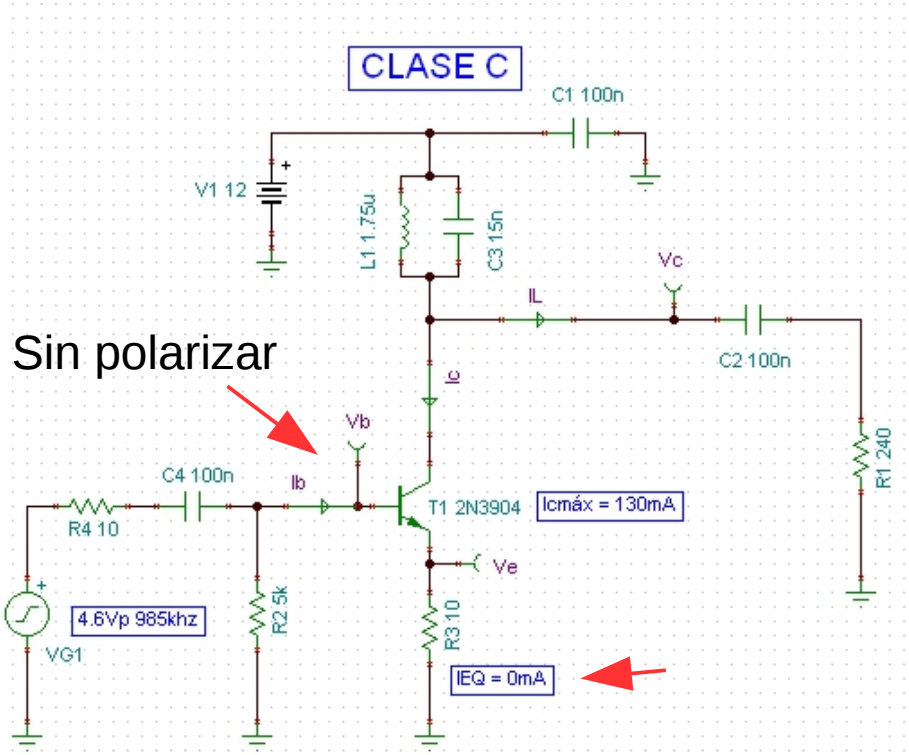
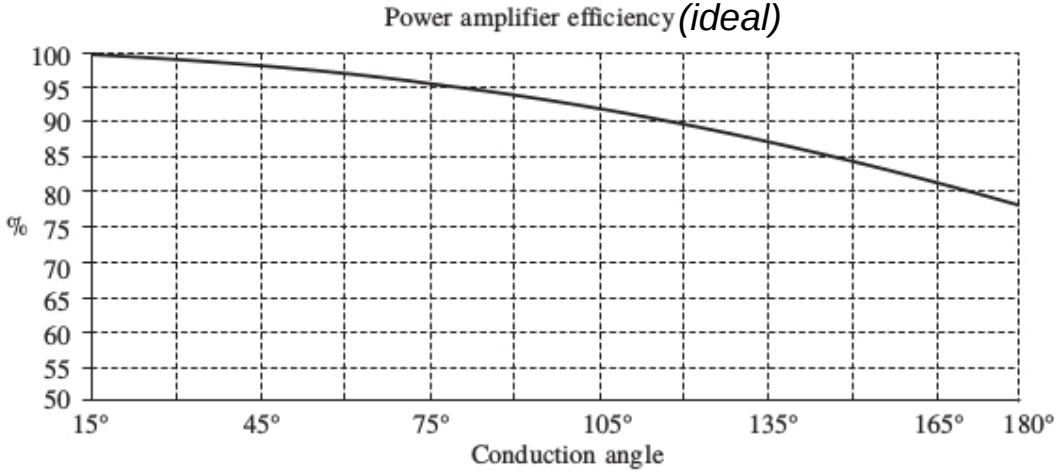
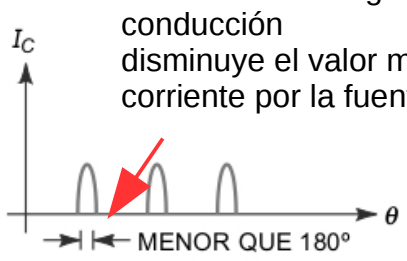
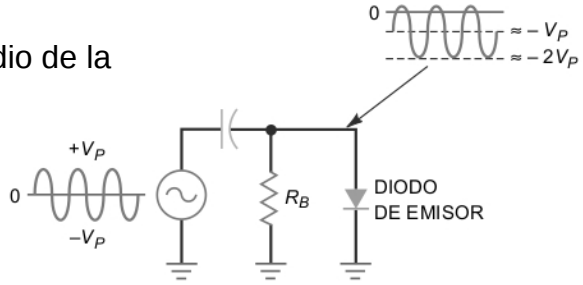
Amplificador clase C:

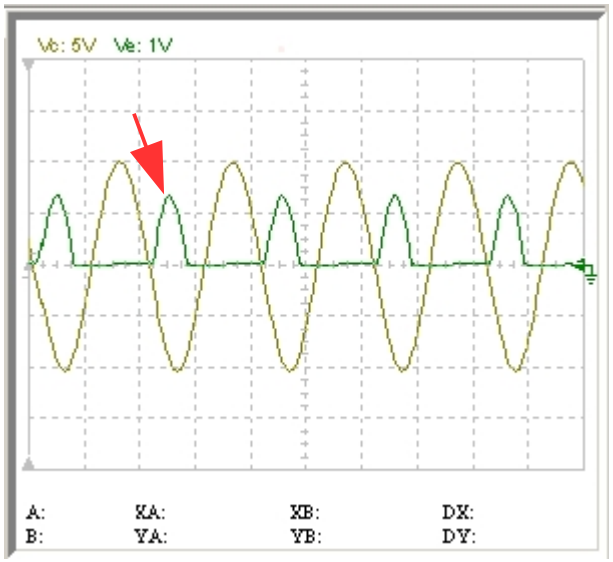




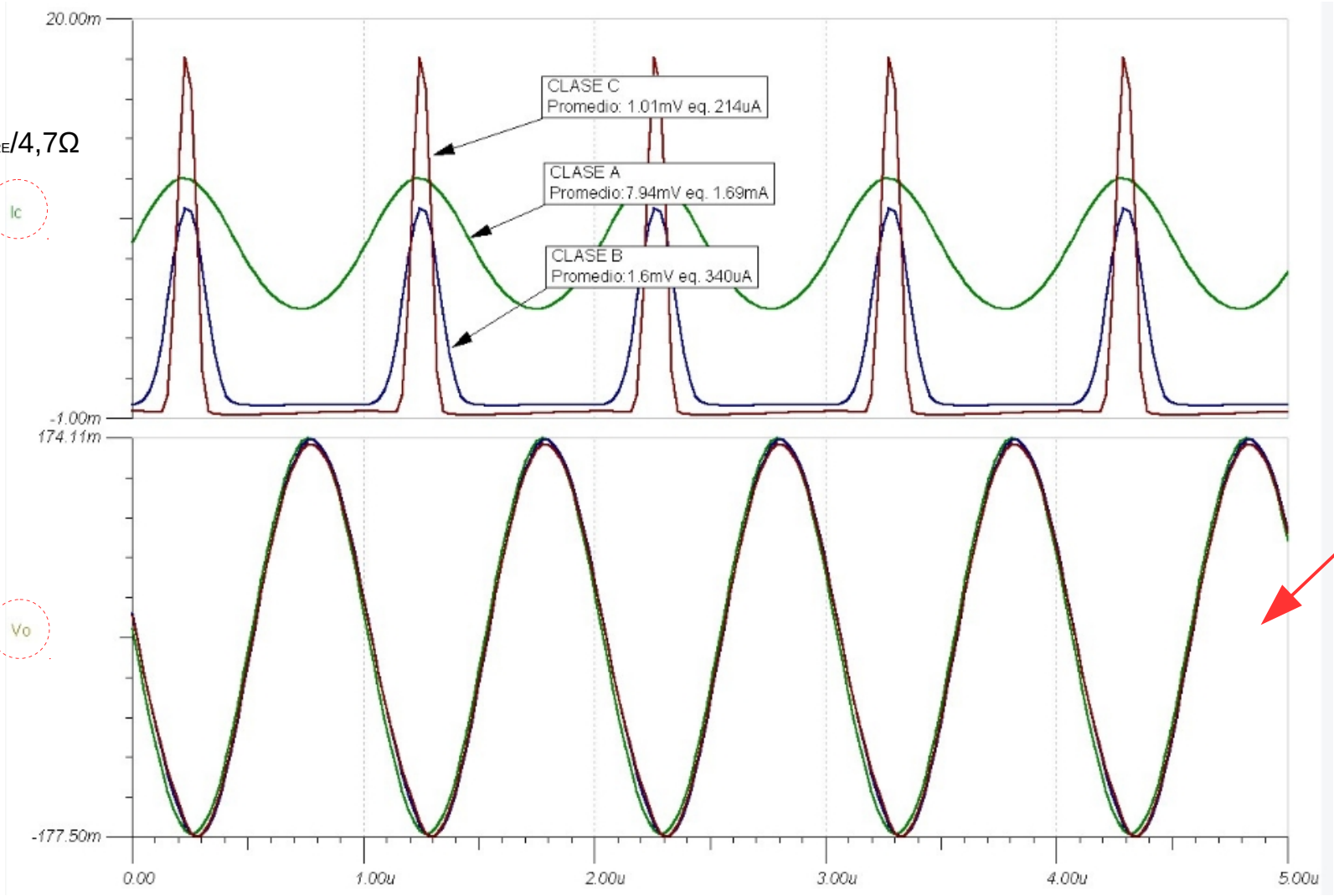
Al disminuir el ángulo de conducción
disminuye el valor medio de la corriente por la fuente







Clase A, B, C comparación (simulación TINA):



Las 3 clases de operación producen la misma excursión de salida con distintos niveles potencia en DC

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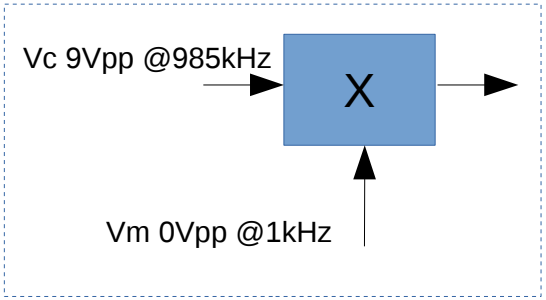
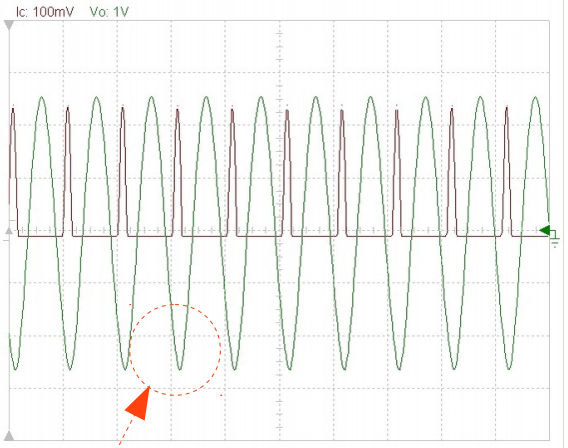
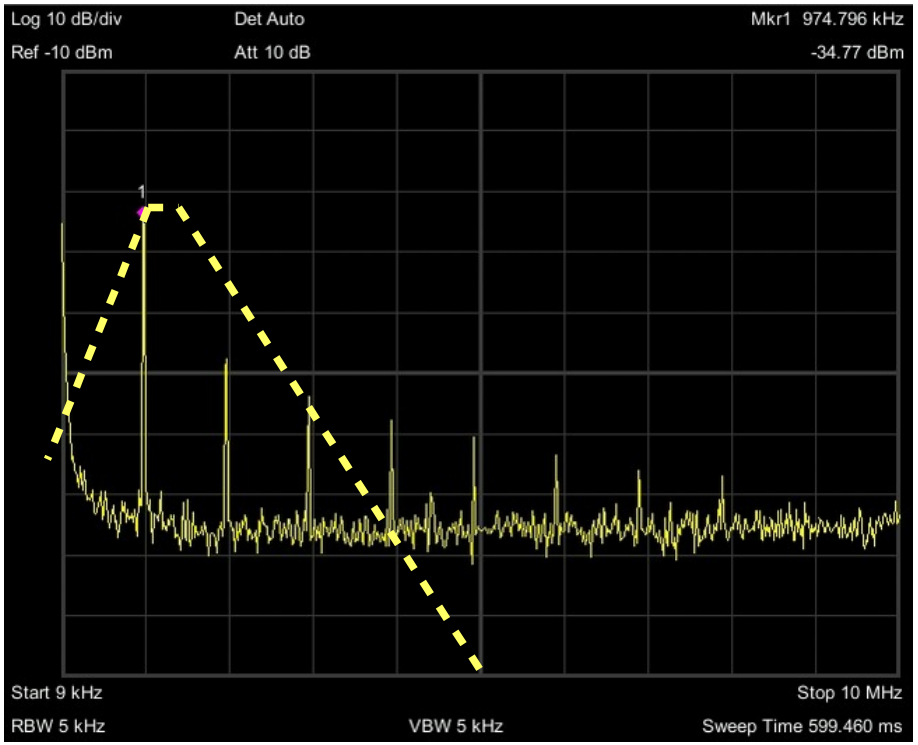
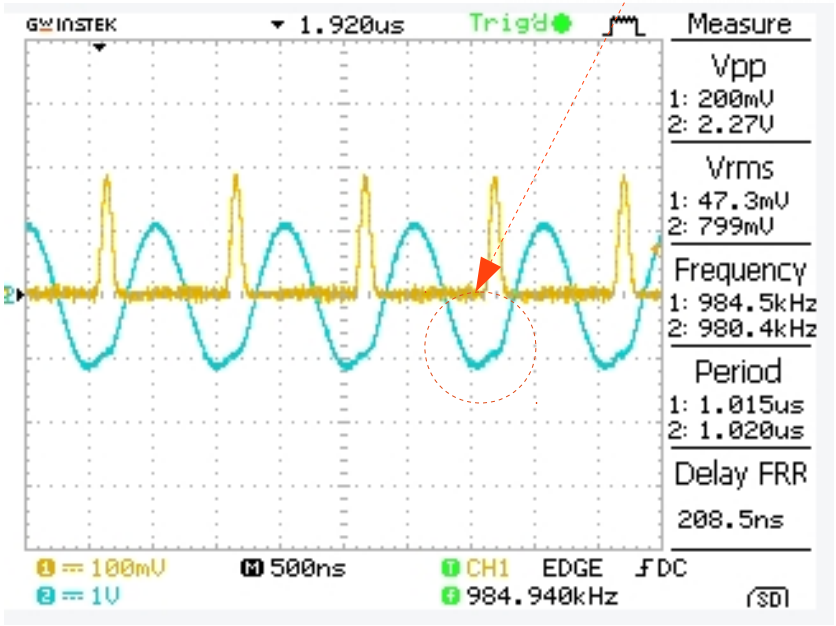
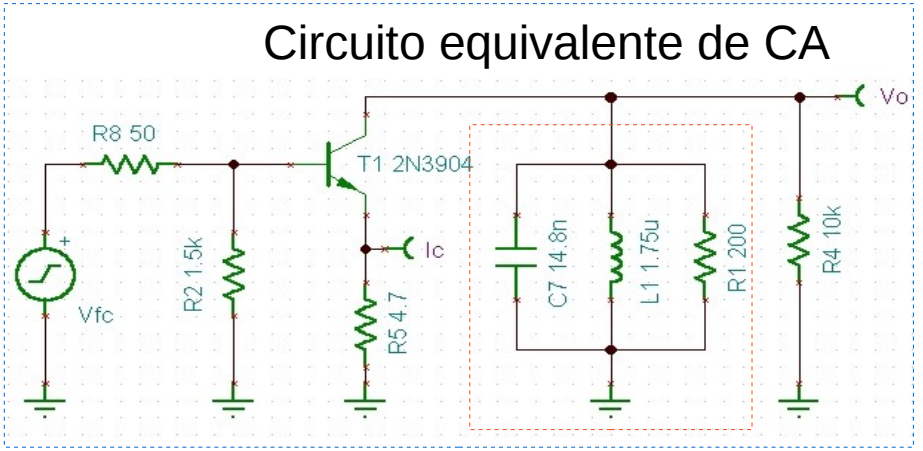
Clase C - Sin modulación :











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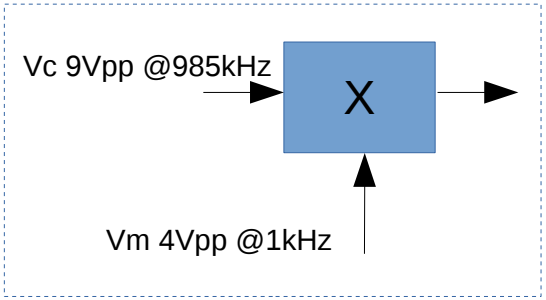
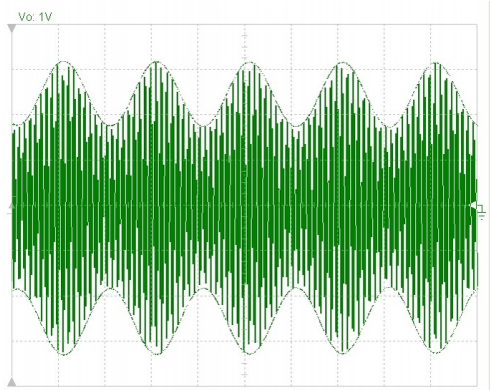
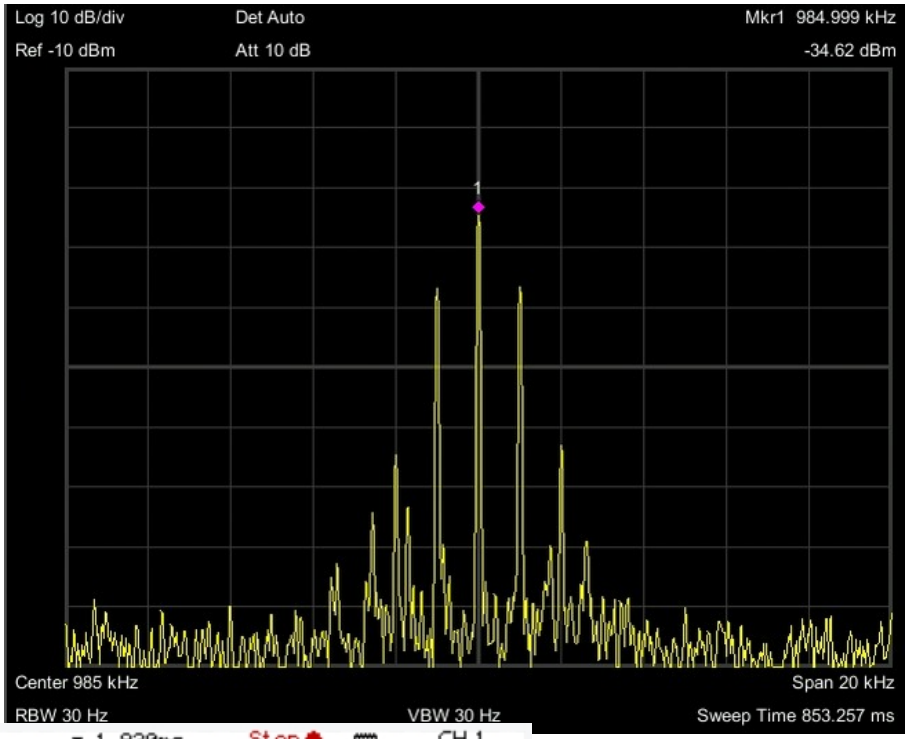
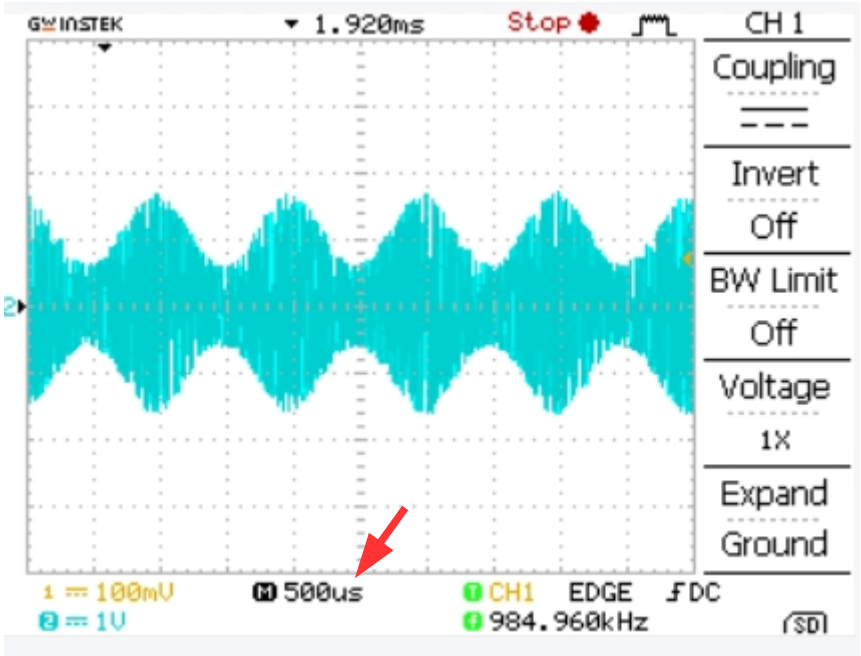
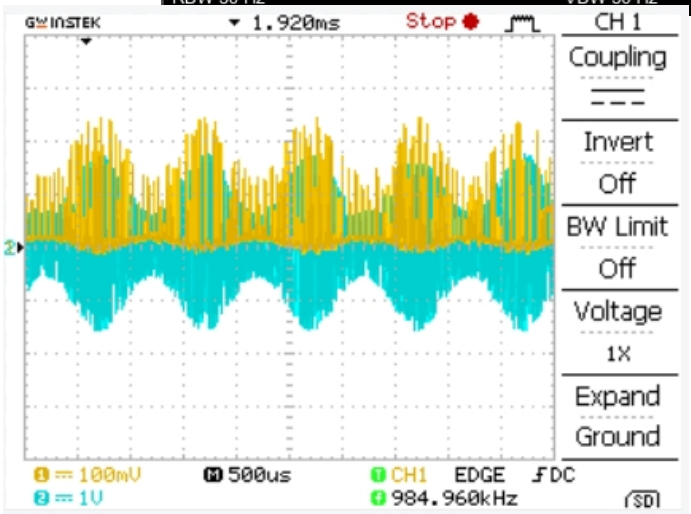
Clase C – Con modulación :











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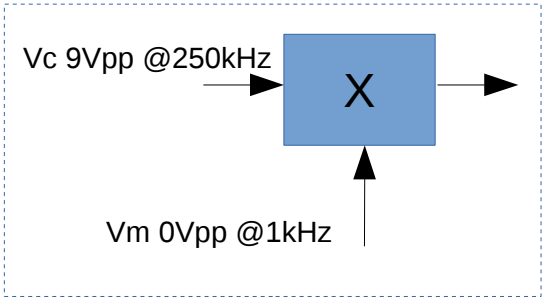
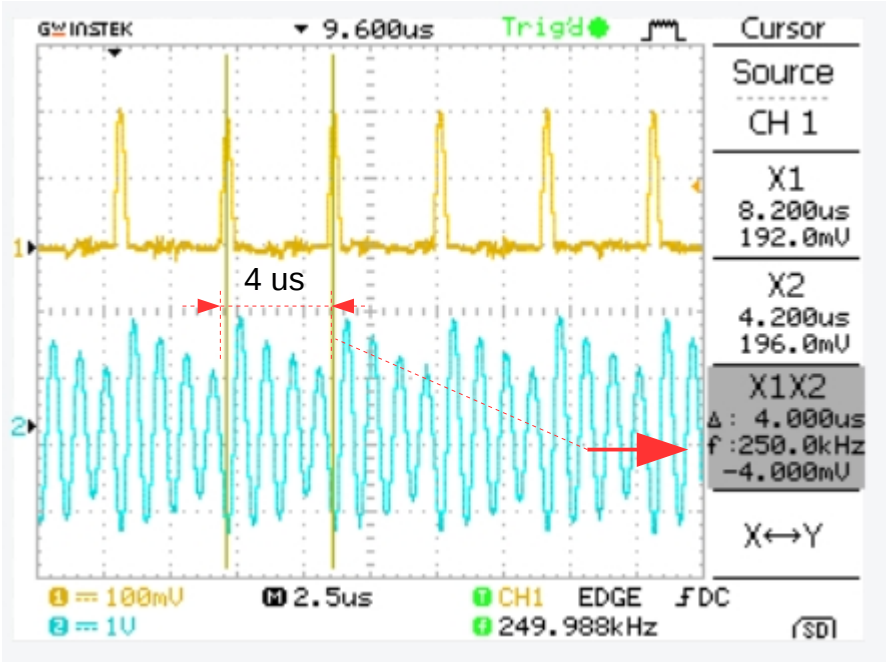
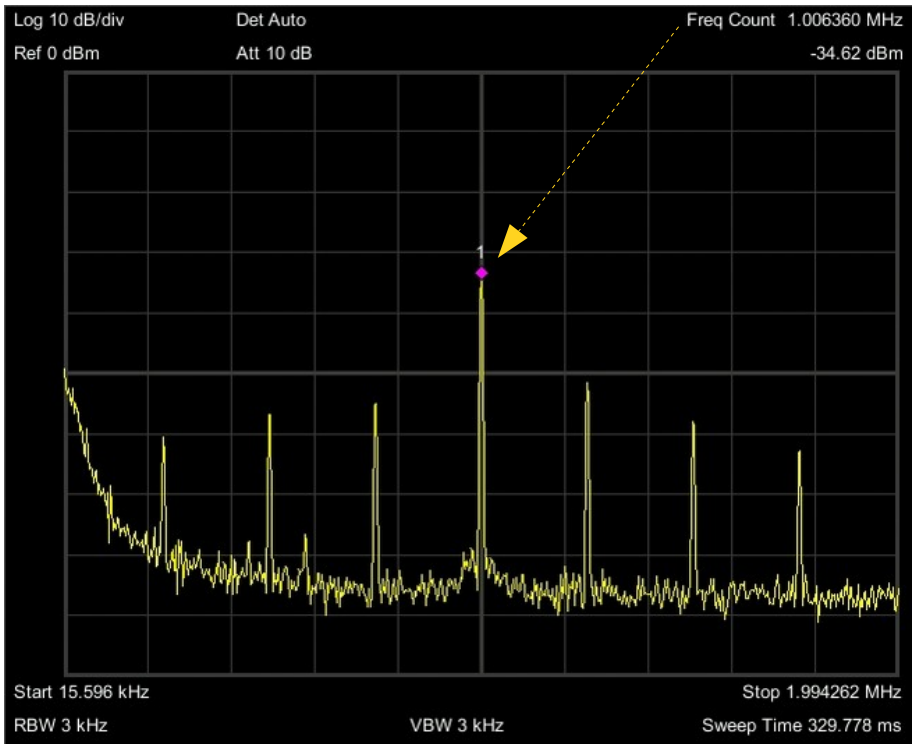
Clase C – Multiplicador de frecuencia :



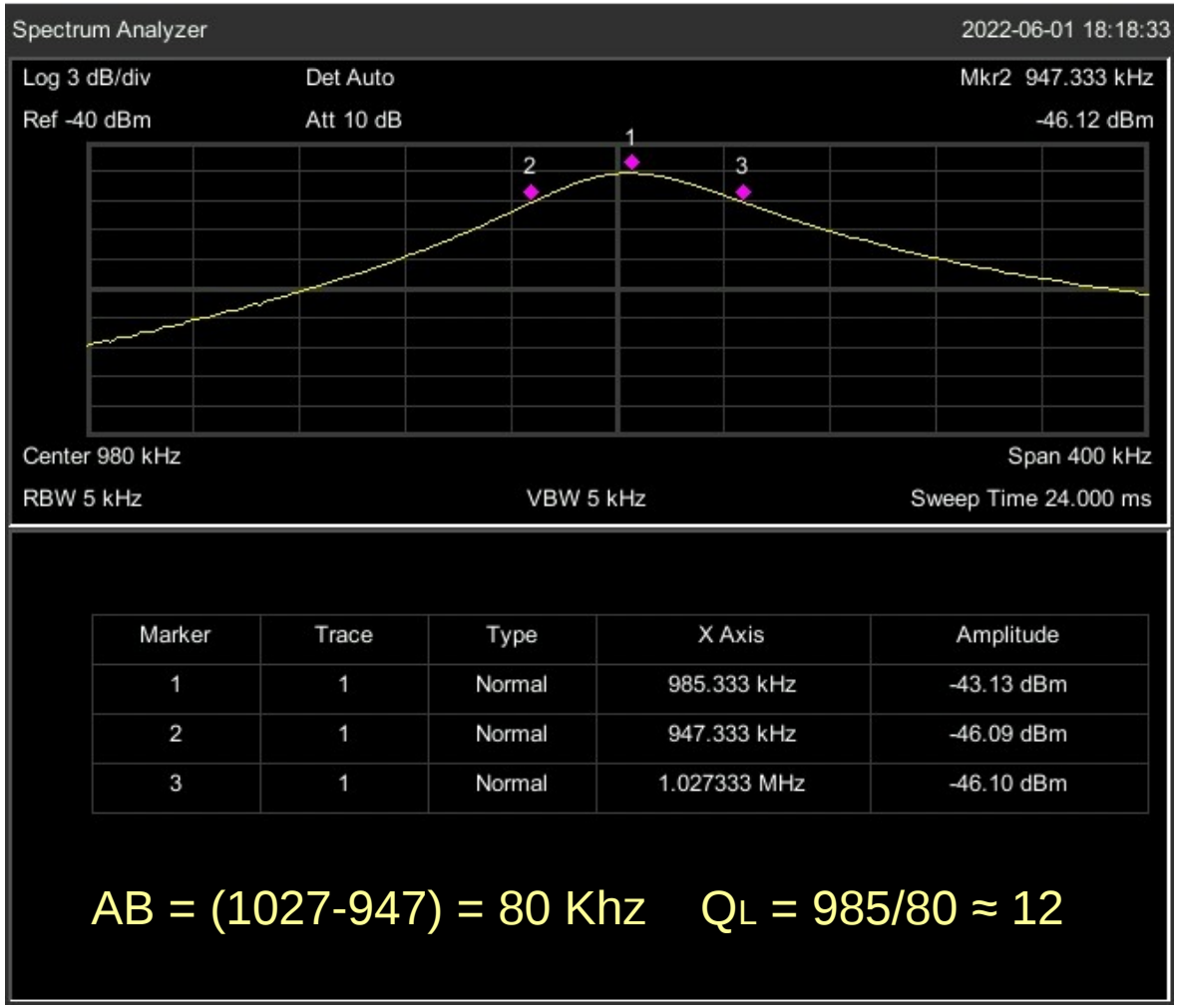




Medición de ancho de banda :

Clase A – SIN Modulación
Con baja excursión de señal de salida.

Esta medición puede realizarse con Osciloscopio y generador de señales



Marker	Trace	Type	X Axis	Amplitude
1	1	Normal	985.333 kHz	-43.13 dBm
2	1	Normal	947.333 kHz	-46.09 dBm
3	1	Normal	1.027333 MHz	-46.10 dBm

AB = (1027-947) = 80 Khz Q_L = 985/80 ≈ 12

Mezclador con amplificador en Clase A :

V1: 985Khz 100mVpp
V2: 1Khz 770mVpp
preset 50% (mover)

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xxxxxxx :

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xxxxxxx :

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https://www.tutorialspoint.com/amplifiers/transformer_coupled_class_a_power_amplifier.htm
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