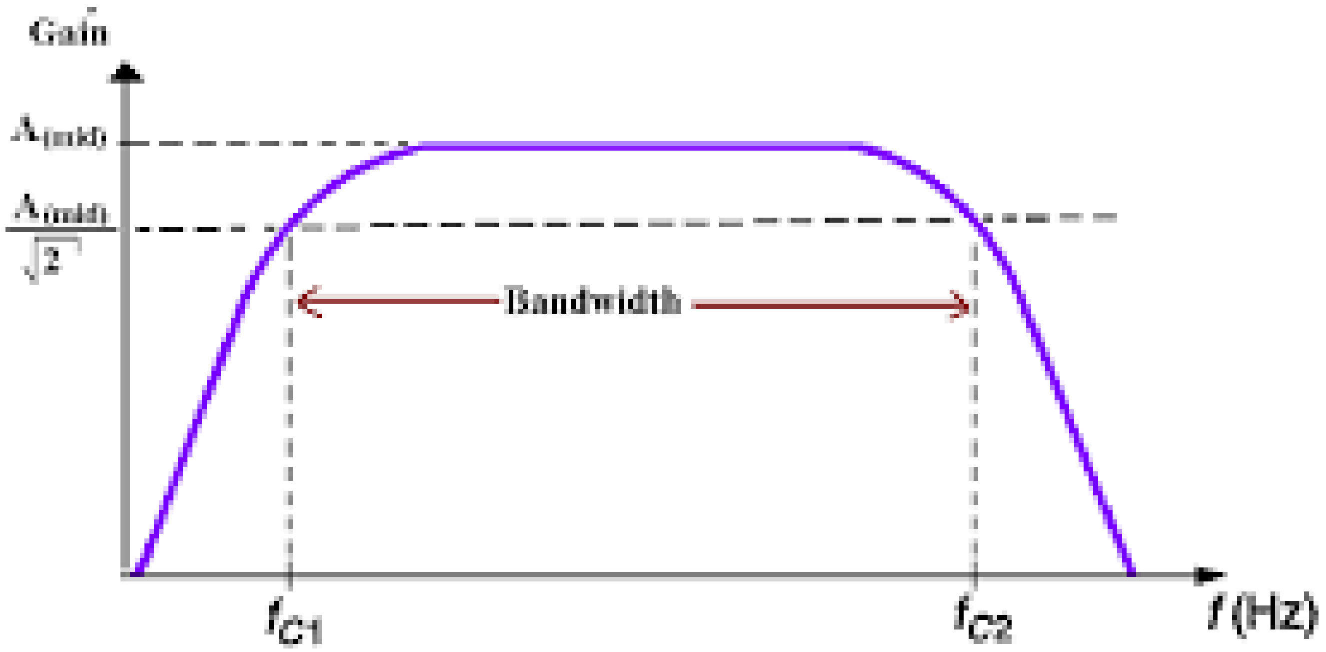
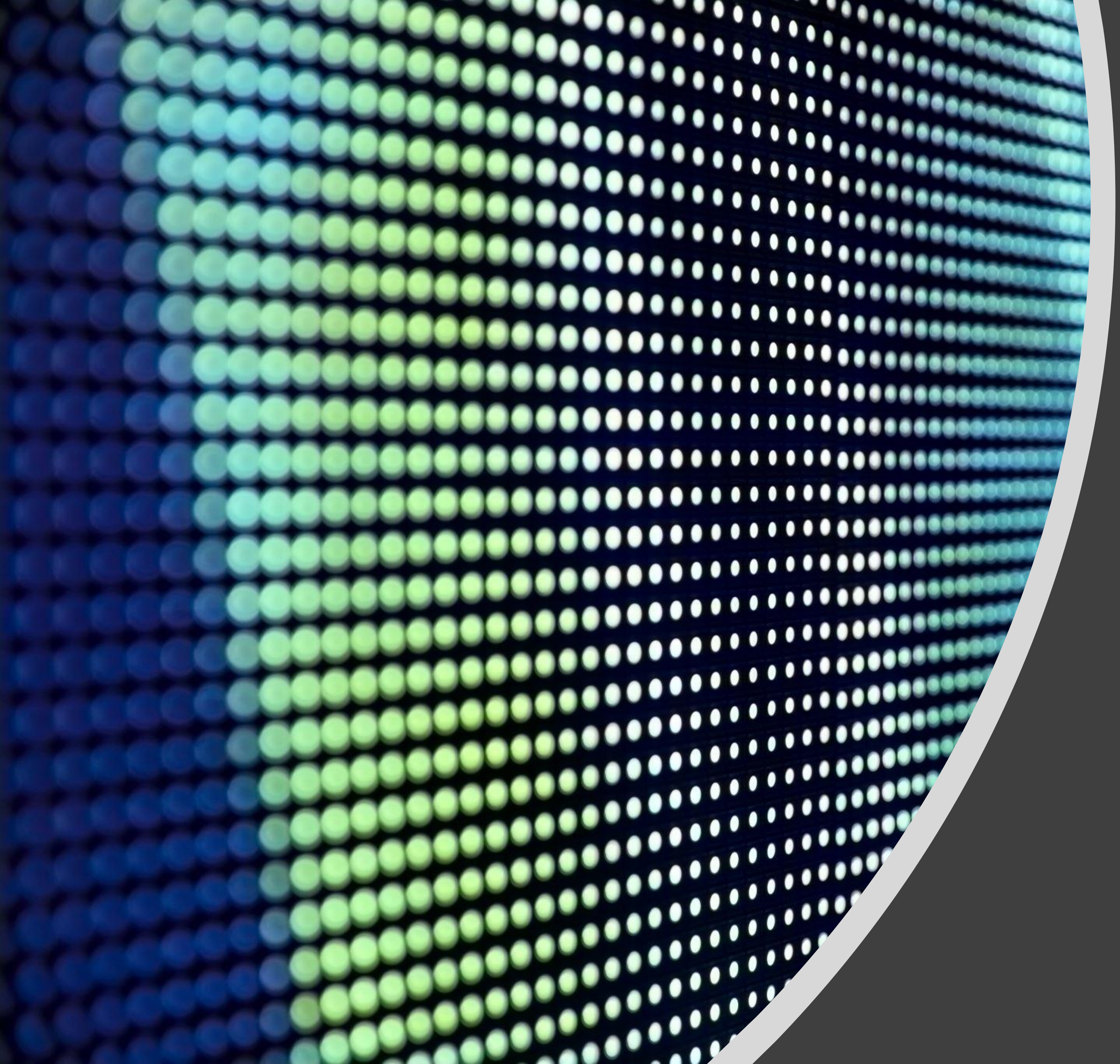
Electronic Circuits (1) EEC2103

LEC (5) BJT Frequency Response

Dr. Nancy Alshaer





Decibel

Logarithms and Linear Scale

- If you hear a sound of a certain loudness (volume or power), and then are asked to choose a sound that is twice as loud as the first sound.
- The sound you choose will in fact be about ten times the intensity (level) of the first sound.
- For this reason, a logarithmic scale, one that goes up by powers of ten, is used to measure the loudness of a sound.

What is a decibel?

- A decibel (dB) is a unit for comparing the loudness of two different sounds; it is not a unit of absolute measurement.

- Generally, dB expresses the ratio of one value of a physical quantity (sound, power, voltage, current) to another on a logarithmic scale.

- **The decibel (symbol: dB) is a relative unit of measurement.**

The Decibel

$$\boxed{G_{dB} = 10\log_{10}\frac{P_2}{P_1}} \quad \text{dB}$$

$$G_{dB} = 10\log_{10}\frac{P_2}{P_1} = 10\log_{10}\frac{V_2^2/R_1}{V_1^2/R_2} = 10\log_{10}\left(\frac{V_2}{V_1}\right)^2$$

Assuming $R_1=R_2$

$$\boxed{G_{dB} = 20\log_{10}\frac{V_2}{V_1}} \quad \text{dB} \qquad \textbf{(9.13)}$$

$$\boxed{G_{dBm} = 10\log_{10}\frac{P_2}{1\text{ mW}}} \quad \text{dBm}$$

For a specified terminal (output) power (P_2) there must be a reference power level (P_1). The reference level is generally accepted to be 1 mW

Mathematical Revision of Logarithms

- The exponent of a number has a relation to its logarithm: $\log_b(a) = c \iff b^c = a$
- From dB to magnitude (linear)value:
  - Power gain: $10^{\frac{G(dB)}{10}}$
  - Voltage gain: $10^{\frac{G(dB)}{20}}$
- From dBm to mwatt $\Rightarrow 10^{\frac{G(dBm)}{10}}$

Voltage gain versus dB levels

EXAMPLE 9.6 Find the magnitude gain corresponding to a voltage gain of 100 dB.

Solution: By Eq. (9.13),

$$G_{\text{dB}} = 20 \log_{10} \frac{V_2}{V_1} = 100 \text{ dB} \Rightarrow \log_{10} \frac{V_2}{V_1} = 5$$

so that

$$\frac{V_2}{V_1} = 10^5 = 100{,}000$$

Voltage Gain, V_o/V_i	dB Level
0.5	–6
0.707	–3
1	0
2	6
10	20
40	32
100	40
1000	60
10,000	80
etc.	

Voltage gain versus dB levels

EXAMPLE 9.7 The input power to a device is 10,000 W at a voltage of 1000 V. The output power is 500 W and the output impedance is 20 Ω.

a. Find the power gain in decibels.
b. Find the voltage gain in decibels.
c. Explain why parts (a) and (b) agree or disagree.

Solution:

a. $$G_{dB} = 10\log_{10}\frac{P_o}{P_i} = 10\log_{10}\frac{500\text{ W}}{10\text{ kW}} = 10\log_{10}\frac{1}{20} = -10\log_{10}20$$
$$= -10(1.301) = \mathbf{-13.01\ dB}$$

b. $$G_v = 20\log_{10}\frac{V_o}{V_i} = 20\log_{10}\frac{\sqrt{PR}}{1000} = 20\log_{10}\frac{\sqrt{(500\text{ W})(20\ \Omega)}}{1000\text{ V}}$$
$$= 20\log_{10}\frac{100}{1000} = 20\log_{10}\frac{1}{10} = -20\log_{10}10 = \mathbf{-20\ dB}$$

c. $$R_i = \frac{V_i^2}{P_i} = \frac{(1\text{ kV})^2}{10\text{ kW}} = \frac{10^6}{10^4} = \mathbf{100\ \Omega \neq R_o = 20\ \Omega}$$

Voltage gain versus dB levels

EXAMPLE 9.8 An amplifier rated at 40-W output is connected to a 10-Ω speaker.

a. Calculate the input power required for full power output if the power gain is 25 dB.
b. Calculate the input voltage for rated output if the amplifier voltage gain is 40 dB.

Solution:

a. Eq. (9.11): $$25 = 10\log_{10}\frac{40\text{ W}}{P_i} \Rightarrow P_i = \frac{40\text{ W}}{\text{antilog}\,(2.5)} = \frac{40\text{ W}}{3.16\times 10^2}$$

$$= \frac{40\text{ W}}{316} \cong \mathbf{126.5\ mW}$$

$10^{\frac{25}{10}}$

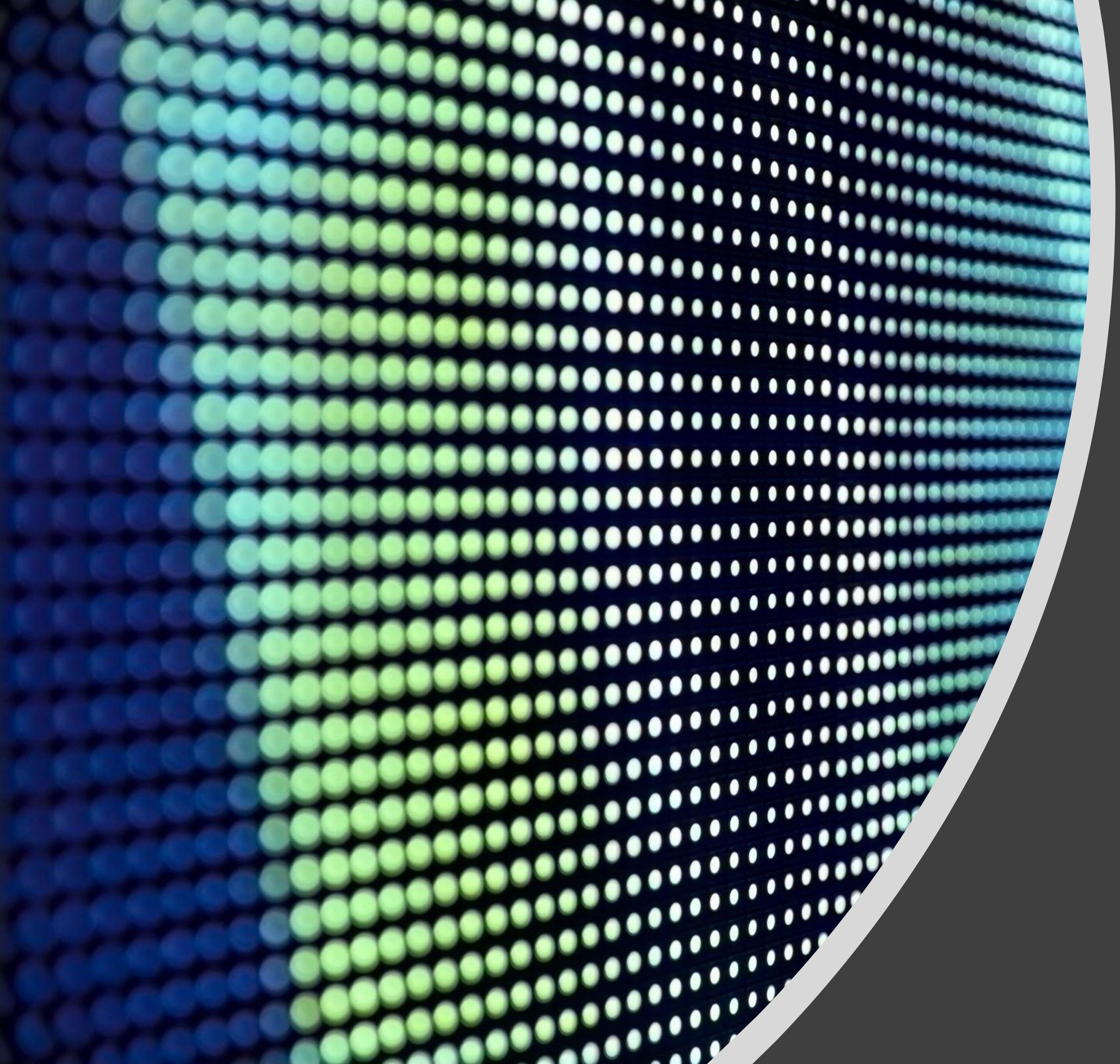
b. $$G_v = 20\log_{10}\frac{V_o}{V_i} \Rightarrow 40 = 20\log_{10}\frac{V_o}{V_i}$$

$10^{\frac{40}{20}}$

$$\frac{V_o}{V_i} = \text{antilog}\,2 = 100$$

$$V_o = \sqrt{PR} = \sqrt{(40\text{ W})(10\text{ V})} = 20\text{ V}$$

$$V_i = \frac{V_o}{100} = \frac{20\text{ V}}{100} = 0.2\text{ V} = \mathbf{200\ mV}$$



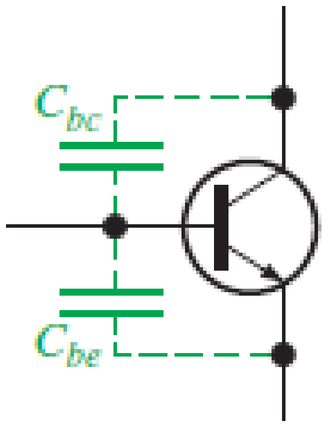
General Frequency Considerations

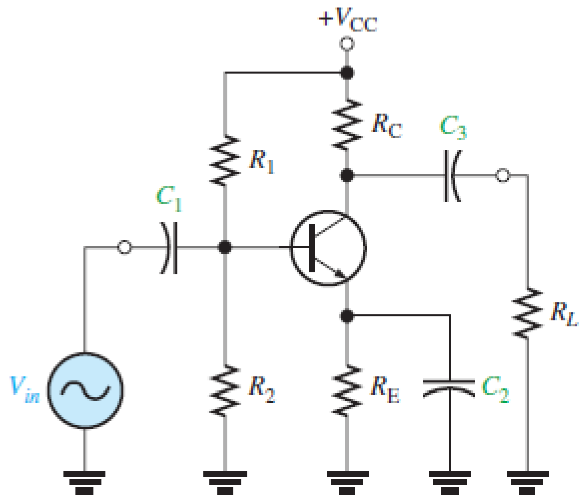
BJT Frequency Response

- What are the categories of capacitors in the traditional BJT amplifier circuit?

(1) Intentional capacitors: **coupling and bypass capacitors** with high capacitance in the **micro Farad** range. Operating as **short circuit** in the operating frequency range.

(2) Unntentional capacitors: **stray/parasitic and device (transistor) capacitors** with low capacitance in the **pico Farad** range. Operating as **open circuit** in the operating frequency range. C_{be} (C_π) is the base-emitter junction capacitance and C_{bc} (C_μ) is the base-collector junction capacitance.

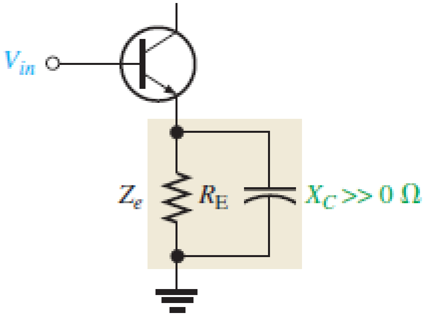




Low Frequency Response

➢ Effect of coupling capacitors:

- At lower frequencies more signal voltage is dropped across $C1$ and $C3$ because their reactances are higher.
- This higher signal voltage drop at lower frequencies **reduces the voltage gain**.
- Also, **a phase shift is introduced by the coupling capacitors** because $C1$ forms a lead circuit with the R_{in} of the amplifier and $C3$ forms a lead circuit with R_L in series with R_C or R_D.



➢ Effect of bypass capacitor:

- When the frequency is sufficiently high Xc≅0, and the $A_v = R_C/r_e$.
- At lower frequencies, Xc>> 0, and $A_v = R_c/(r_e + z_e)$.

Variation in $X_C = \dfrac{1}{2\pi f C}$ *with frequency for a 1-μF capacitor*

f	X_C	
10 Hz	15.91 kΩ	Range of possible effect
100 Hz	1.59 kΩ	
1 kHz	159 Ω	
10 kHz	15.9 Ω	
100 kHz	1.59 Ω	Range of lesser concern (≅ short-circuit equivalence)
1 MHz	0.159 Ω	
10 MHz	15.9 mΩ	
100 MHz	1.59 mΩ	

- At low frequency range, the gain falloff due to coupling capacitors and bypass capacitors.
- As signal frequency ⇓, the X_C ⇑ - no longer behave as short circuits.

High Frequency Response

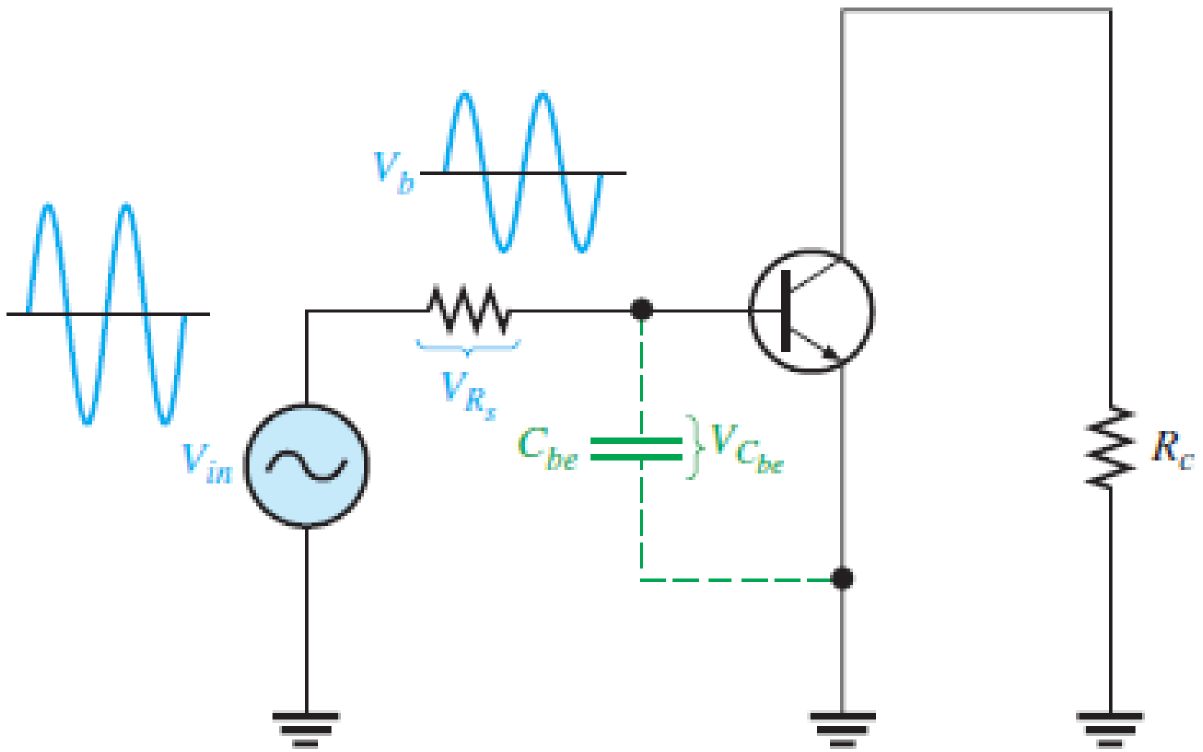
- As the signal frequency increases the internal transistor junction capacitances C_{be} *and* C_{bc}, reduce the amplifier's gain and introducing phase shift.
- At high frequencies, the coupling and bypass capacitors become effective ac shorts and do not affect an amplifier's response.

Variation in $X_C = \dfrac{1}{2\pi fC}$ *with frequency for a 5 pF capacitor*

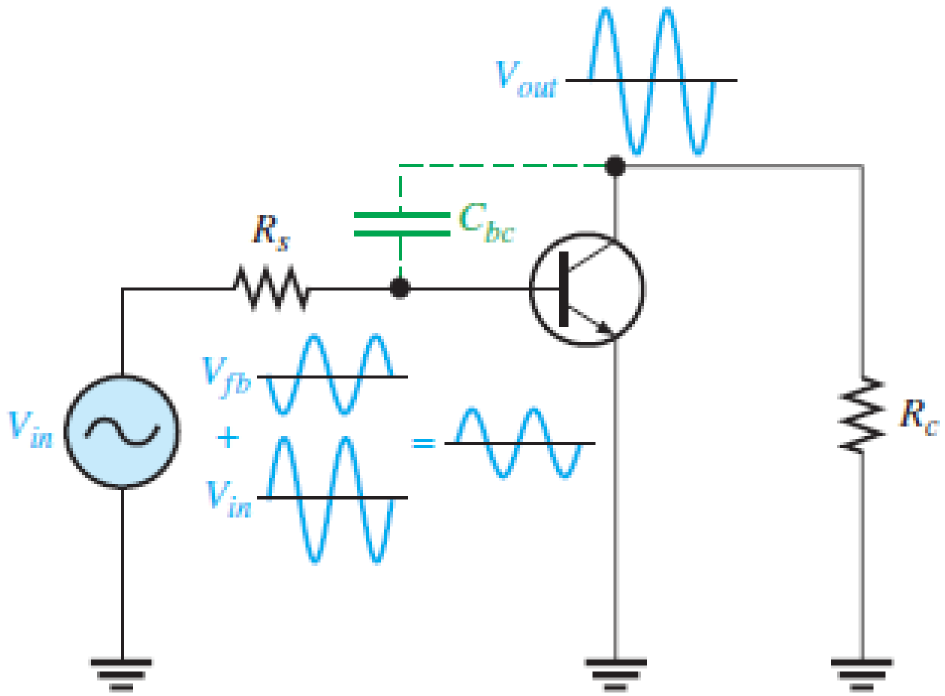
f	X_C	
10 Hz	3,183 MΩ	Range of lesser concern ($\cong$ open-circuit equivalent)
100 Hz	318.3 MΩ	
1 kHz	31.83 MΩ	
10 kHz	3.183 MΩ	
100 kHz	318.3 kΩ	Range of possible effect
1 MHz	31.83 kΩ	
10 MHz	3.183 kΩ	
100 MHz	318.3 Ω	

- At **high** frequency range, the gain falloff due to **parasitic and device capacitors**
- As signal frequency ⇑, the X_C ⇓ - no longer behave as **open** circuits.

High Frequency Response

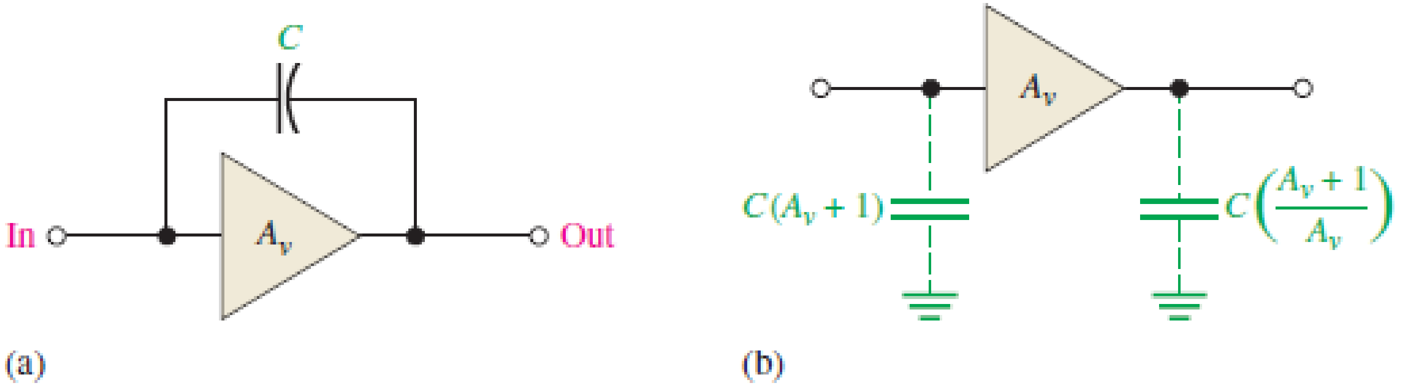


(a) Effect of C_{be}, where V_b is reduced by the voltage-divider action of R_s and $X_{C_{be}}$.

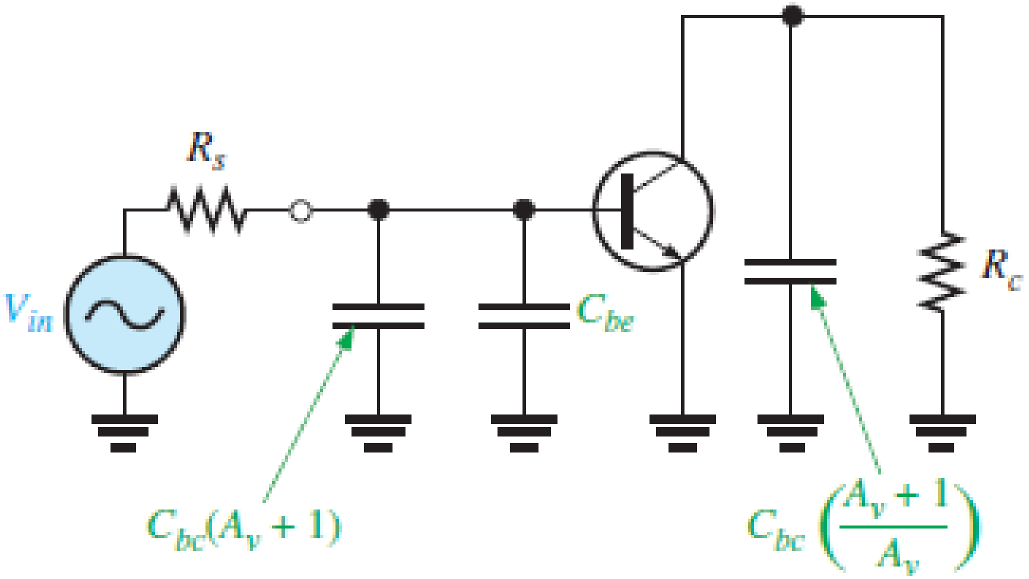


(b) Effect of C_{bc}, where part of V_{out} (V_{fb}) goes back through C_{bc} to the base and reduces the input signal because it is approximately 180° out of phase with V_{in}.

Miller's Effect



Miller's theorem is used to simplify the analysis of inverting amplifiers at high frequencies



$$C_{in(Miller)} = C(A_v + 1)$$

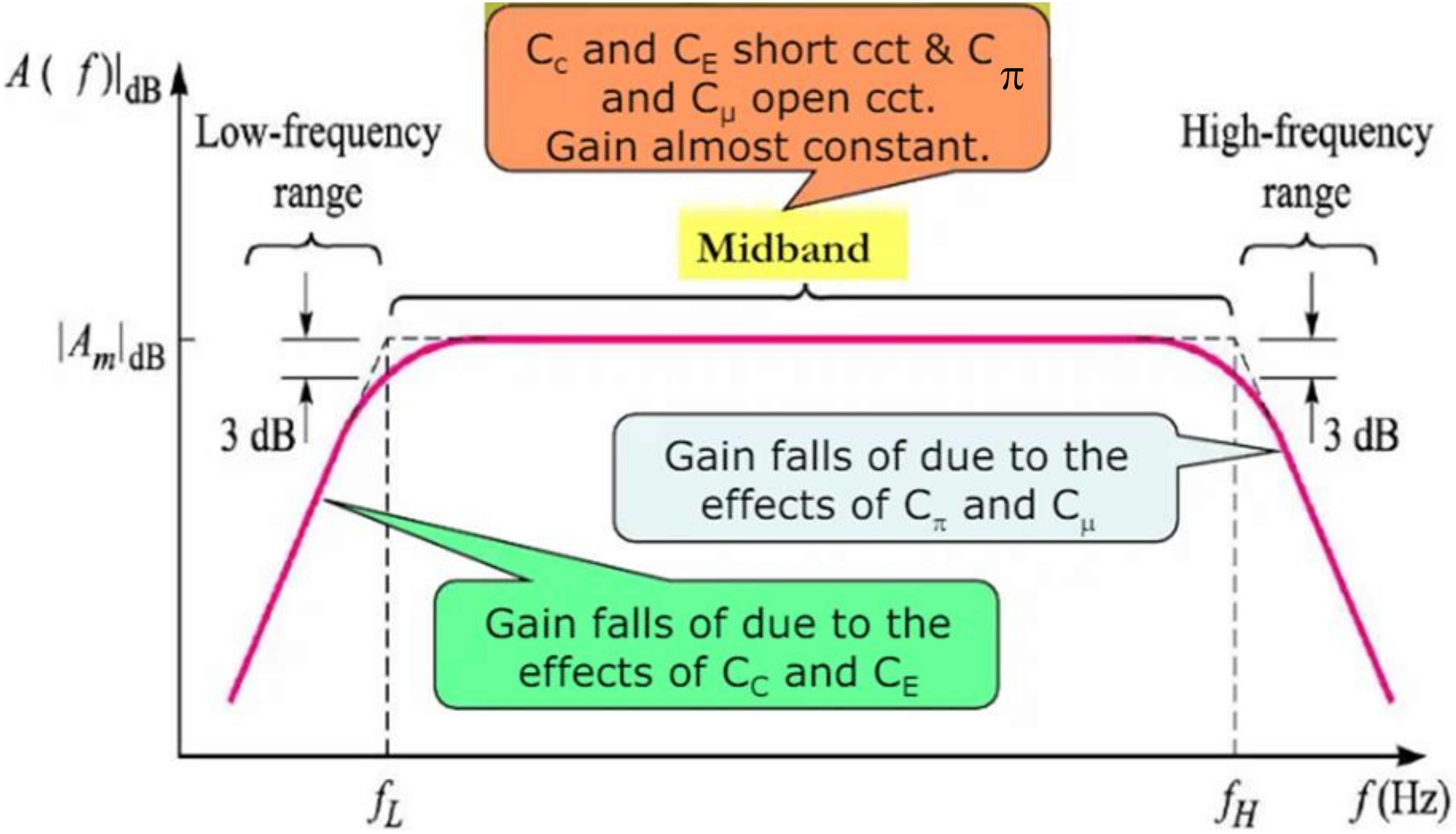
$$C_{out(Miller)} = C\left(\frac{A_v + 1}{A_v}\right)$$

Medium Frequency Range

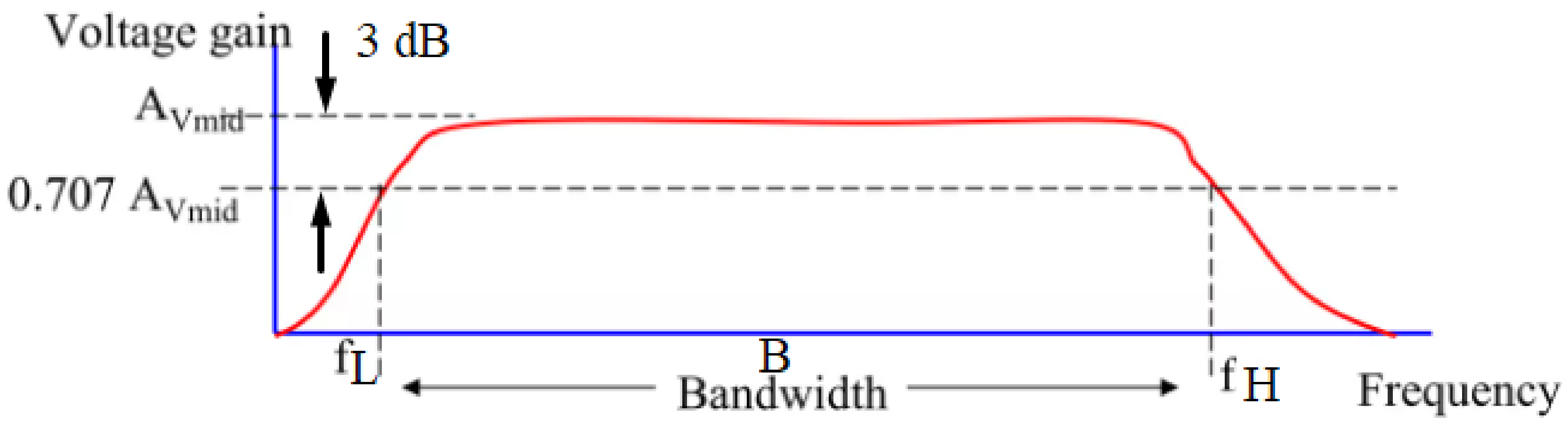
In the mid-frequency range the effect of the capacitive elements is largely ignored and the amplifier considered ideal and composed simply of resistive elements and controlled sources.

The result is that *the effect of the capacitive elements in an amplifier are ignored for the mid-frequency range when important quantities such as the gain and impedance levels are determined.*

BJT Frequency Response



Frequency Response \ Definitions



Av_{mid} = voltage gain of amplifier at middle frequencies

$0.707\ Av_{mid}$ = voltage gain of amplifier at lower cutoff frequency and higher cutoff frequency (when output power is half the output power at middle frequencies)

The frequencies f_L and f_H are generally called the corner, cutoff, band, break, or **half-power frequencies**.

B is the 3-dB bandwidth, the half-power bandwidth, or simply the bandwidth (of the midband region).

The bandwidth (or passband) of each system is determined by f_H and f_L, that is,

$$\boxed{\text{bandwidth (BW)} = f_H - f_L}$$

Frequency Response \ Definitions

The multiplier 0.707 was chosen because at this level the output power is half the midband power output, that is, at midfrequencies **(mid)**

$$P_{o_{\text{mid}}} = \frac{|V_o^2|}{R_o} = \frac{|A_{v_{\text{mid}}} V_i|^2}{R_o}$$

and at the half-power frequencies **(HPF):**

$$P_{o_{HPF}} = \frac{|0.707\, A_{v_{\text{mid}}} V_i|^2}{R_o} = 0.5\,\frac{|A_{v_{\text{mid}}} V_i|^2}{R_o}$$

$$\boxed{P_{o_{HPF}} = 0.5\, P_{o_{\text{mid}}}}$$

Normalization Process of the Frequency Response Graph

The graph of the frequency response of amplifier circuits can be plotted with a ***normalized gain.*** (gain is divided by the gain at middle frequencies.)

$$\text{Normalized Gain} = \frac{A_V}{A_{Vmid}}$$

where : A_V = voltage gain at frequency f

A_{Vmid} = voltage gain at middle frequency

Normalized Plot of Voltage Gain Versus Frequency

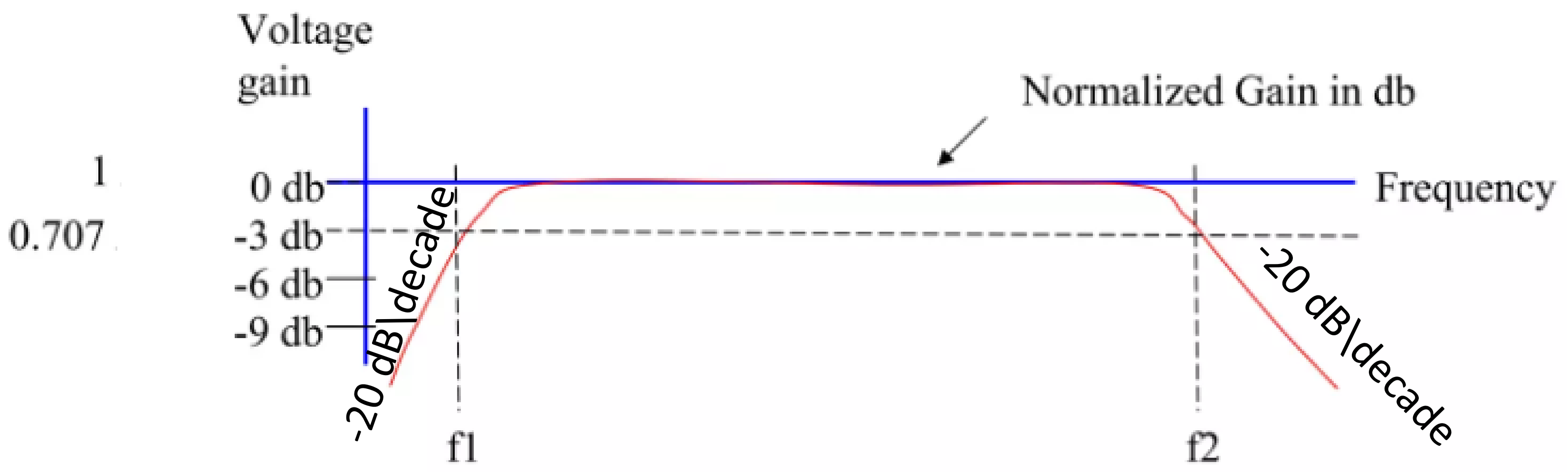
Bode Plot

A ***decibel plot of the gain*** can be made using the following formula:

$$\left.\frac{A_V}{A_{Vmid}}\right| db = 20\log\frac{A_V}{A_{Vmid}} = \text{normalized gain in db}$$

where : A_V = voltage gain at frequency f

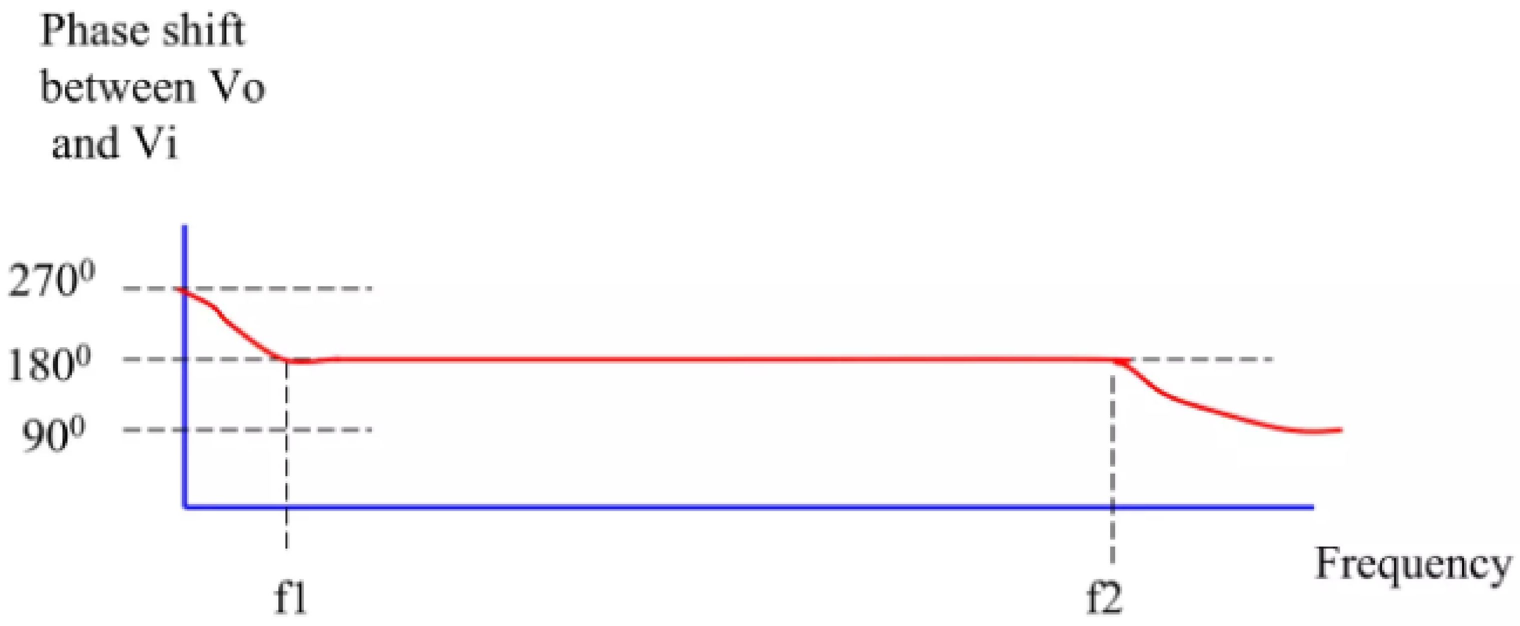
A_{Vmid} = voltage gain at middle frequency



20 dB/decade means that magnitude changes 20 dB whenever the frequency changes tenfold or one decade.

Effect of Frequency on Operation of Circuits

- The ***180 degrees phase shift*** of most amplifiers (Common emitter, common source) is ***only true at middle frequencies***.
- At ***low frequencies***, the phase shift is ***more than 180 degrees***.
- At ***high frequencies***, the phase shift is ***less than 180 degrees***.



Phase shift between Vo and Vi

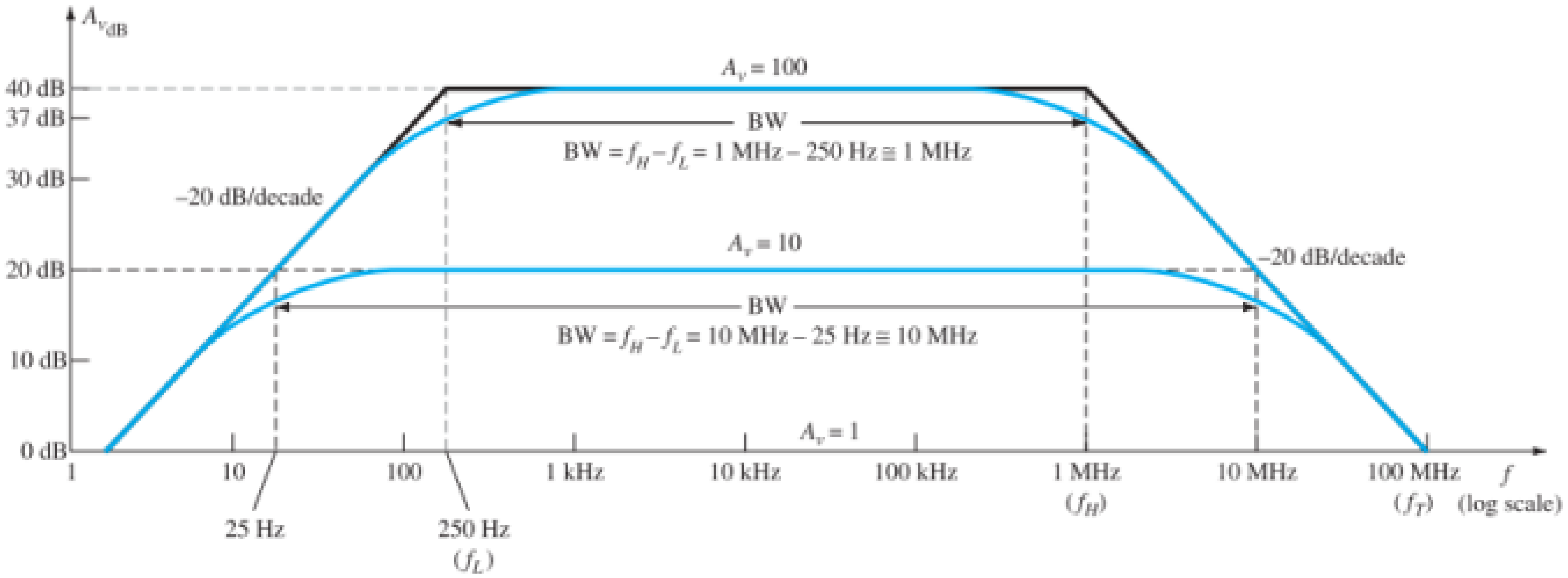
Gain Bandwidth Product (GBP)

- There is a Figure of Merit applied to amplifiers called the Gain-Bandwidth Product (GBP) that is commonly used to initiate the design process of an amplifier.
- It provides important information about the relationship between the gain of the amplifier and the expected operating frequency range.

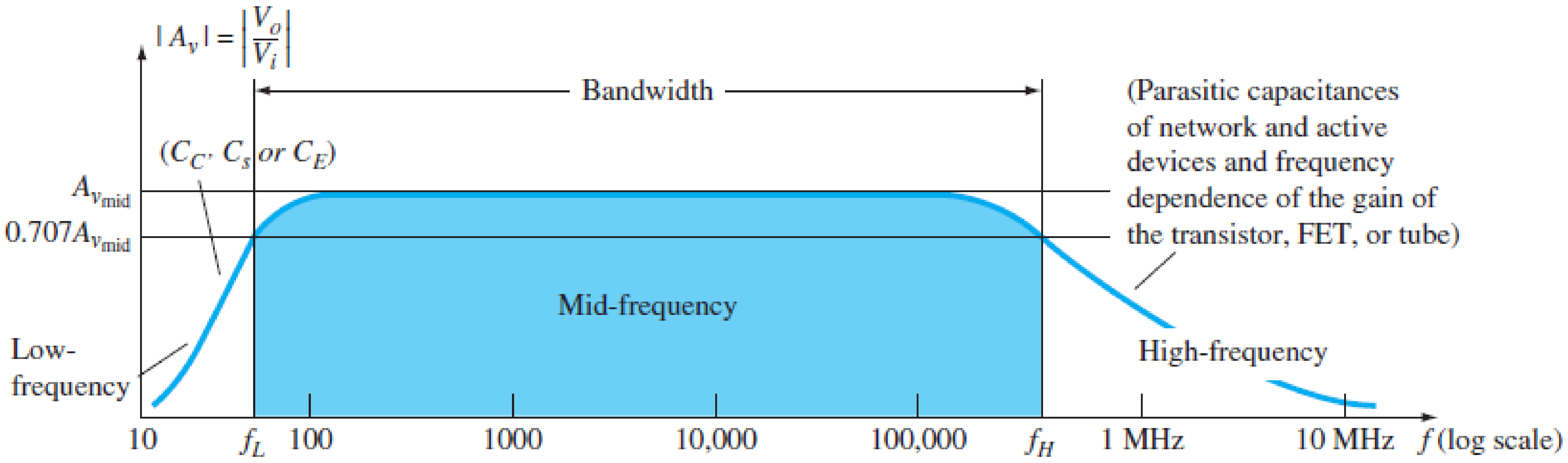
$$\boxed{GBP = A_{v_{mid}} BW}$$

$$BW = f_H - f_L \cong f_H$$

(Hz)

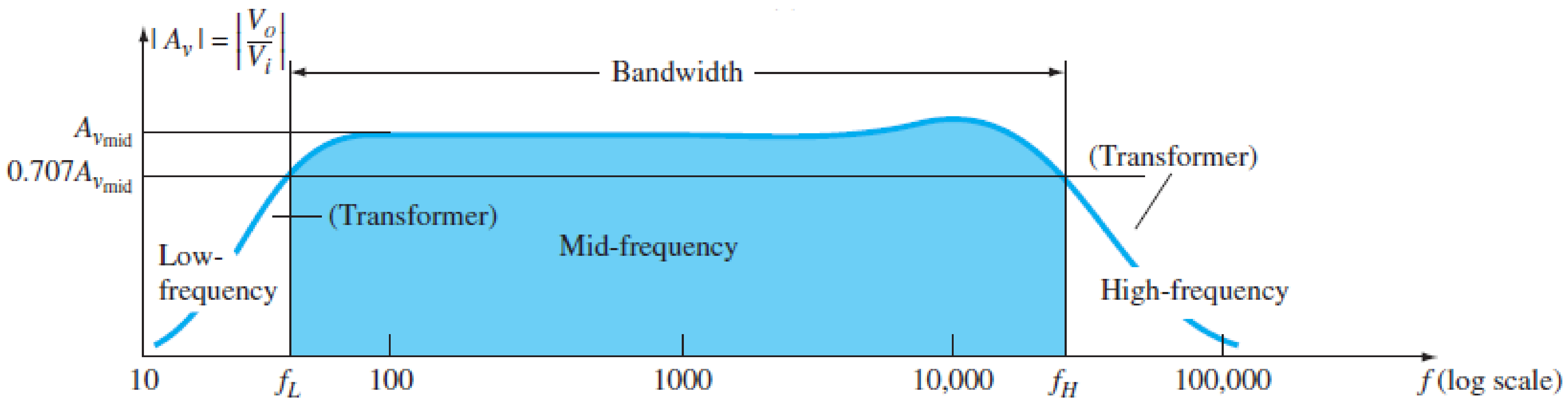


Typical Frequency Response / capacitor coupled amplifiers



- The drop at low frequencies is due to the increasing reactance of C_C, C_s, or C_E .
- Whereas its upper frequency limit is determined by either the parasitic capacitive elements of the network or the frequency dependence of the gain of the active device.

Typical Frequency Response / Transformer coupled amplifiers

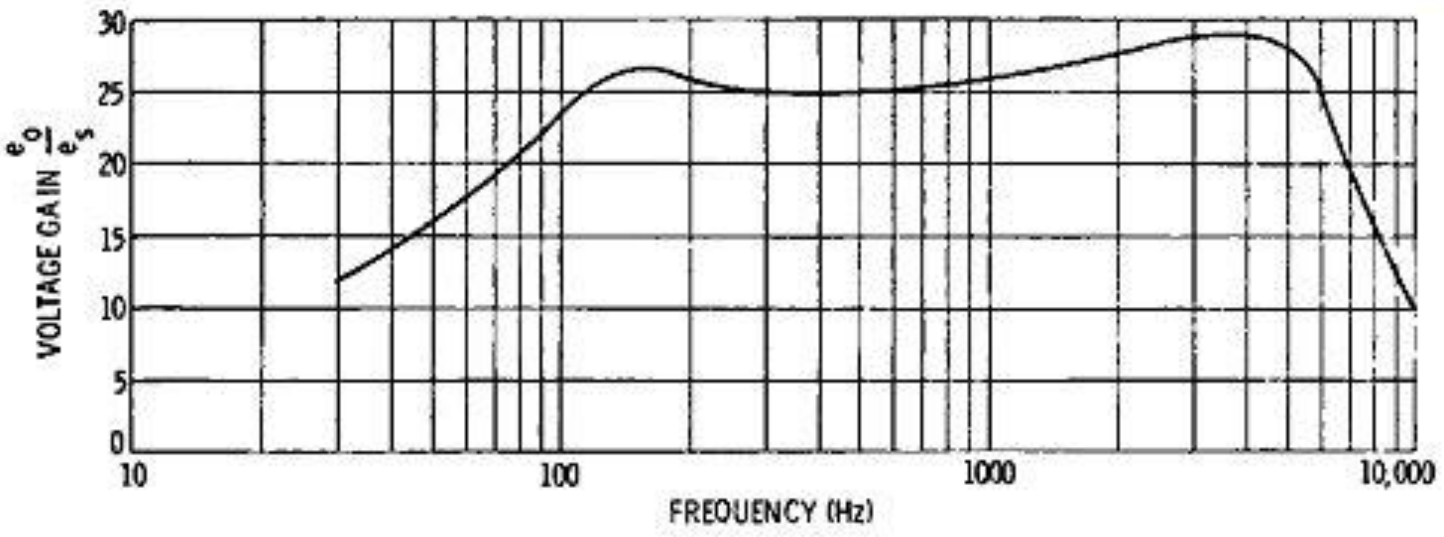


- At low frequency: the drop in the gain is simply due to the "**shorting effect**" (across the input terminals of the transformer) of the magnetizing inductive reactance at low frequencies ($X_L = 2\pi f L$).

- At $f = 0$: **the gain must obviously be zero** because at this point there is no longer a changing flux established through the core to induce a secondary or output voltage.

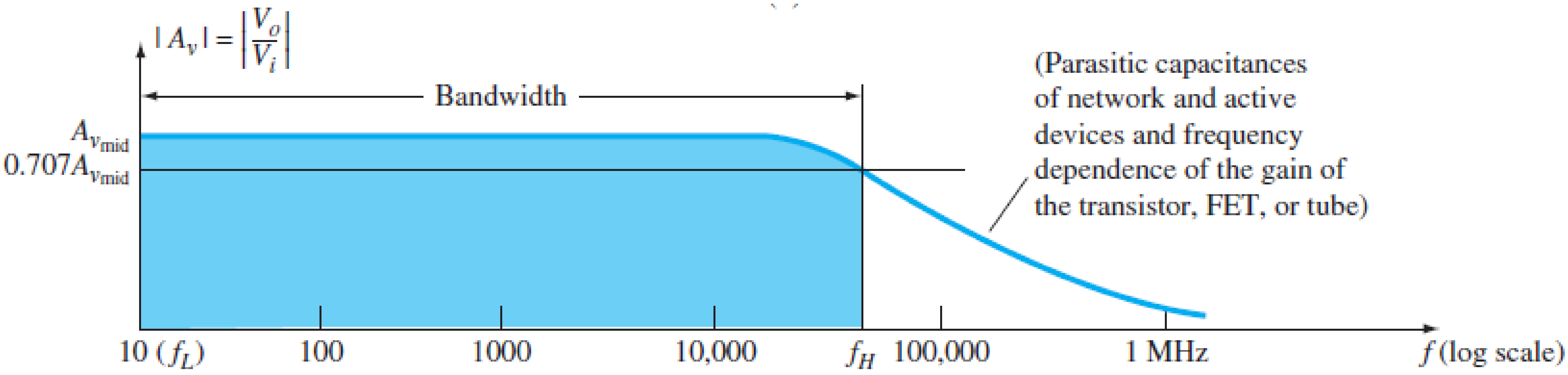
- The high-frequency: response is controlled primarily **by the stray capacitance between the turns of the primary and secondary windings.**

Typical Frequency Response / Transformer coupled amplifiers



- Although the gain is high, it varies considerably with frequency. Hence a poor frequency response.

Typical Frequency Response / Direct coupled amplifiers



For the direct-coupled amplifier, there are no coupling or bypass capacitors to cause a drop in gain at low frequencies.