

# Oscillators

---

How they *really* work

Goal of this talk is to give the listener the tools to be able to do a back-of-the-envelope analysis of an oscillator circuit.

I assume you already understand how to change impedance levels using a transformer and how Ohm's Law works. Not much beyond that is needed.

No fancy math will be used!

## Oscillator Components

Resonator - the most important part

Mechanically Solid

Temperature Stable

High Q

Limiting Amplifier - must provide power to the resonator but not compromise its performance

Output Buffer - necessary to isolate oscillator from external influences

## Conceptual tools for basic understanding

How a tapped resonator acts like an ideal transformer

How a JFET or BJT acts as a limiter

How to connect the JFET or BJT to the resonator

In a high-Q oscillator all the voltages and currents are almost-perfect sine waves. Output currents from the limiting amplifier are very much smaller than the circulating currents in the resonator.

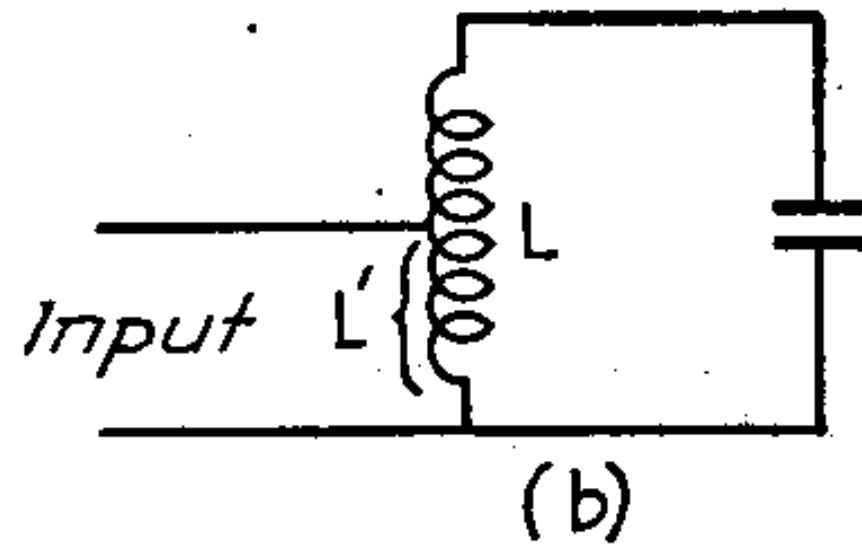
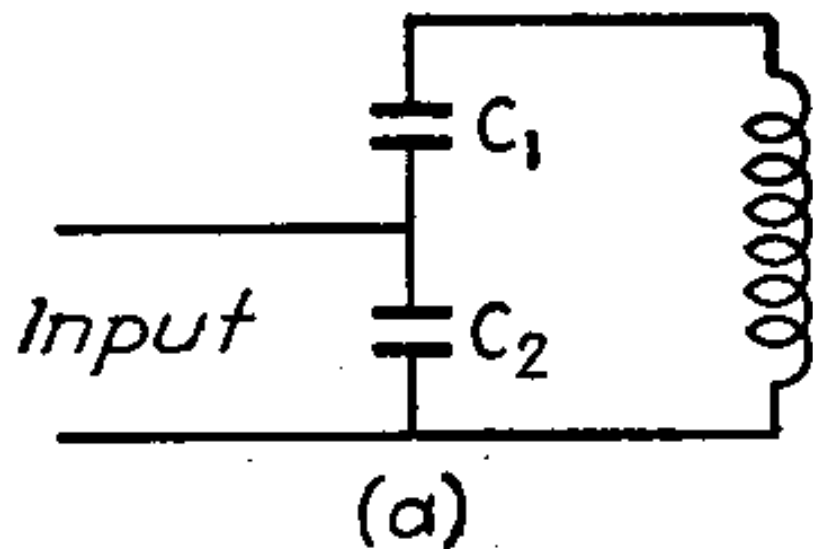


FIG. 11.—Tapped parallel resonant circuits.

*Parallel Resonance with Tapped Circuits.*—Parallel resonance circuits are frequently operated with the input connected across only a portion of the total circuit, as illustrated in Fig. 11. At frequencies near resonance, the effect of this method of operation is to make the impedance offered to the input terminals less in magnitude than the parallel impedance of the entire circuit without changing the character of the impedance curve as far as shape or equivalent  $Q$  is concerned. Tapping a parallel resonance circuit accordingly offers a means of adjusting the magnitude of impedance obtained without changing the circuit itself.

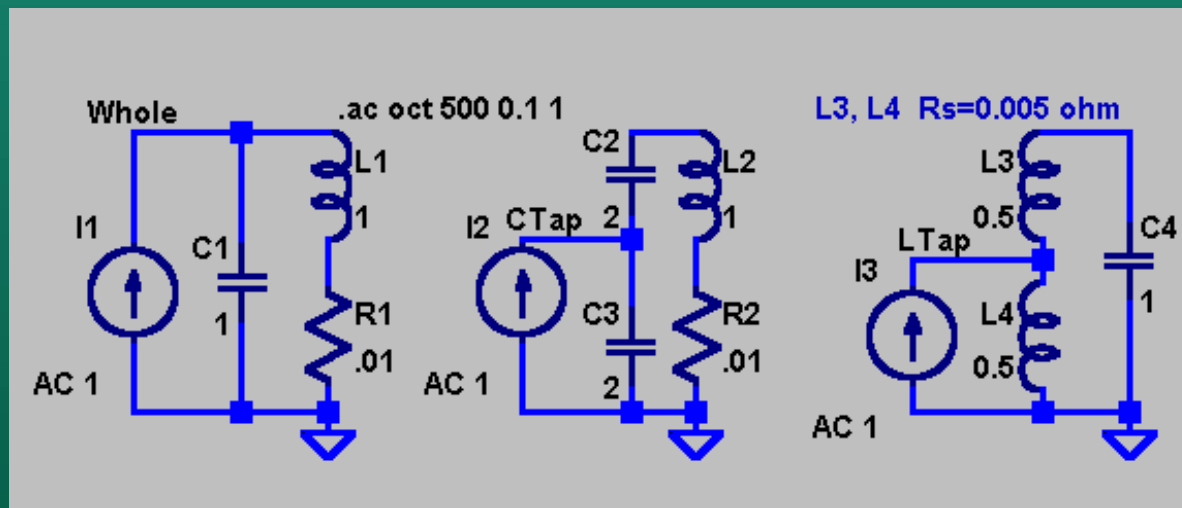
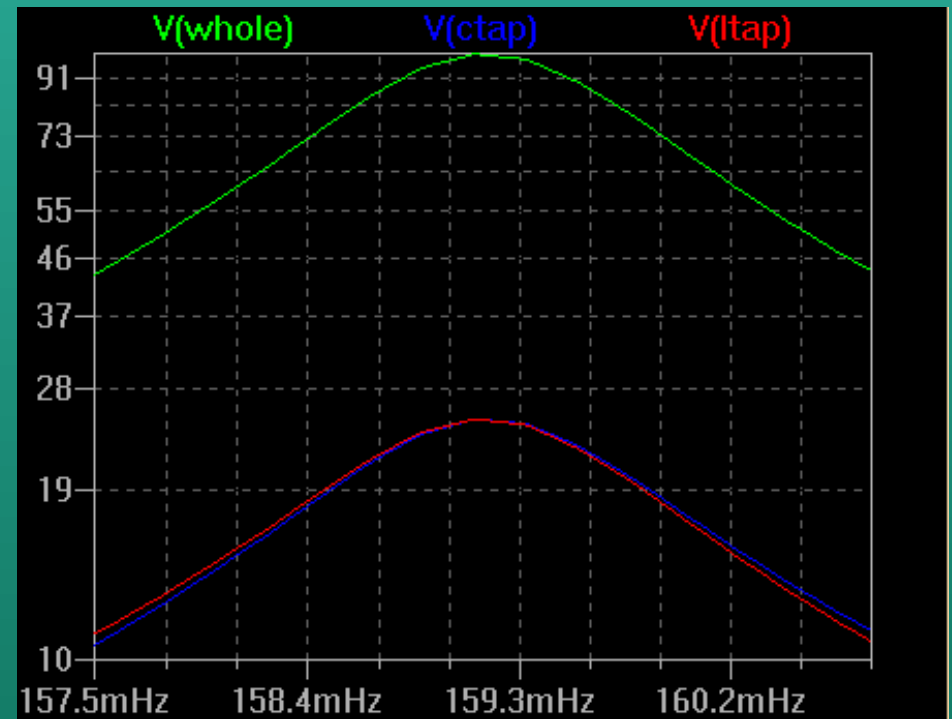
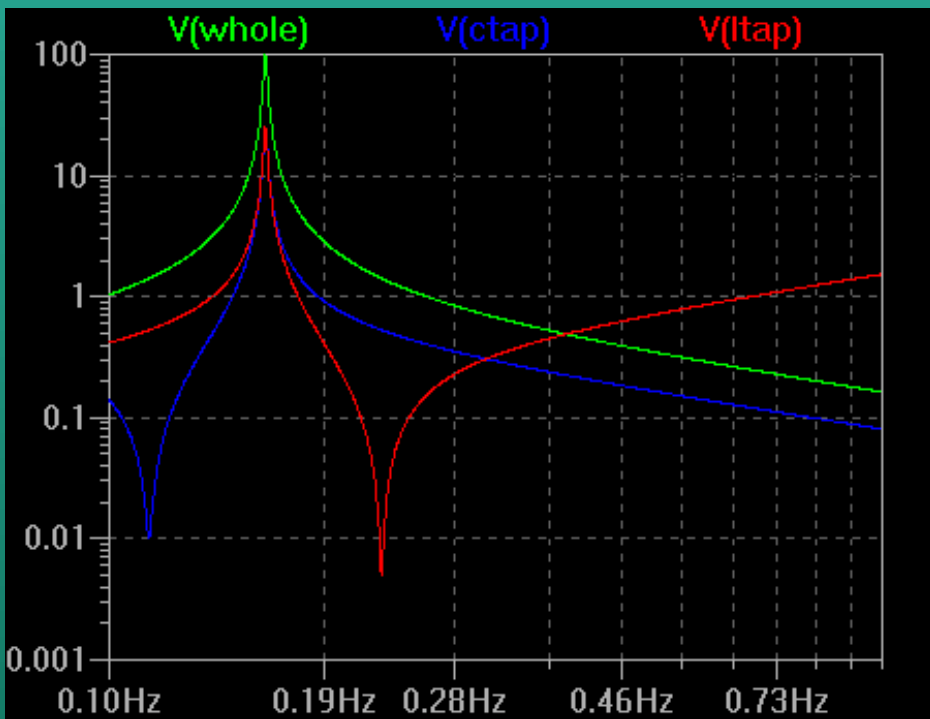
With the circuit of Fig. 11a, one has near the resonant frequency

$$\frac{\text{Impedance offered to input}}{\text{Parallel impedance of circuit}} = \left( \frac{C_1}{C_1 + C_2} \right)^2 \quad (20)$$

Similarly, for Fig. 11b

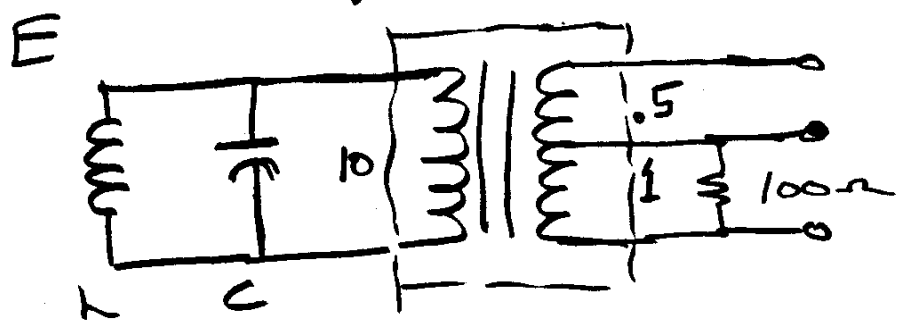
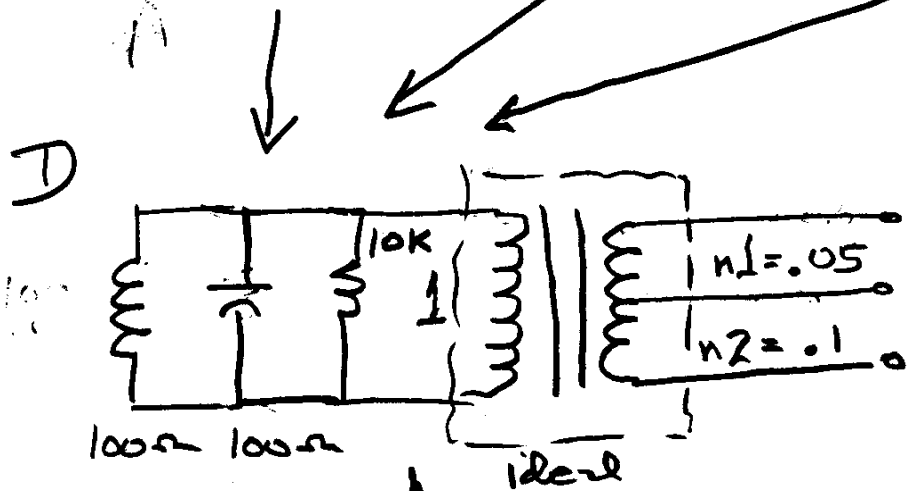
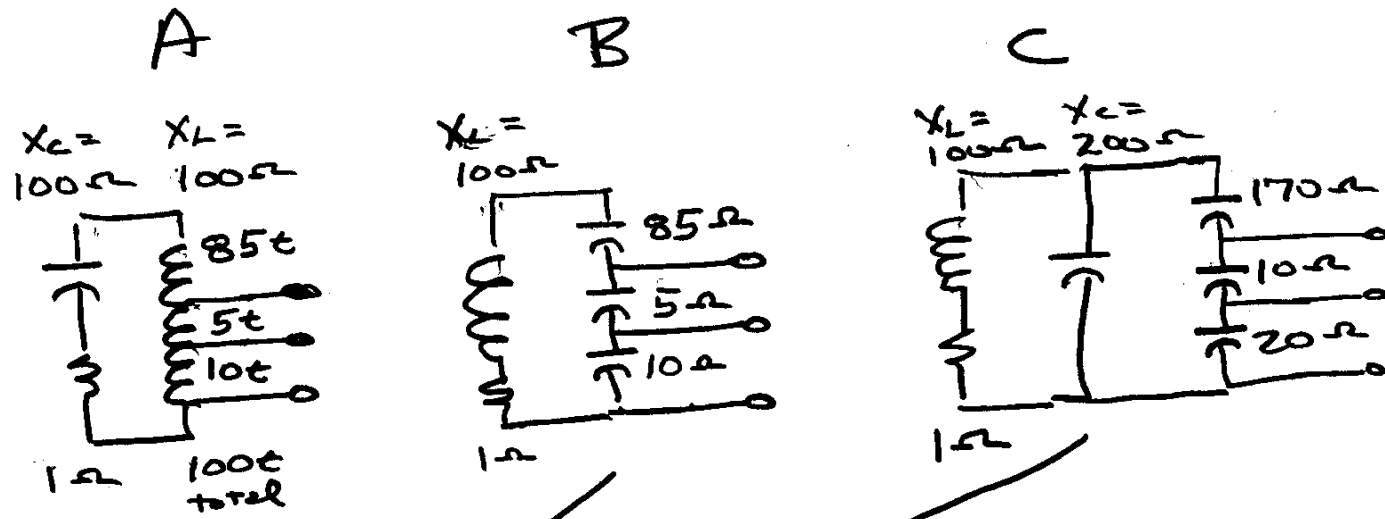
$$\frac{\text{Impedance offered to input}}{\text{Parallel impedance of circuit}} = \left( \frac{M_{eq}}{L} \right)^2 \quad (21)$$

where  $M_{eq}$  is the total equivalent mutual inductance between  $L'$  and the entire coil  $L$ , including both common and inductive coupling.



# Tapped Resonator Comparison

# Tapped Resonator Impedance Transformation- LC Resonator

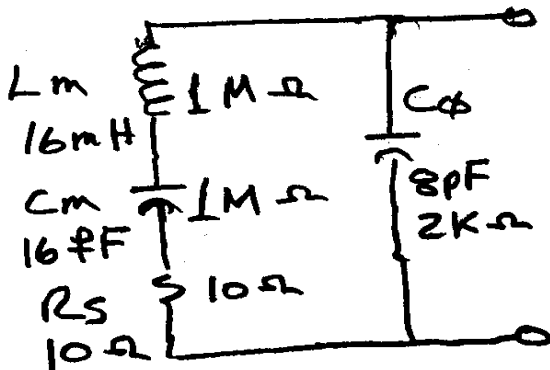


10 MHz crystal

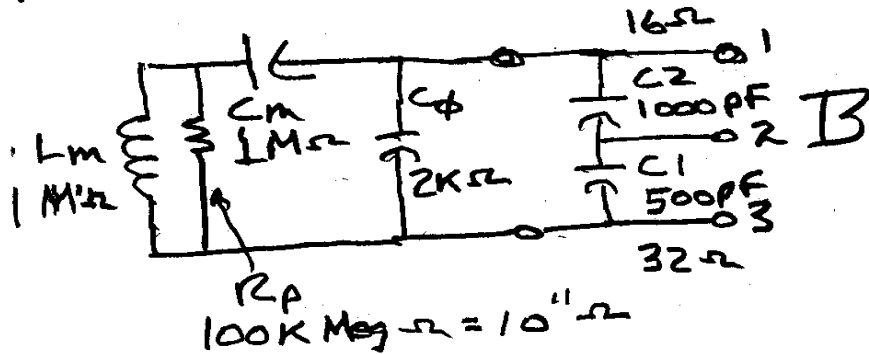
$$R_s = 10 \Omega$$

$$C_\phi = 8 \text{ pF}$$

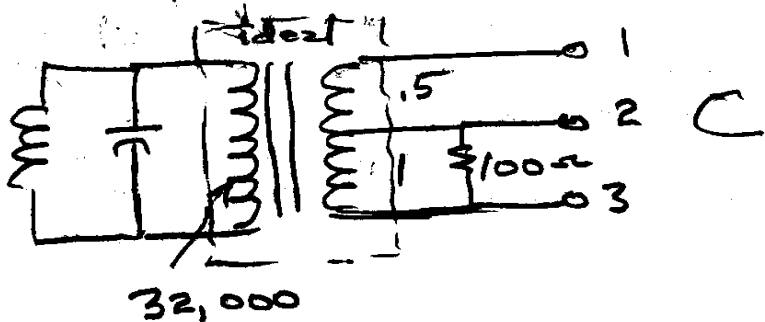
$$Q = 100,000$$



A



B

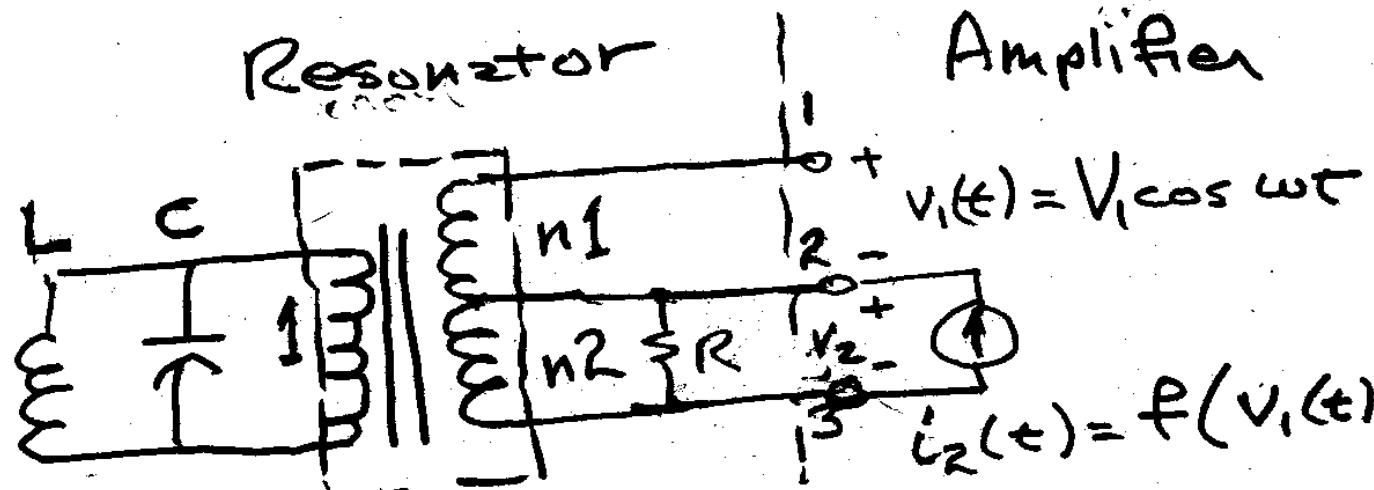


C

## Quartz Crystal

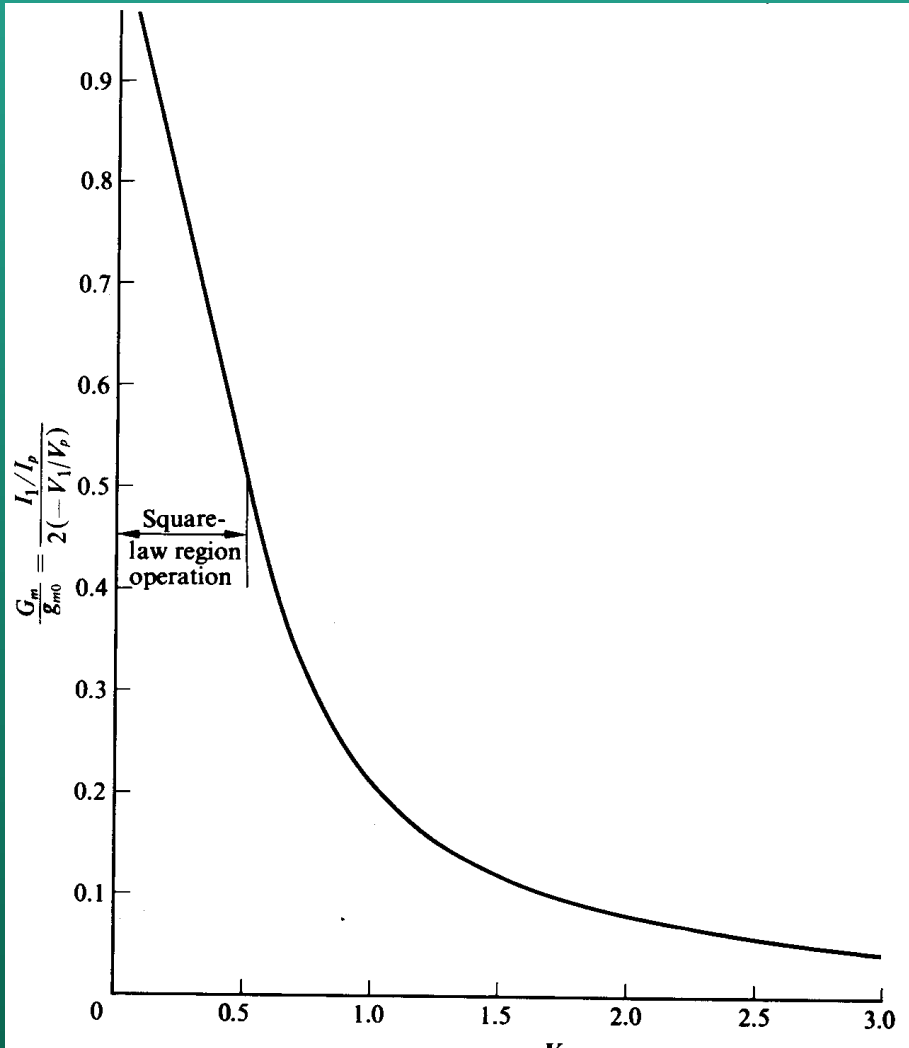
Despite extreme element values, transformed impedances are reasonable.

Power dissipated in the crystal must be limited. Power is just voltage times current. You know the current from the BJT bias or the JFET  $I_{dss}$  and can measure the AC voltage with a diode and DC voltmeter.



ideal transformer  $i_2(t) = I_0 + I_1 \cos \omega t + I_2 \cos 2\omega t + \dots$   
 dc                      fundamental      2nd Harmonic

# JFET Limiter



Relative Gain

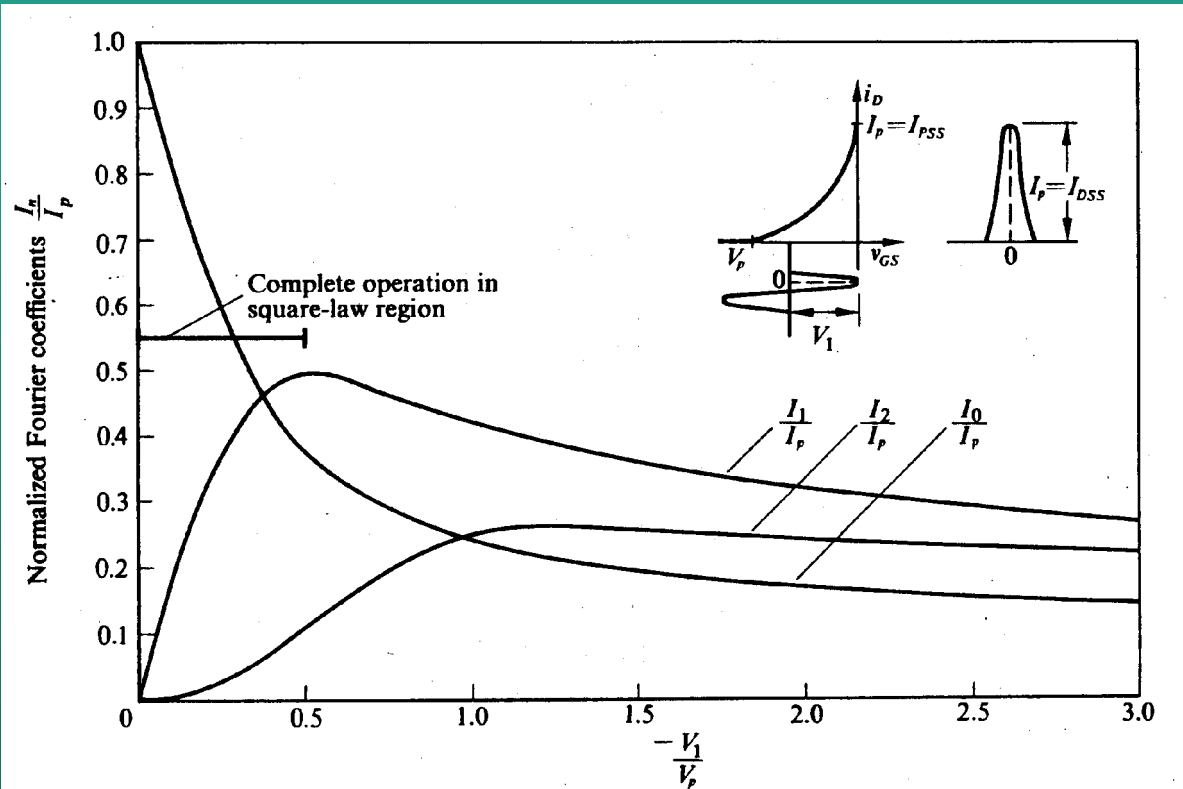
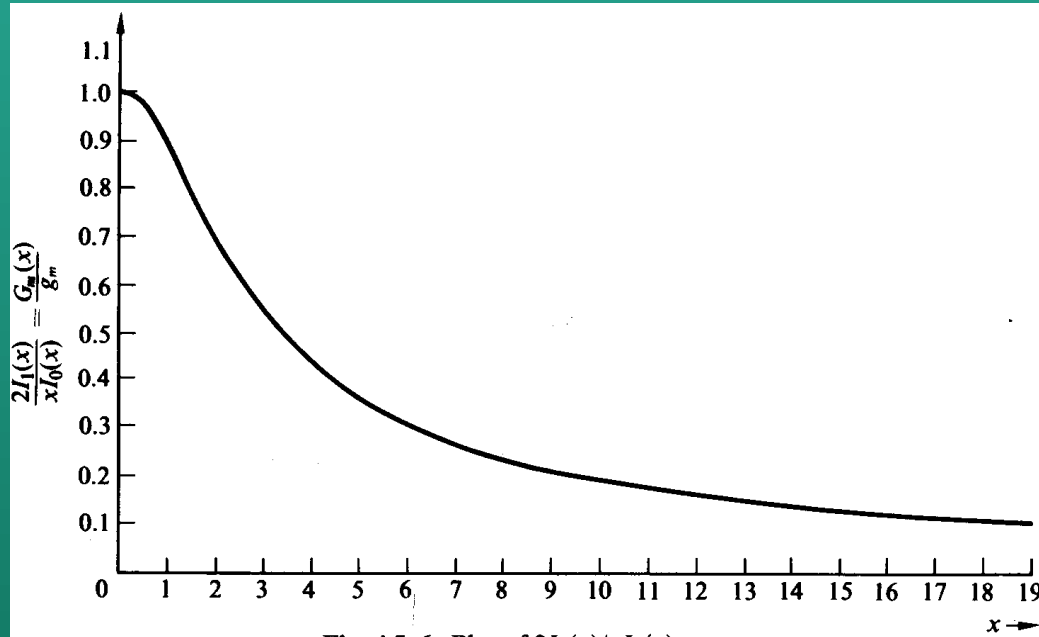


Fig. 4.9-3 Plot of  $I_n/I_p$  vs.  $V_1/V_p$  for a peak-clamped sine-wave drive to a half-square-law amplifier ( $n = 0, 1, 2$ ).

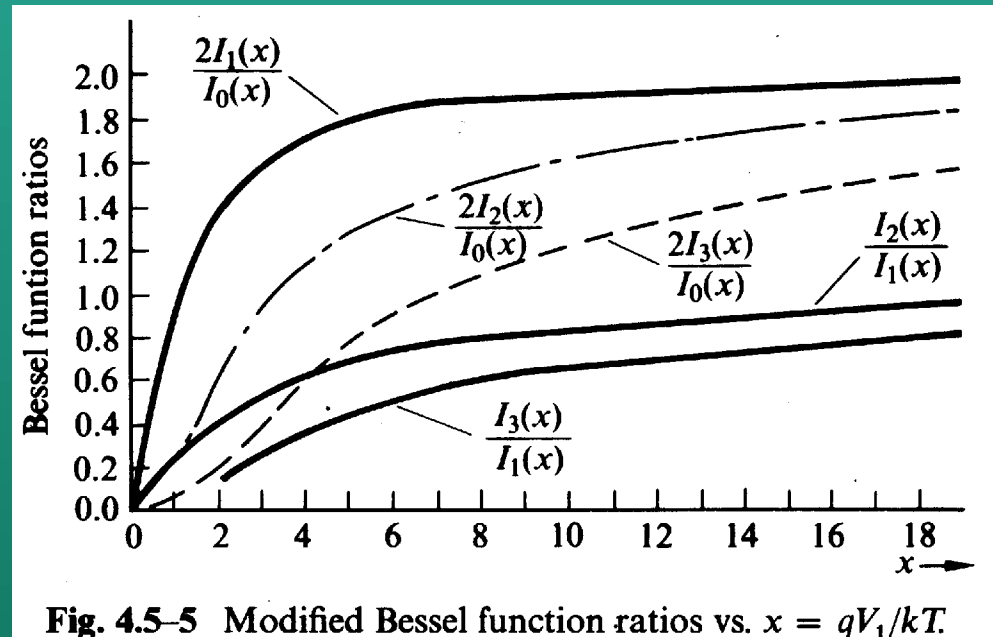
Output Level

Output level depends on  $I_{DSS}$  of the individual JFET, which is poorly specified.

# Bipolar Transistor Limiter, Constant Average Current



Relative Gain



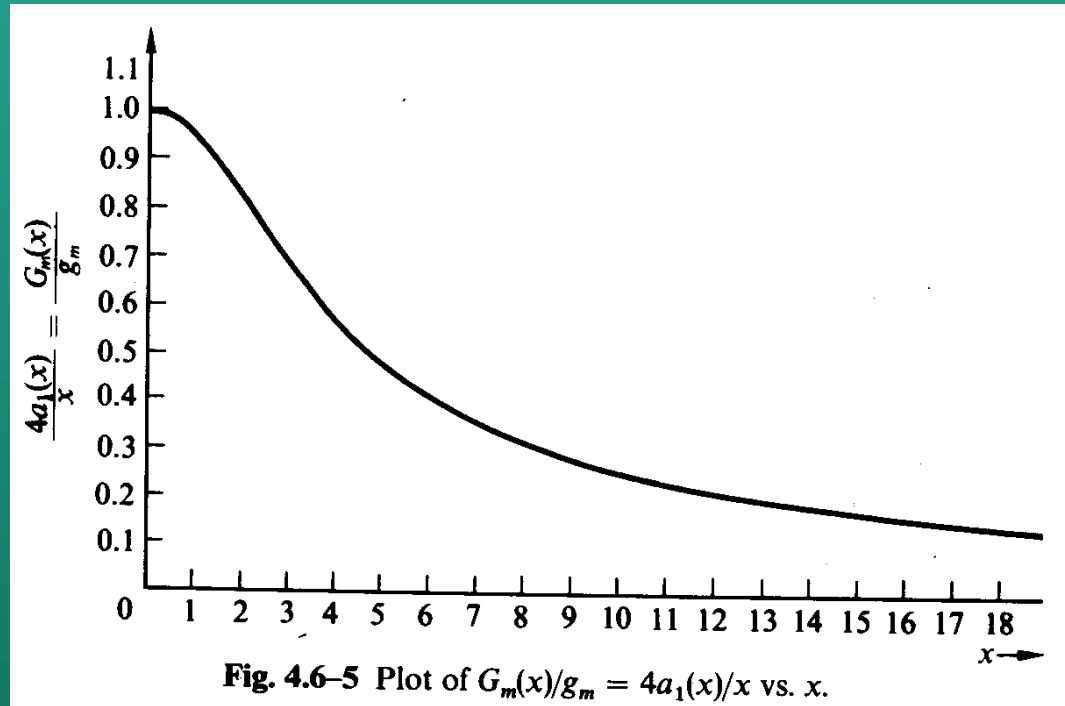
Output Level

$X=26\text{mV}$  peak

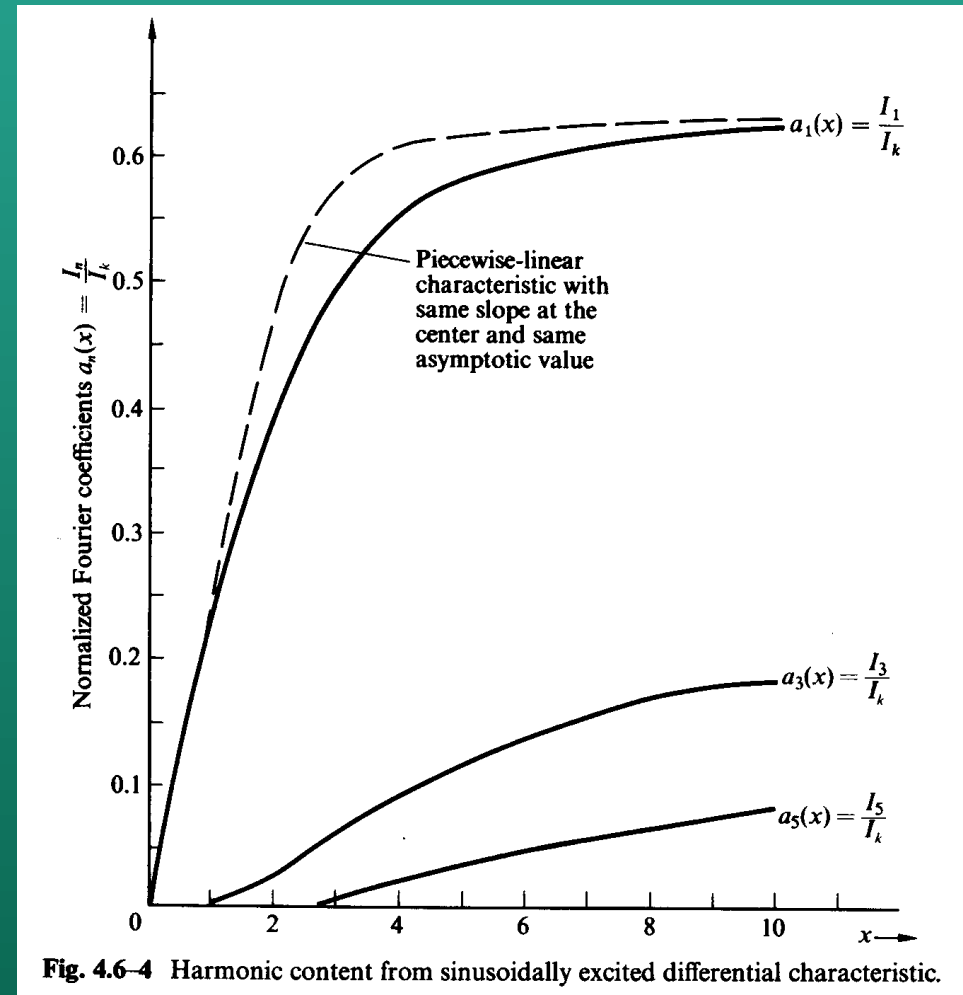
Gain falls to half at  $x=3.5$  or  $91\text{ mV}$  peak

Output level limits at twice the bias current

# BJT Differential Amplifier Limiter



Relative Gain



Output Level

$X=26\text{mV}$  just as in single BJT limiter

Output limits at  $0.636 \times$  tail current  
Note NO even harmonics in output

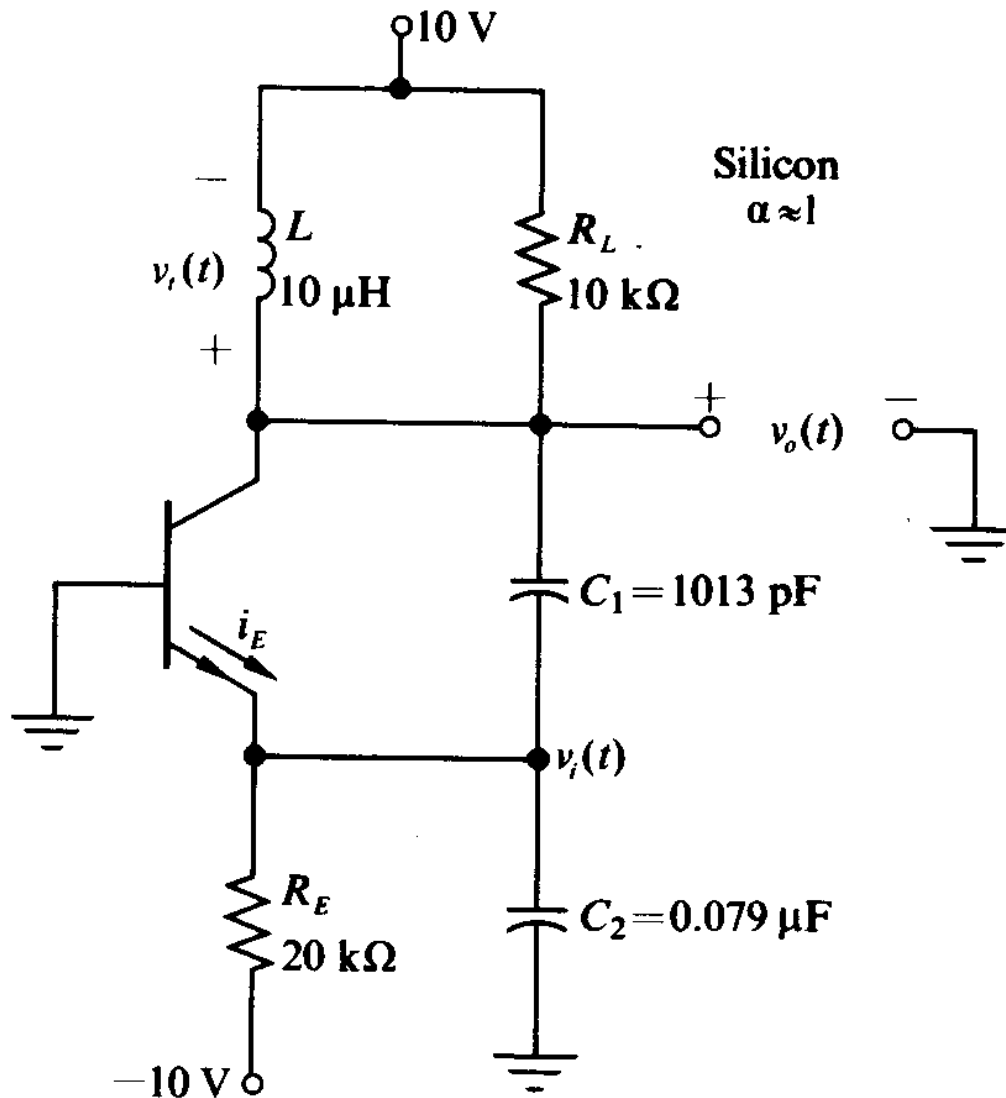
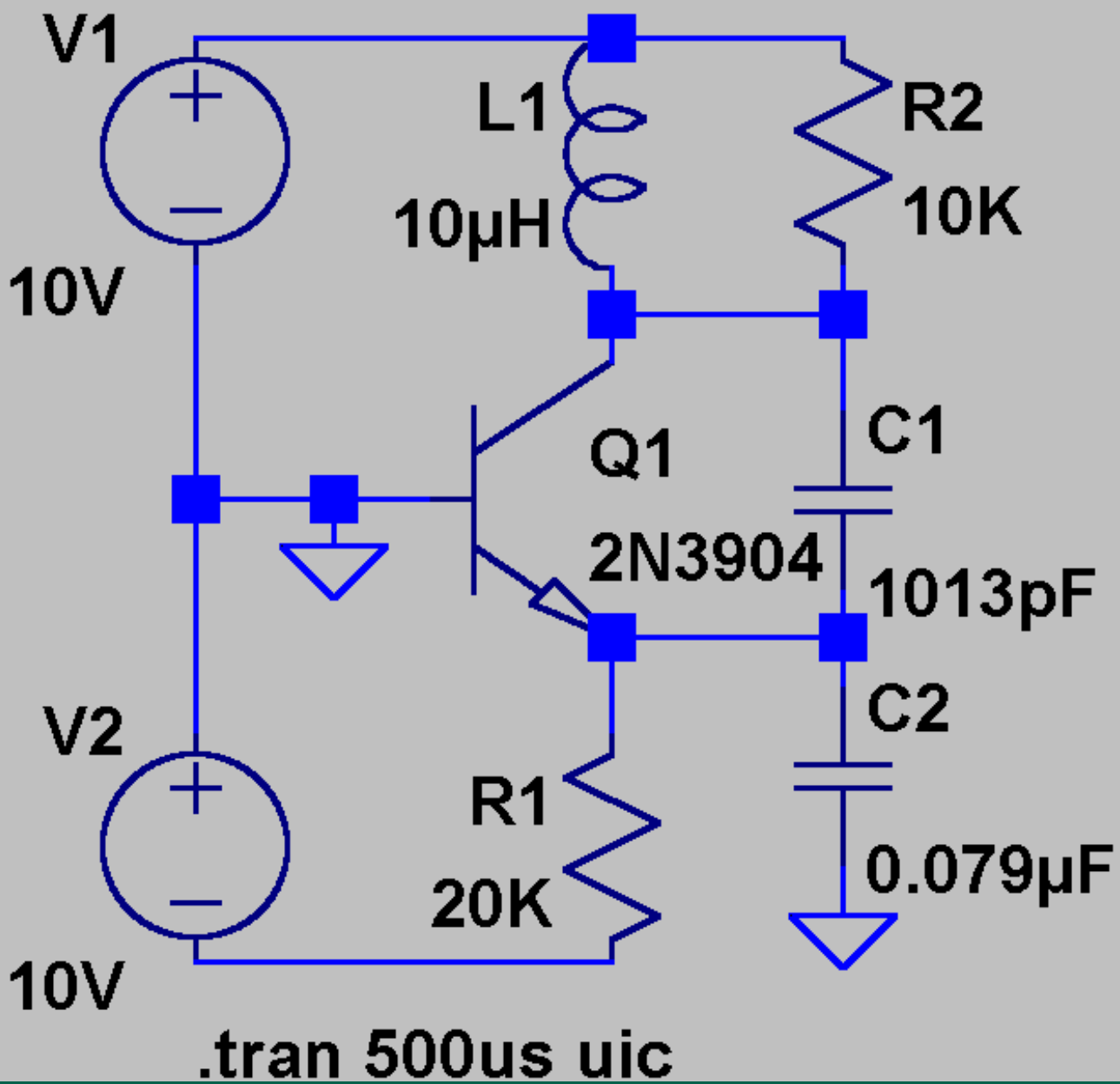
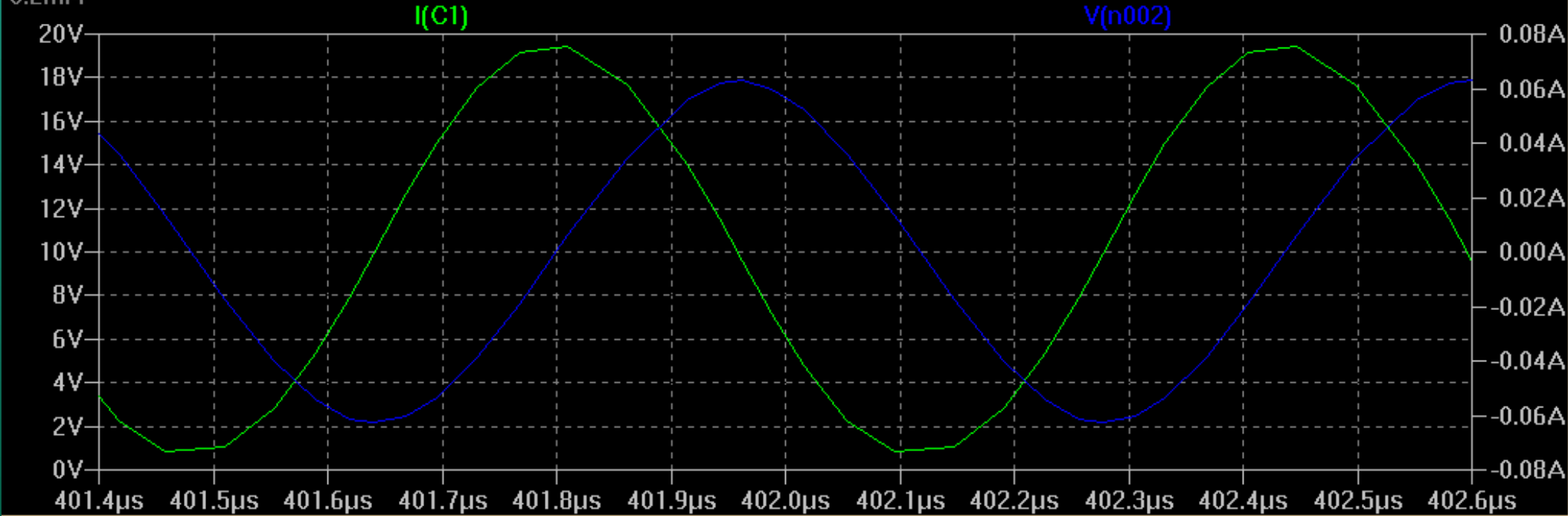
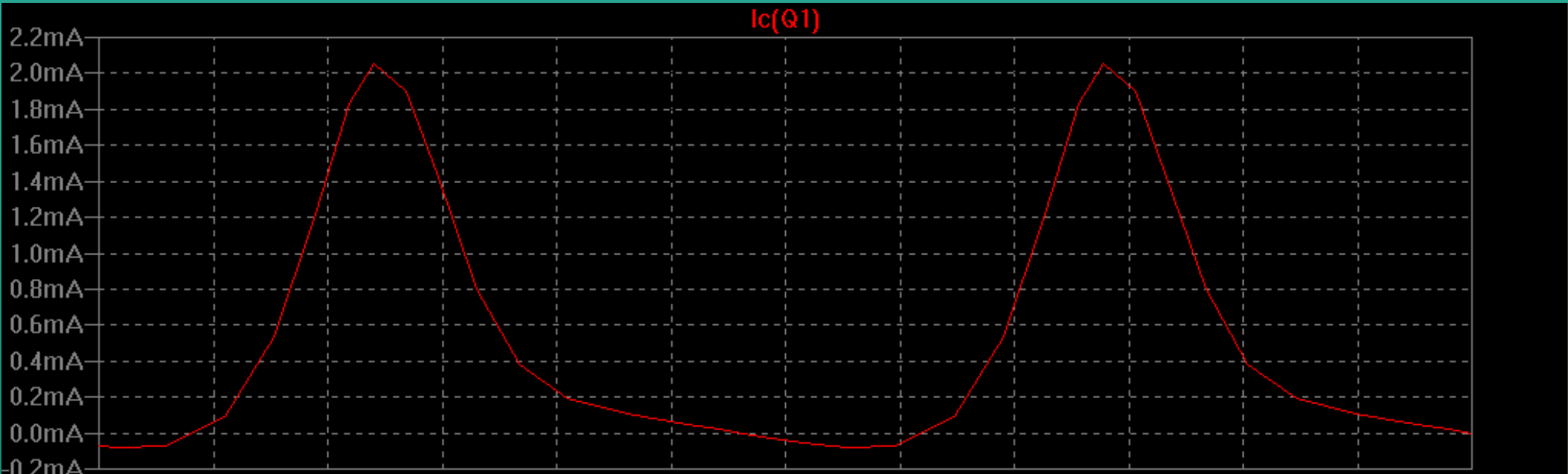
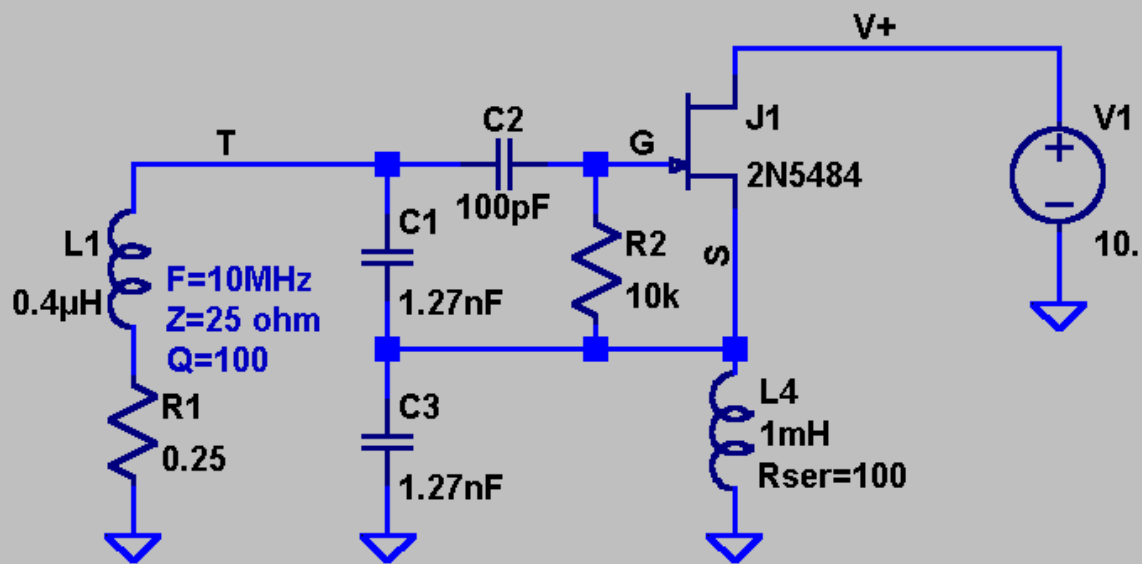
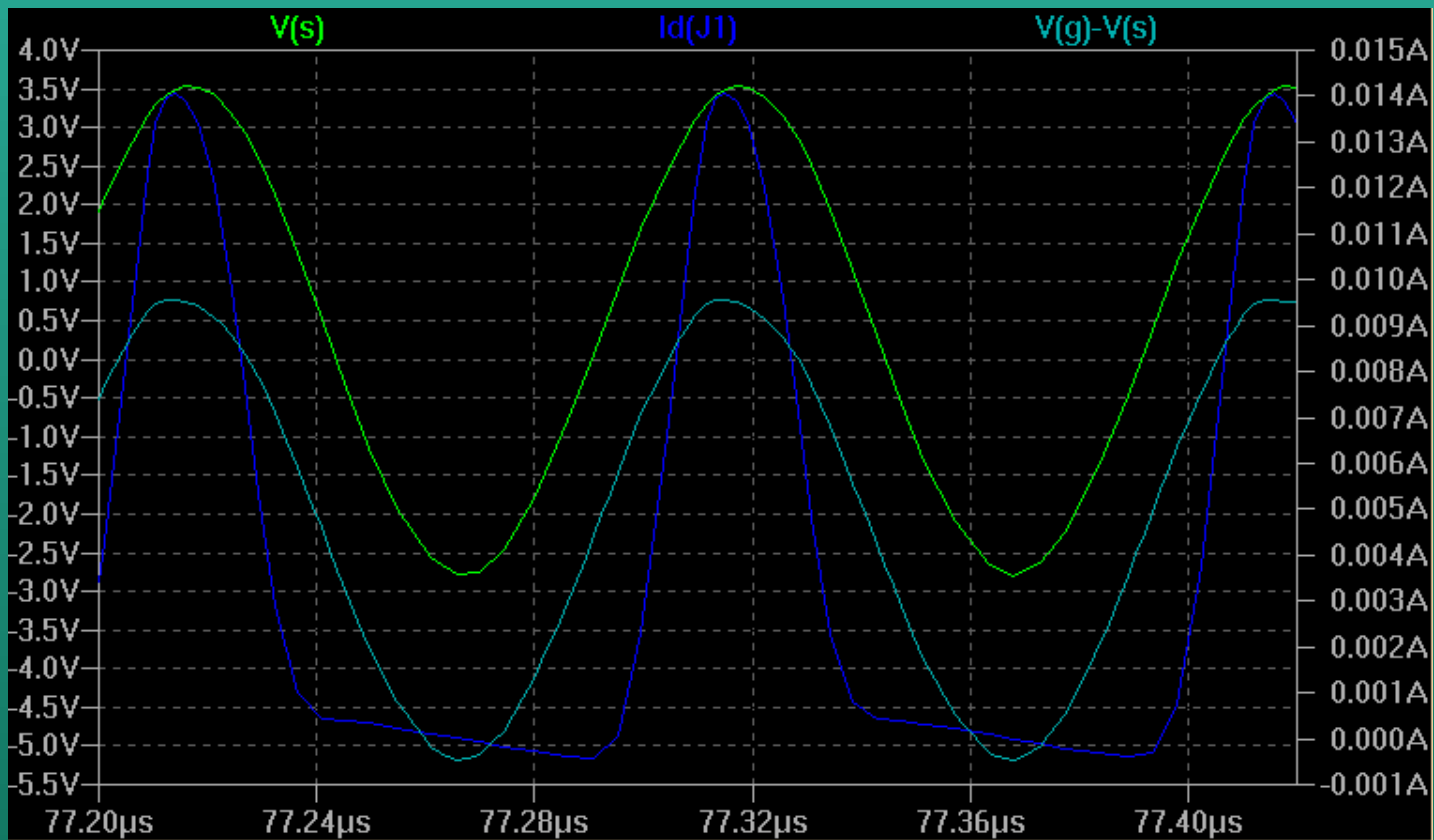


Figure 6.4-5

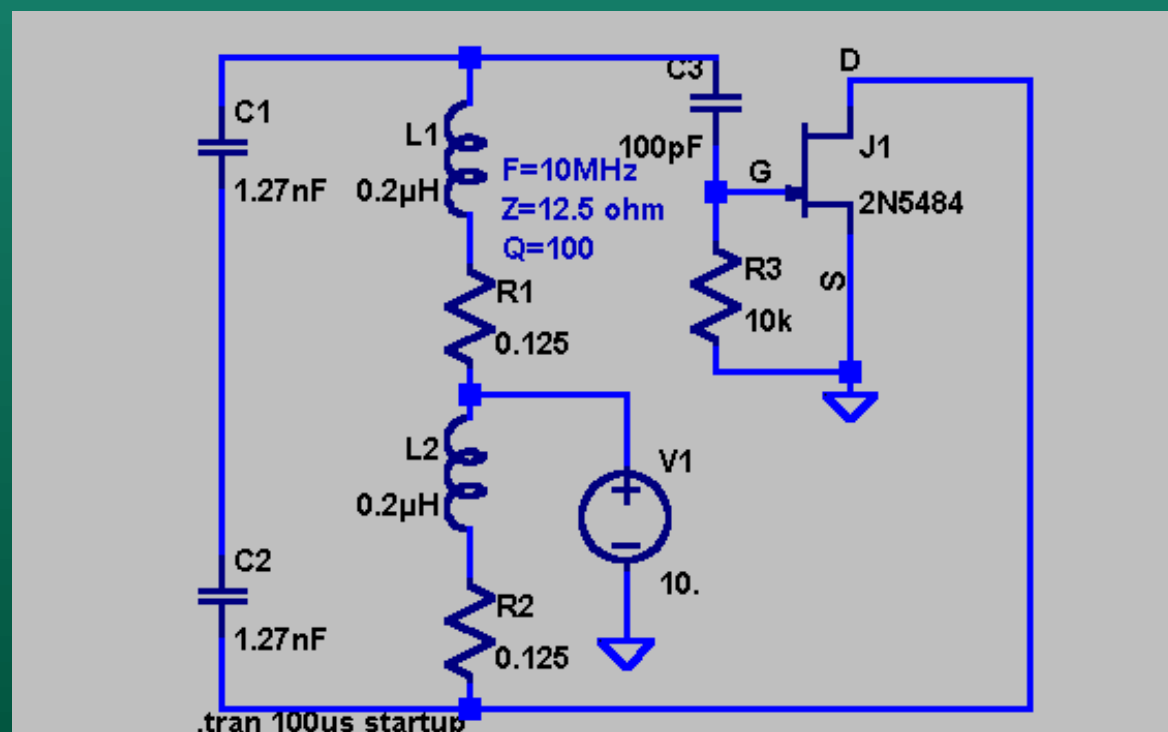
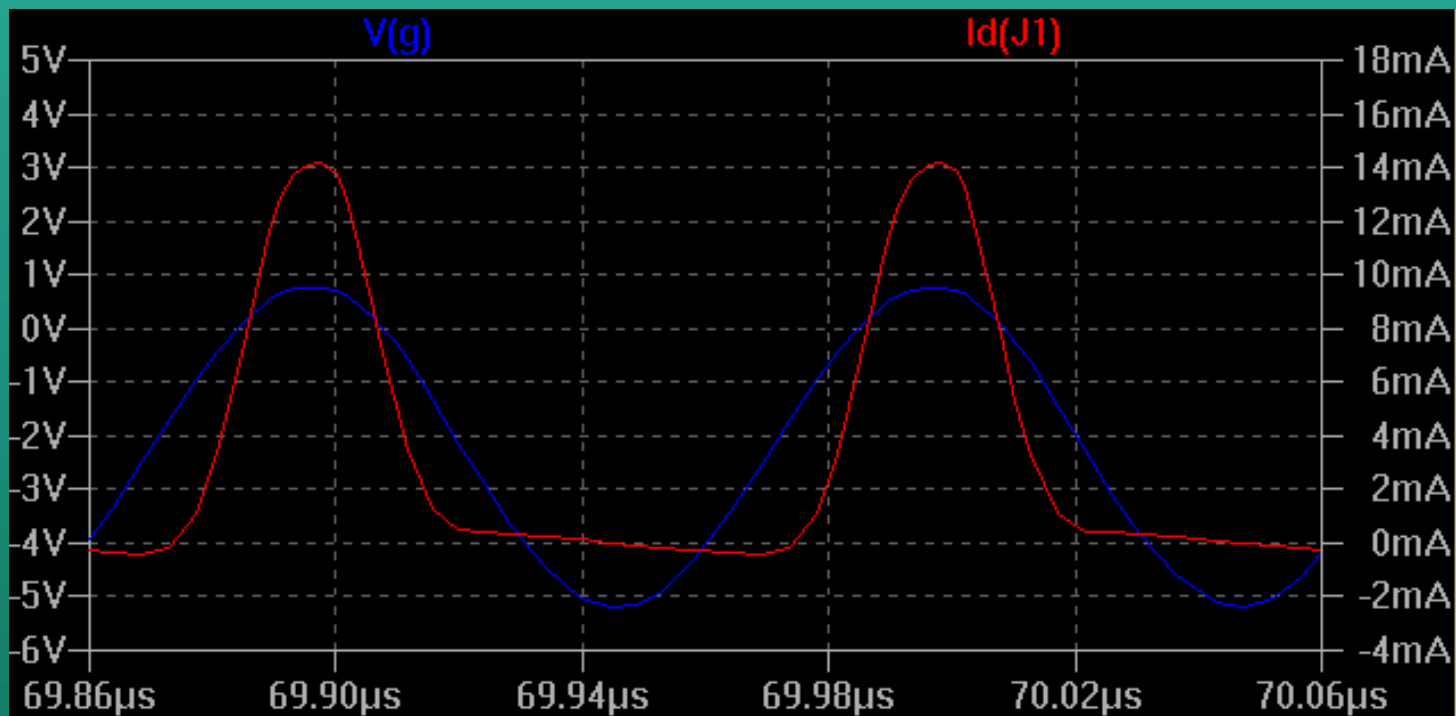
BJT Oscillator Example  
 Clarke-Hess p. 226







.tran 100u startup



## Summary

- 1) Design a good stable high-Q resonator
- 2) Choose a limiting amplifier  
Hint - use a BJT differential amplifier
- 3) Tap down on the resonator to match the chosen amplifier  
Hint - use link coupling to save need for RF choke.
- 4) Choose an output buffer amplifier  
Hint - use one or more grounded-base stages, no overall feedback

## For low phase noise

- 1) High Q
- 2) High power
- 3) Low noise limiter amplifier  
Hint - use local emitter degeneration for each BJT