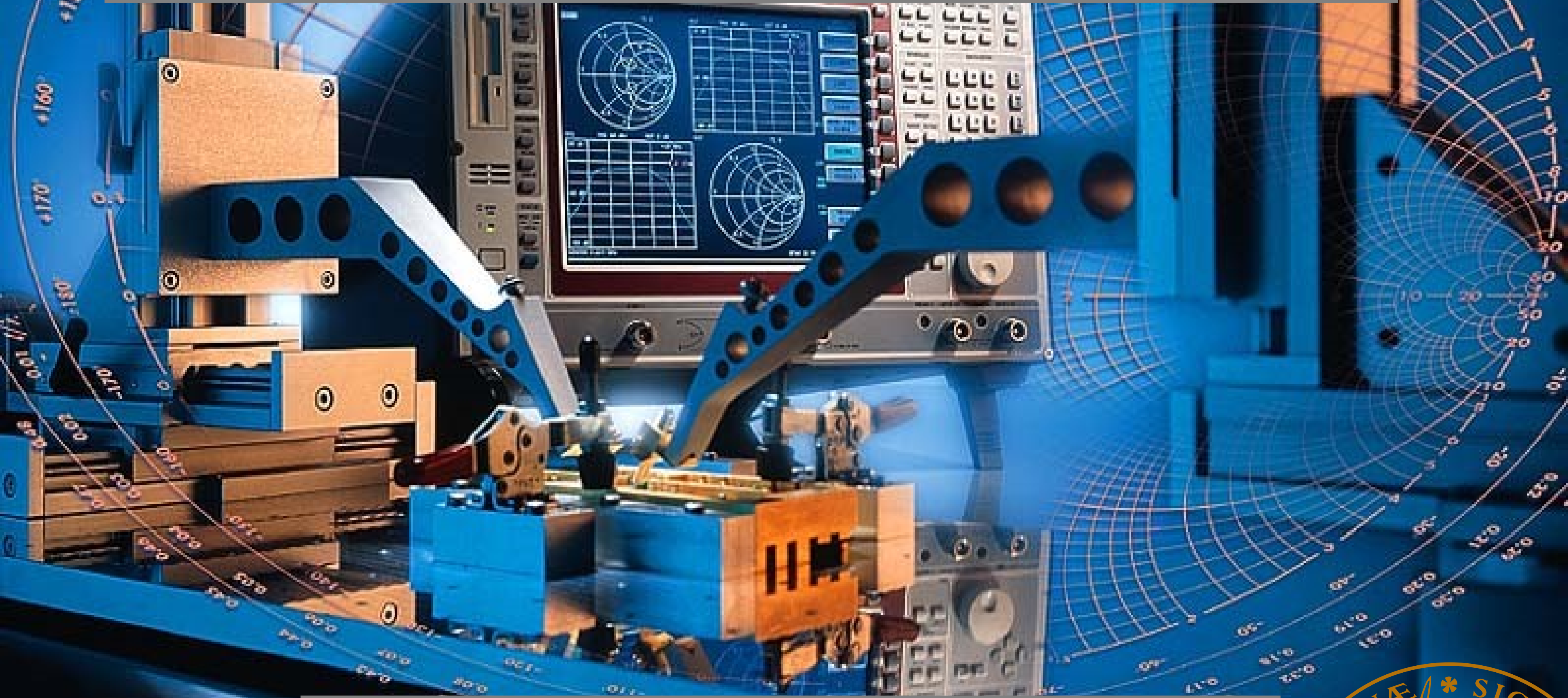
Lecture 8

2019-12-02

RF Amplifier Design



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Schedule Reminder

- Hand-in 2: Friday, Dec 6, 23:59
  - Matching and bias design for an LNA
  - …to be validated in laboratory session 3
- Hand-in 1: with Hand-in 2
  - Revise according to feedback from supervisor
  - Re-submit corrected version
- Lab 3: Thursday, Dec 12, 8:15-12:00
  - Amplifier, IF and RF, characterisation

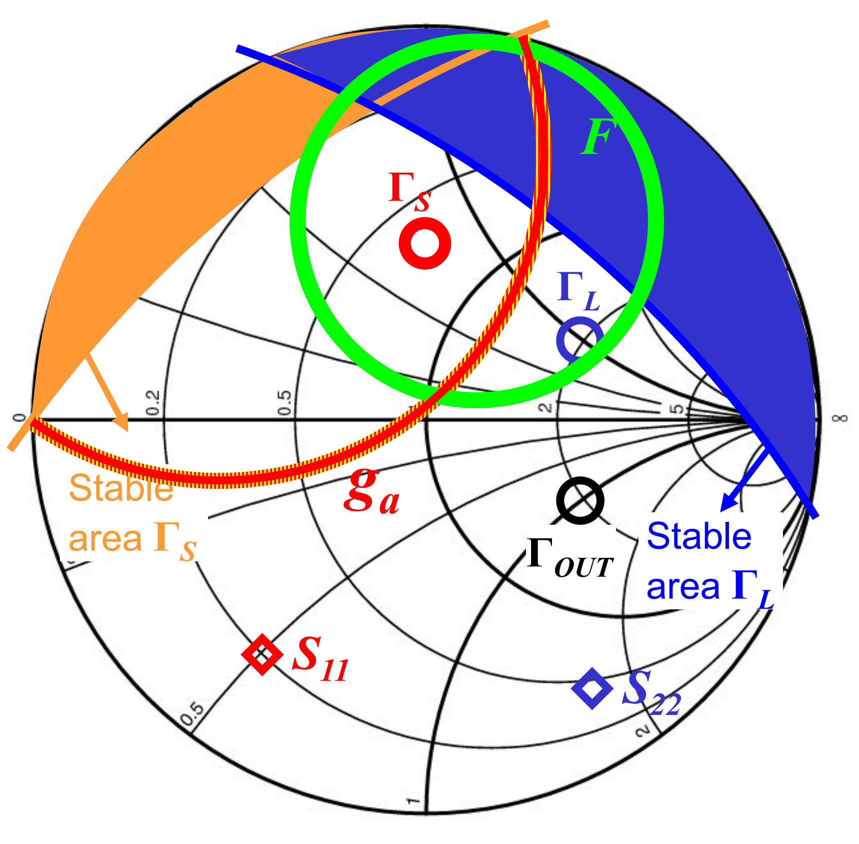
Lecture 8

- Amplifier Design
  - Summary of Design Methods
  - Transistor Biasing
    - Voltage and Current Drive of Bipolar Transistors
    - Temperature Dependence
  - Passive Biasing Circuits
  - Active Biasing Circuits
  - Biasing of Field Effect Transistors
  - Isolating the Bias Design from Signal Designs

Summary of Amplifier Design Methods

Specific G_T and F

1. Decide if the transistor is unconditionally stable or not
2. Calculate stability circles if the transistor is conditionally stable
3. Choose the design method for specific gain
4. Assume that conjugate match will be applied at the output
5. Calculate and draw the gain circle ($g_a < G_{MSG}$) and noise circle (F)
6. Select a Γ_S in the stable area that provides a suitable compromise between gain and noise figure
7. Calculate Γ_{OUT} regarding the selected Γ_S
8. Calculate $\Gamma_L = \Gamma_{OUT}$* and check for stability
9. Design the matching networks and verify stability for all frequencies of interest
10. Design the biasing circuits for proper DC settings of the transistor



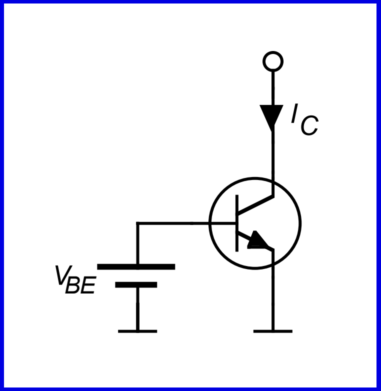
Bipolar Junction Transistor (BJT) Biasing

- How is the bias setting specified?
  - collector current I_C and
    collector-emitter voltage V_{CE} for BJT
    (I_D and V_{DS} for FET)

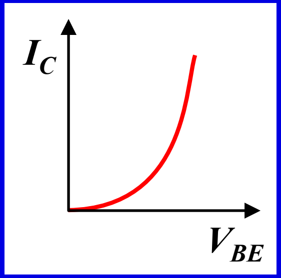
- Why controlling the biasing?
  - S-parameters or similar are only valid at a specific operating point (small signal parameters)
  - temperature essentially controls the properties of the transistor

Voltage or Current Drive of the Transistor

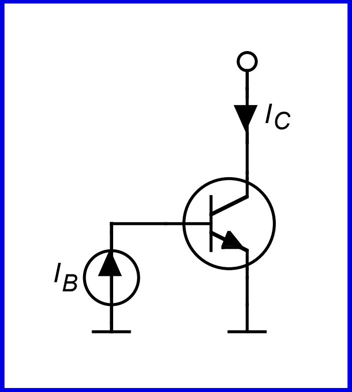
- Voltage drive:



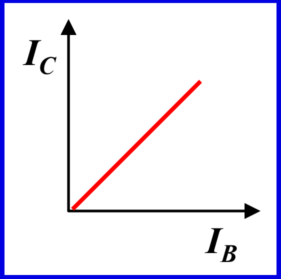
The collector current increase exponentially wrt the base voltage



- Current drive:



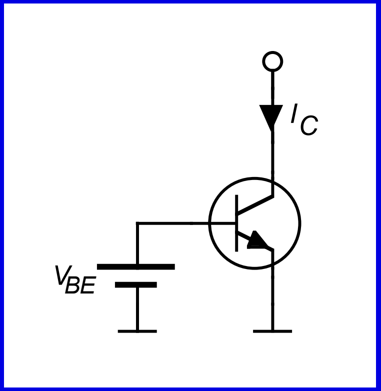
The collector current depends linearly wrt the base current



Voltage Drive of Bipolar Transistors

- Simplified relationship:

$$I_C = I_S\left[\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right] \approx$$
$$\approx I_S \exp\left(\frac{V_{BE}}{V_T}\right) \text{ if } V_{BE} > V_T$$



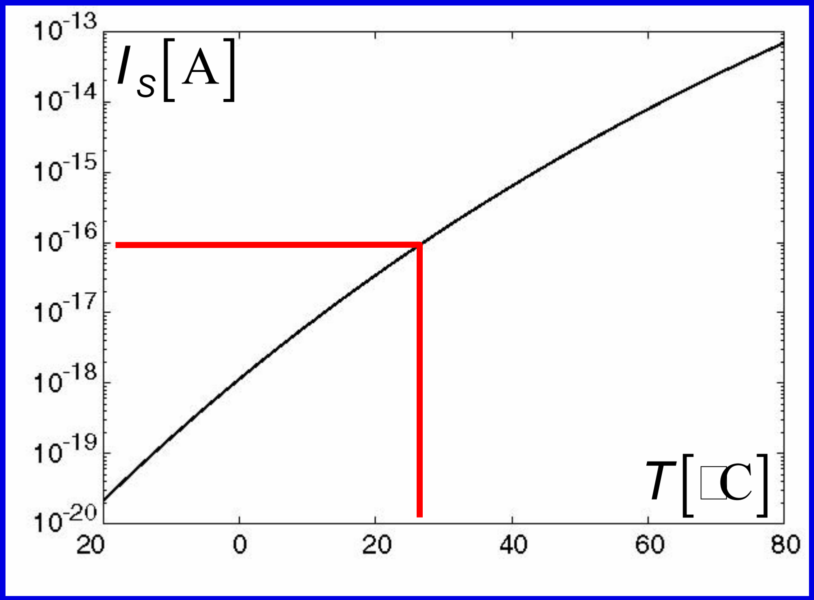
  – where the thermal voltage $V_T = kT/q \approx 25 \text{ mV}$ at $T = T_0 = 290 \text{ K}$

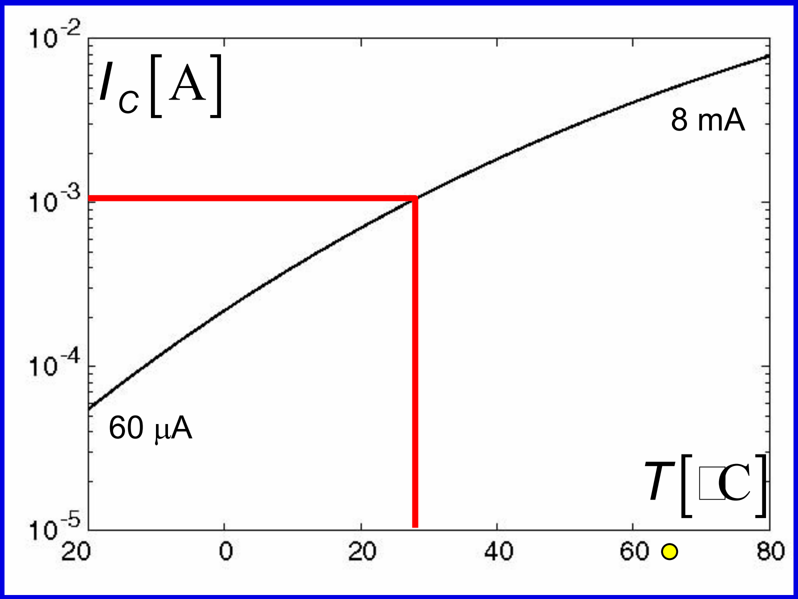
    - k = Boltzmann's constant = $1.38 \cdot 10^{-23}$ [J/K]
    - T = absolute temperature [K]
    - q = charge of the electron = $1.6 \cdot 10^{-19}$ [C]

  – base emitter drive is often about 0.7 V (Si BJT) in active operation

- The saturation current I_S varies between different transistors
- V_T and I_S are both temperature dependent

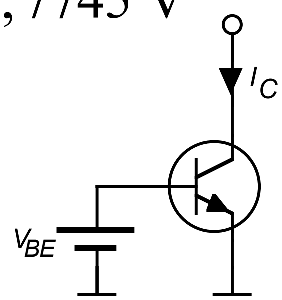
Temperature Dependence at Voltage Driven Biasing





- Example:
  Calculate the collector current at constant V_{BE}

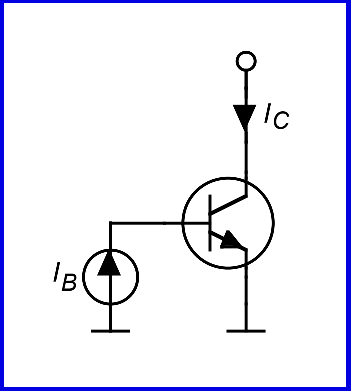
$$V_{BE} = 0,7745 \text{ V}$$



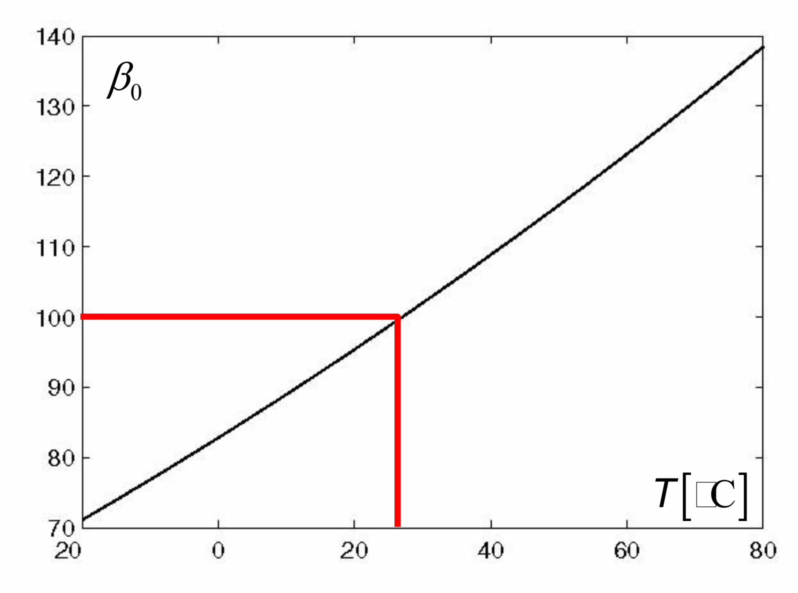
$$I_C \approx I_S \exp\left(\frac{V_{BE}}{V_T}\right) = = 1 \text{ mA at } T = 290 \text{ K}$$

-20℃ to 80℃ is a standard temp. range for a commercial design

Temperature Dependence at Current Driven Biasing



$$I_C = \beta_0 I_B$$

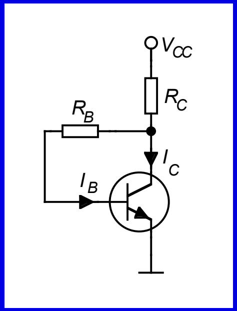


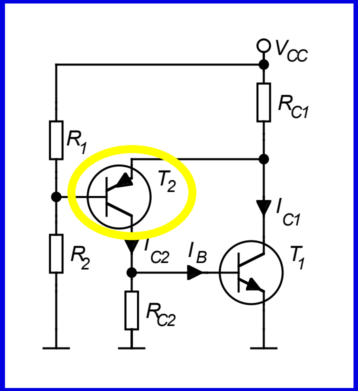
The sensitivity of current driven biasing is considerably ”friendlier” as compared to voltage driven biasing. Current changes, from -20 to 80 C, with a factor of **2** (current drive) compared to **130** (voltage drive)!

Controlling the Operating Point

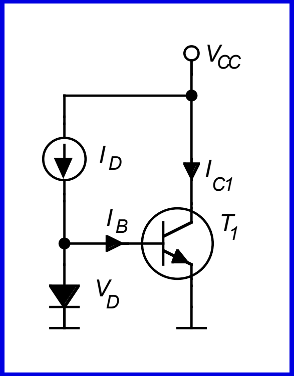
- The operating point needs to be controlled to avoid thermal runaway effect that might destroy the device

- Three common methods to implement the feedback:
  - passive current or voltage driven biasing





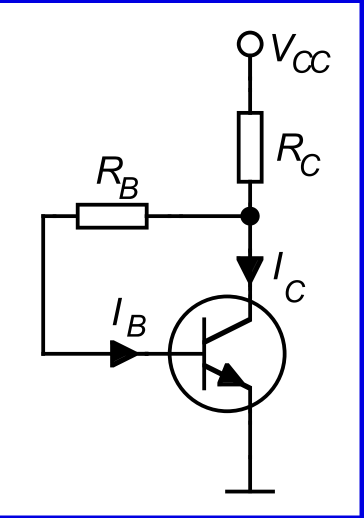
  - active biasing
  - thermal feedback



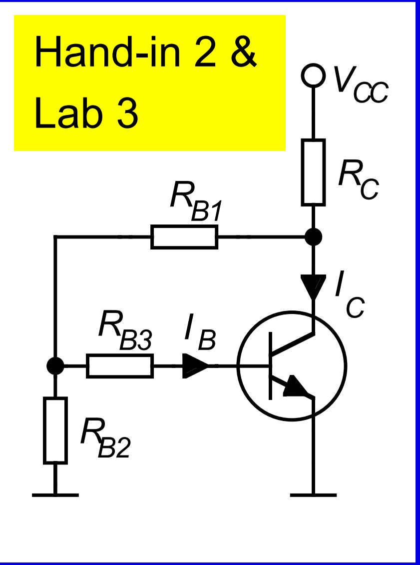
Gain with negative feedback, $A_f = A_v/(1 + A_v\beta)$, where A_v is the forward gain and β denotes the feedback factor, producing the loop gain $A_v\beta$.

Current Driven Biasing

- The simplest circuitry:
  - Moderate temperature dependency
  - Sensitive to variations in the current gain, β_0
  - Requires large resistance values
  - Loop gain: $\frac{\beta_0 R_C}{R_B}$
  - Large loop gain if the ratio V_{CC} / V_{CE} is large

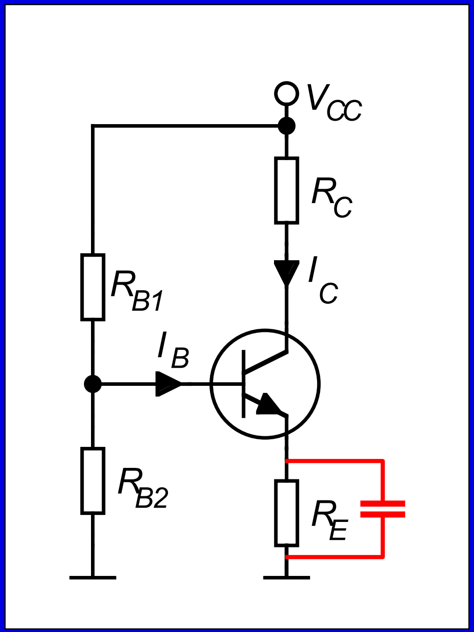


- Alternative circuit solution:
  - Not strictly current driven
  - Moderate temperature dependency
  - Less sensitive to variations in the current gain
  - Does not require large resistance values
  - Loop gain : $\frac{\beta_0 R_C}{R_{B3}} \frac{R_{B2}}{R_{B1} + R_{B2}}$
  - Large loop gain if the ratio V_{CC} / V_{CE} is large



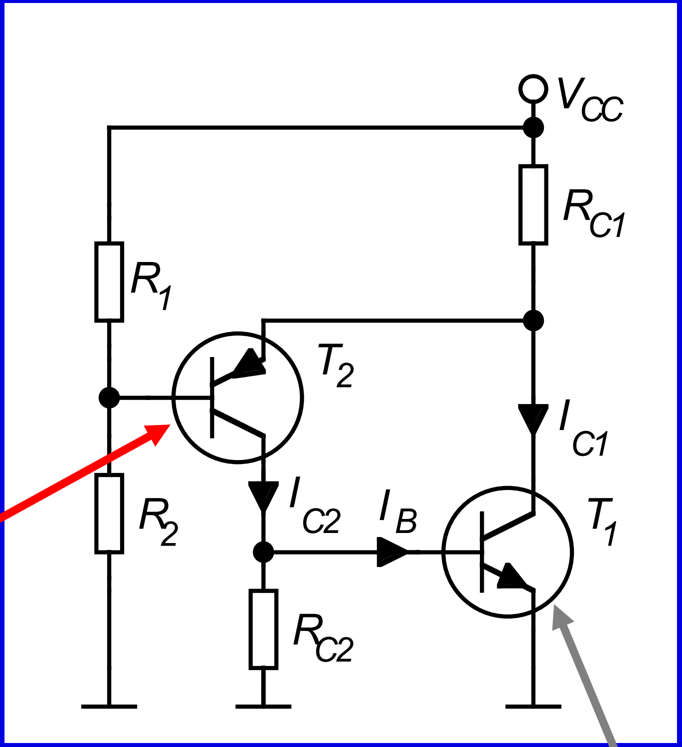
Voltage Driven Biasing

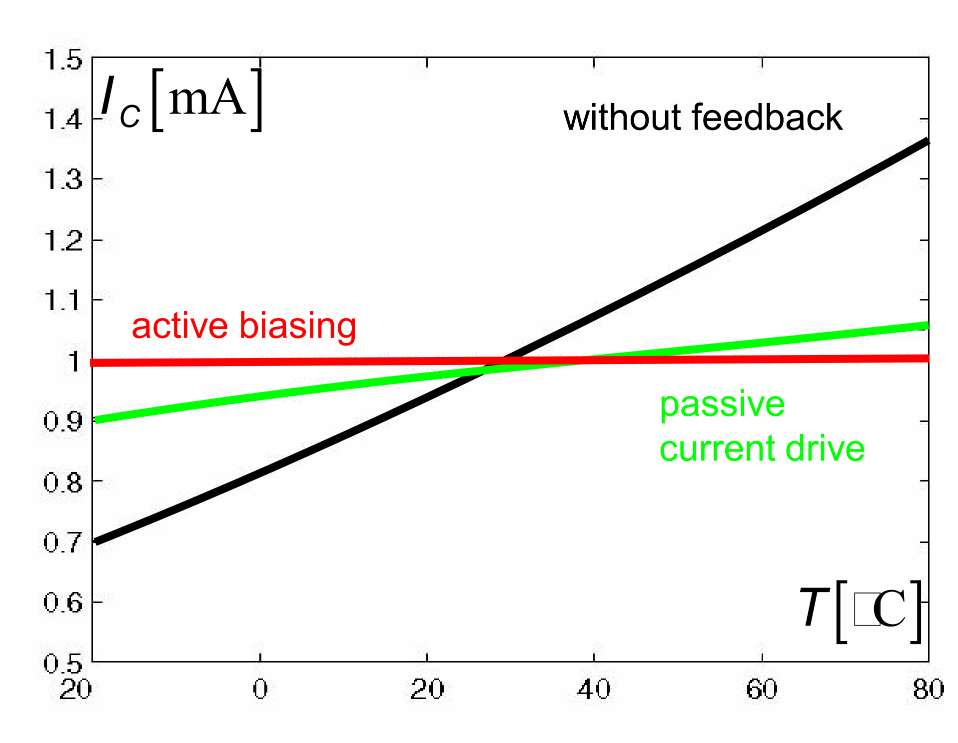
- Series feedback
- Decent temperature dependence
- Not sensitive to variations in the current gain
- R_C may be replaced with an RFC*
- Loop gain: $g_m \cdot R_E$
- Not suitable at high frequencies
  - due to difficulties to signal ground the emitter without introducing stability problems



*RFC = Radio-Frequency Choke, a large reactance coil intended for high frequencies

Example of Active Biasing Circuit

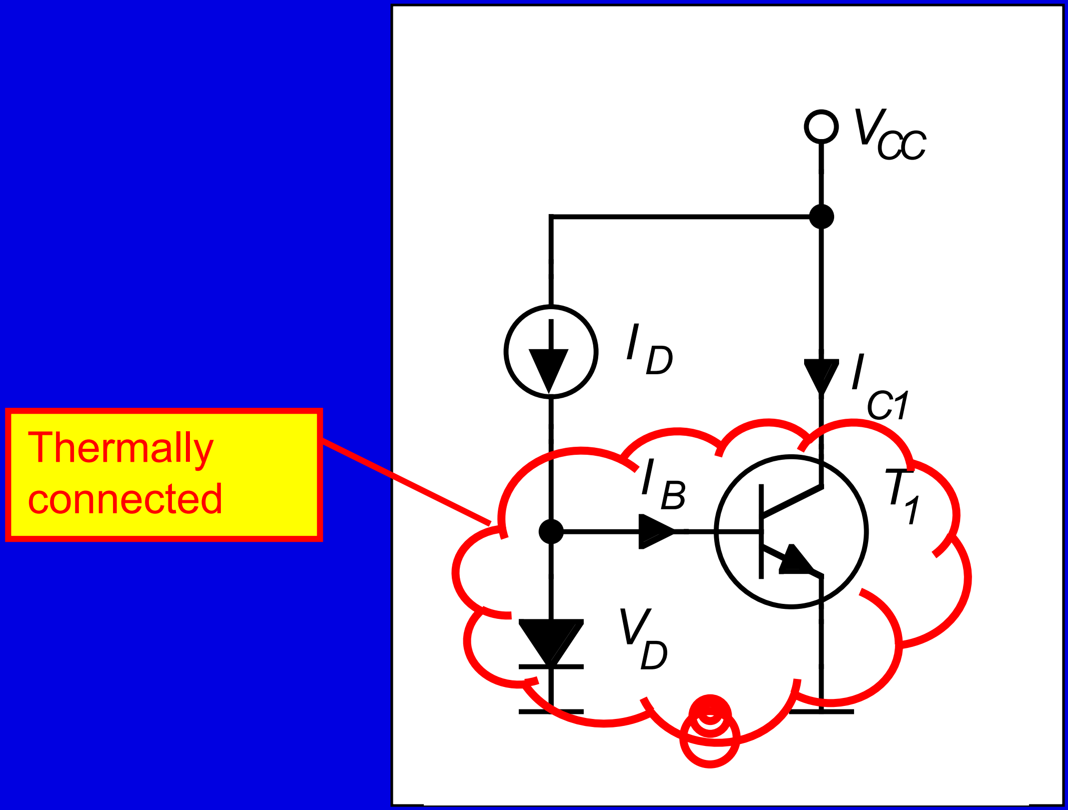




T_2: low frequency transistor working as current generator

T_1: high frequency transistor

Control by Thermal Feedback



The diode V_D is thermally connected to the transistor

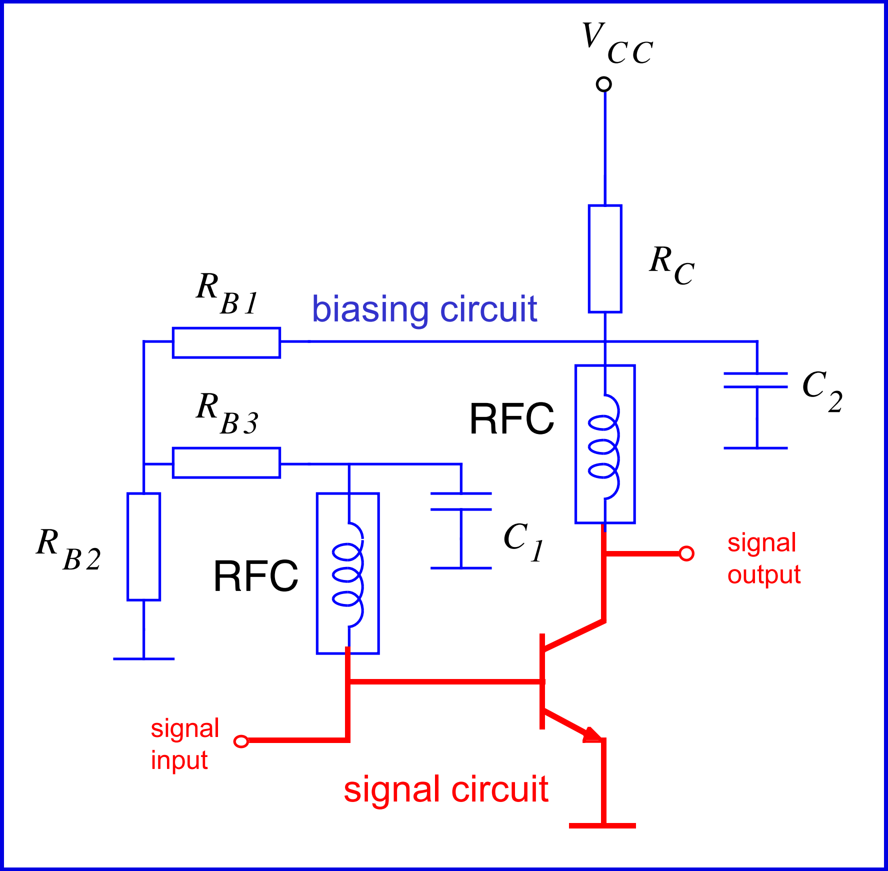
Good in PAs etc. where high currents heat it up

Biasing of Field Effect Transistors (FETs)

- The FET shows a slight temperature dependence compared to the BJT
- Large spreading in the threshold voltage compared to the BJT
- Only voltage driven biasing possible
- Passive biasing circuits are not usable if there is a large variation in the threshold voltage

Isolating the Bias Design from the Signal Design

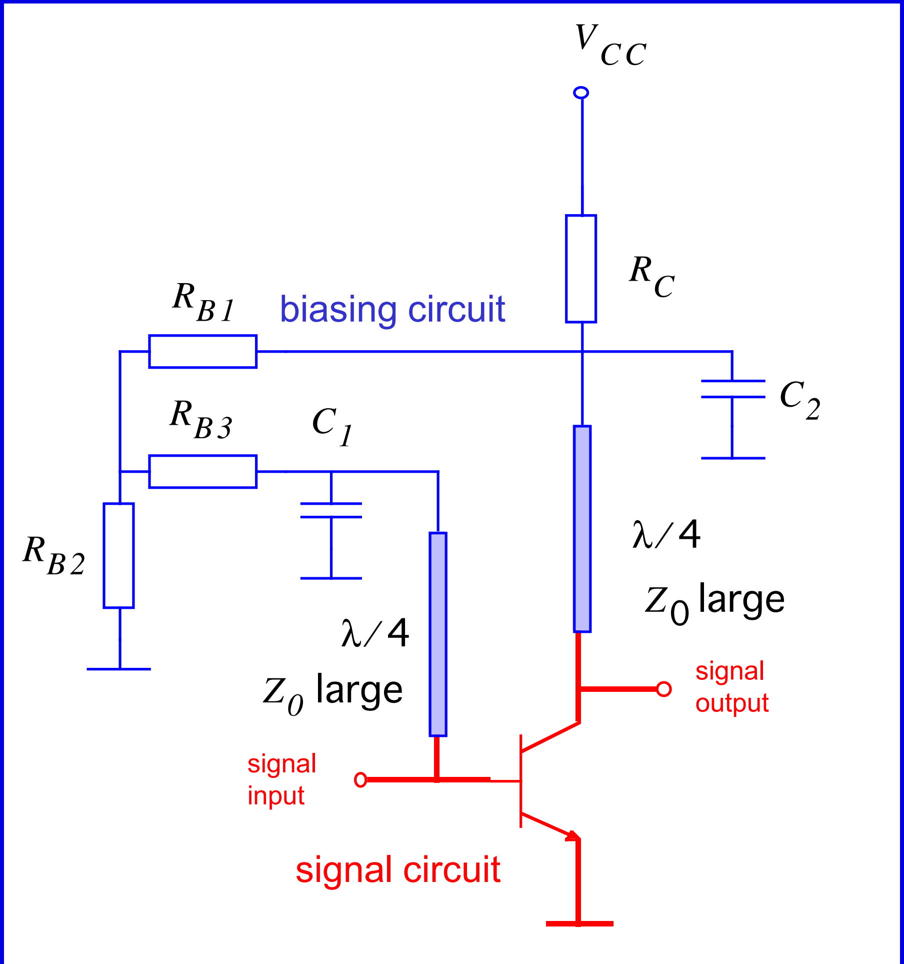
Example using RFC's



RFC = Radio-Frequency Choke
may be used up to medium high frequencies

Isolating the Bias Design from the Signal Design

Example using stubs



At high frequencies the RFC's are replaced with line elements

Lab 3 – RF amplifier