Communication Circuits Design

Academic year 2018/2019 – Semester 2 – Week 2
Lecture 2.4: Amplifiers

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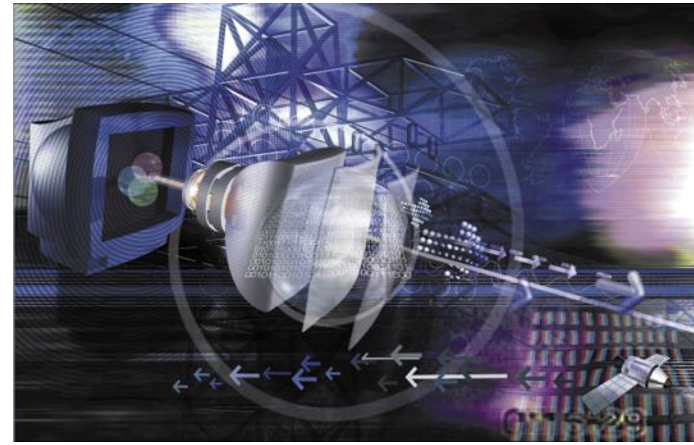
Outline



- **Amplifiers in communication systems**
- **Simple circuital models**
- **System view of amplifiers (block diagram)**
- **Metrics of quality**

References:

•*R. Sobot, "Wireless Communication Electronics", Springer, <u>at UoG Library online</u> – Chapter 7*

•*J. Beasley, G. Miller, "Modern Electronic Communication", Pearson, 9th ed. – Pages 135, 261, 313*

•*B. Razavi, "RF Microelectronics", Prentice Hall, 2nd ed. – Chapter 5*

Amplifiers

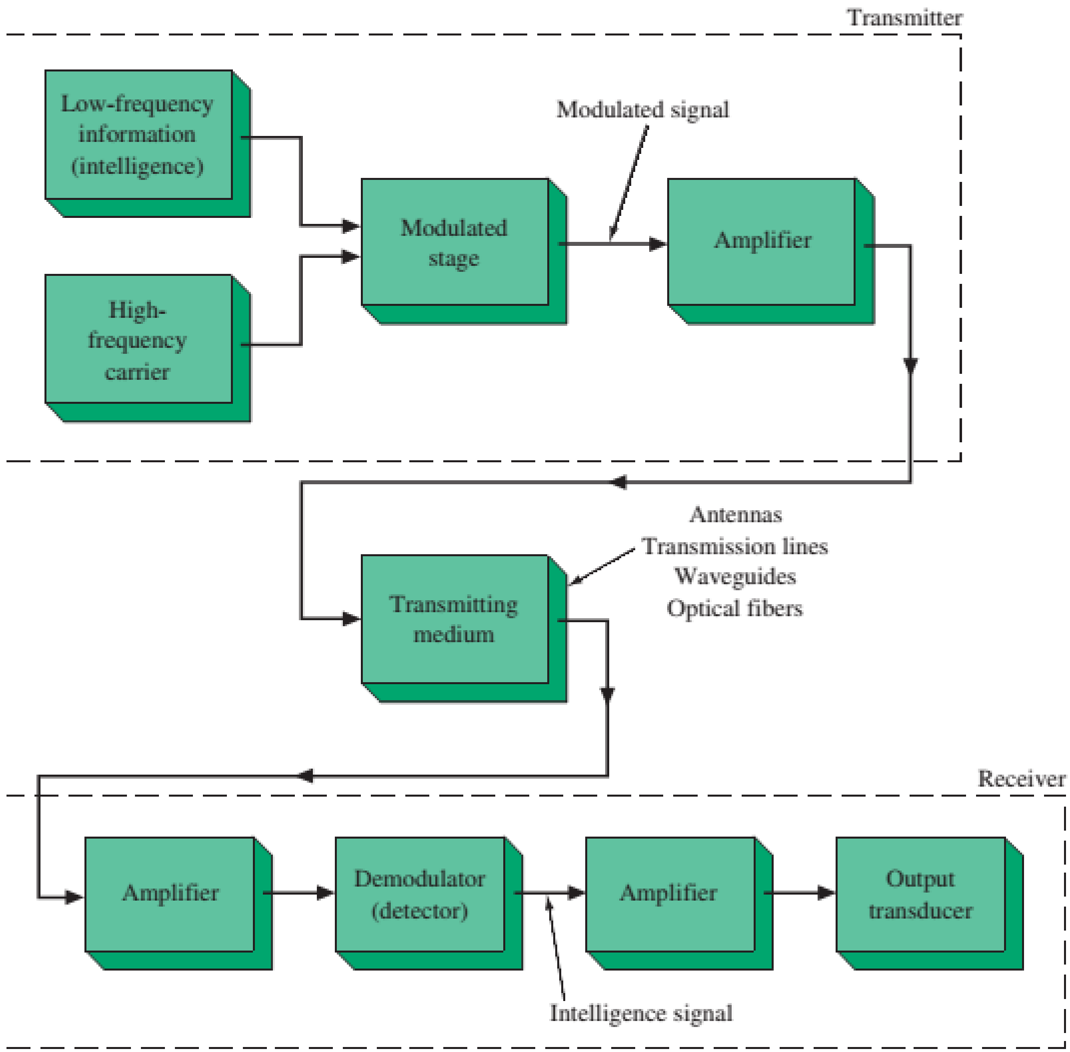


FIGURE 1 A communication system block diagram.

A typical communication system has amplifiers at both the transmitter and the receiver side (see the generic block diagram from the Beasley-Miller book).

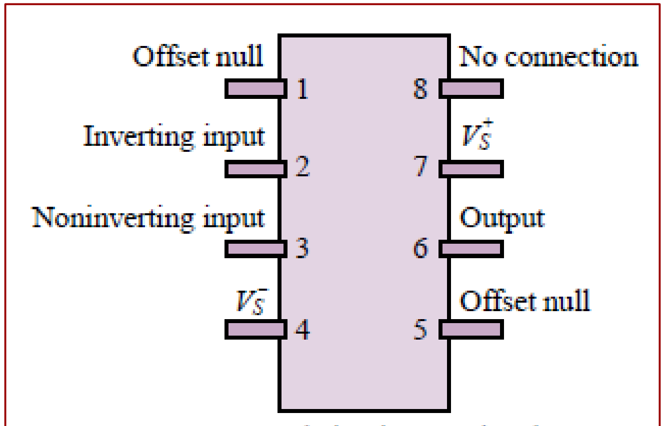
Why do we need them?

As the name suggests, they amplify the signal carrying information, so that it is larger than the noise.

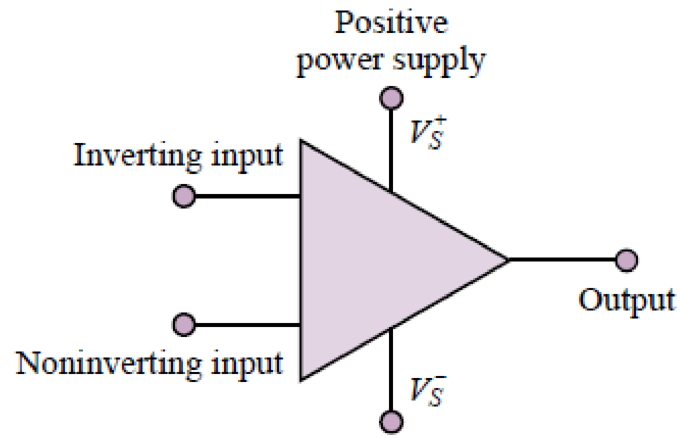
Amplifiers

In Circuits Analysis and Design you studied Operational Amplifiers, for example the LM741 used in the lab whose model is shown below.

You may recall the inverting and non-inverting configurations of op-amp, and the calculation of their gain.



Integrated circuit operational amplifier (IC op-amp)



Simplified circuit symbol

In general an amplifier takes an input x(t) and amplifies it to an output y(t) by a certain gain K. K can also be measured in dB (log-scale)

So $y(t) = Kx(t)$

Amplifiers models

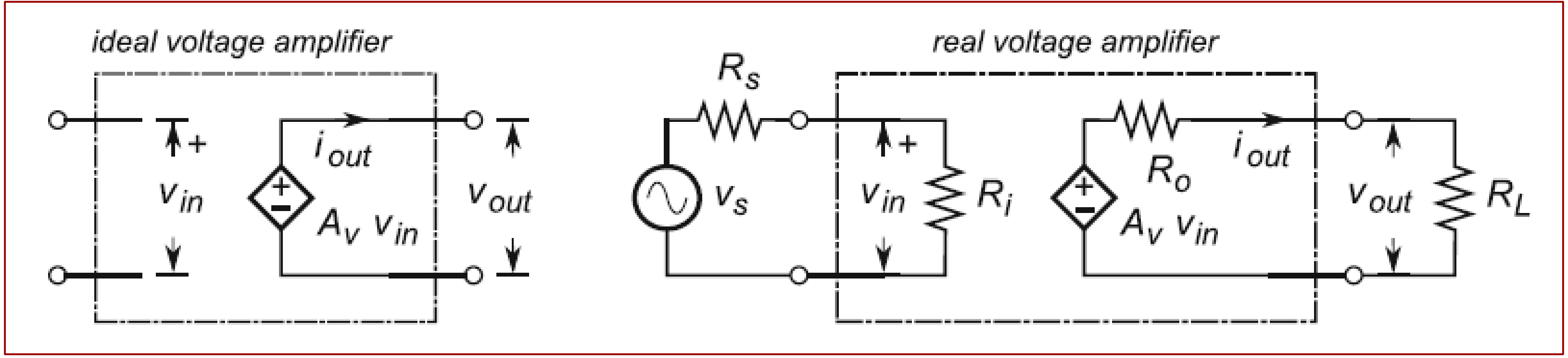
Four ideal models of amplifiers can be considered if we associate to the input variable x(t) and the output variable y(t) the meaning of voltage or current.

Model	Input	Output (gain highlighted in red)
Voltage amplifier	V_{in}	$V_{out} = A_v V_{in}$
Current amplifier	I_{in}	$I_{out} = A_i I_{in}$
Transconductance amplifier	V_{in}	$I_{out} = G_m V_{in}$
Transresistance amplifier	I_{in}	$V_{out} = A_R I_{in}$

Note that the gain (in red) can be a dimensionless unit as for voltage/current amplifiers, or have the dimension of conductance [Siemens] or resistance [Ohm].

Voltage amplifier model

Let us look at the model of a voltage amplifier



For the **ideal** model, no components at the input, any voltage is transferred inside the amplifier with no losses. $\boxed{v_{\text{out}} = A_{\text{v}} v_{\text{in}}}$
Input impedance Z_{in}=∞ (open circuit), output impedance Z_O=0 (ideal V source)

For the **real** model, resistors are added to account for source resistance R_s, load resistance R_L, internal input and output resistances R_i and R_o

Now:

$$\boxed{v_{\text{in}} = i_{\text{in}} R_{\text{i}} = \frac{v_{\text{S}}}{R_{\text{S}} + R_{\text{i}}} R_{\text{i}}}$$

$$\boxed{v_{\text{out}} = i_{\text{out}} R_{\text{L}} = \frac{A_{\text{v}} v_{\text{in}}}{R_{\text{o}} + R_{\text{L}}} R_{\text{L}}}$$

Voltage amplifier model

So, if we want our real amplifier to be as similar as possible to the ideal model (a “good” amplifier), at design stage we need to

-maximise its input resistance R_i (with respect to source resistance)

-minimise its output resistance R_o (with respect to load resistance)

-outside the amplifier, reduce the source resistance R_s and increase the load resistance R_L

How do we see this? Just combine the two previous formulae to find the ratio Vout/Vs for the real amplifier, basically its **gain**.

$$\boxed{\frac{R_\mathrm{i}}{R_\mathrm{S}+R_\mathrm{i}} A_\mathrm{v} \frac{R_\mathrm{L}}{R_\mathrm{o}+R_\mathrm{L}}}$$

If $R_i \rightarrow \infty$ and $R_o \rightarrow 0$, then the real gain is similar to the ideal one Av.

Note that Av is (for now!) constant, a number, for any frequency.

Ideal and real amplifiers

Here we generalise the conditions for "good" amplifiers to the 4 models we introduced, where "good" means real amplifiers that behave as much as possible as ideal ones.

High/low is always compared to what is around the amplifier. For the input Z_i this is the source impedance, for the output Z_o this is the load impedance.

Model	**Input**	**Output (gain highlighted in red)**	**Desired design of amplifier**
Voltage amplifier	V_{in}	$V_{out} = A_v V_{in}$	High Z_i Low Z_o
Current amplifier	I_{in}	$I_{out} = A_i I_{in}$	Low Z_i High Z_o
Transconductance amplifier	V_{in}	$I_{out} = G_m V_{in}$	High Z_i High Z_o
Transresistance amplifier	I_{in}	$V_{out} = A_R I_{in}$	Low Z_i Low Z_o

Inside the amplifier

So far we have not considered what is “inside” the amplifier, what components can be used to design/make one.

The easiest model is given by **single stage amplifiers**, where only one transistor is used, BJT or FET device. There are 3 topologies shown in the figure below from Sobot’s book (assuming BJT device):

-Common base CB (or common gate for FET)

-Common emitter CE (or common source for FET)

-Common collector CC (or common drain for FET)

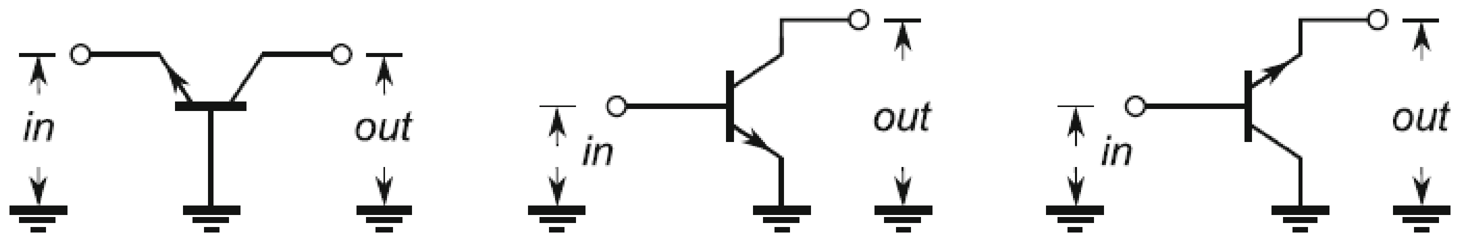


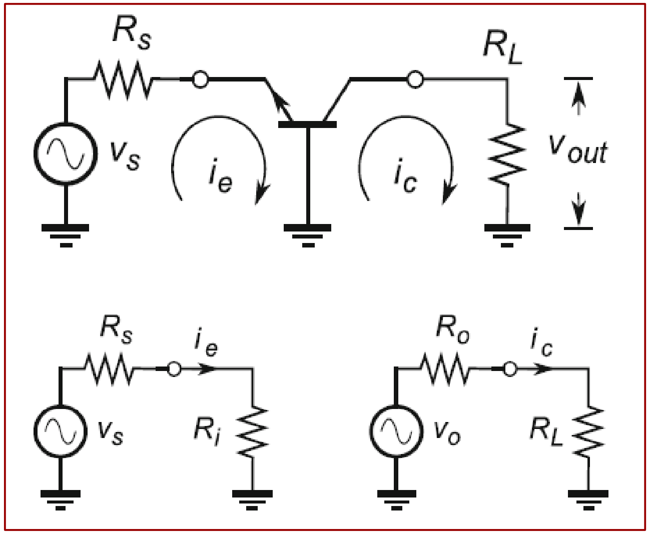
Fig. 7.5 Basic single-stage amplifiers: common gate (*left*), common emitter (*centre*), and common collector (*right*).

For each topology, we can characterise input/output impedance and gain. Mathematical details in chapter 7 of Sobot’s book.

Common-Base Amp - Ri

It can be demonstrated that the **input resistance R_i** depends on the load resistance R_L and the internal resistances at emitter, collector, base of the BJT

$$R_\mathrm{i} = R_\mathrm{e} + R_\mathrm{b} - \frac{R_\mathrm{b}(R_\mathrm{b} + \alpha R_\mathrm{c})}{R_\mathrm{b} + R_\mathrm{c} + R_\mathrm{L}}$$



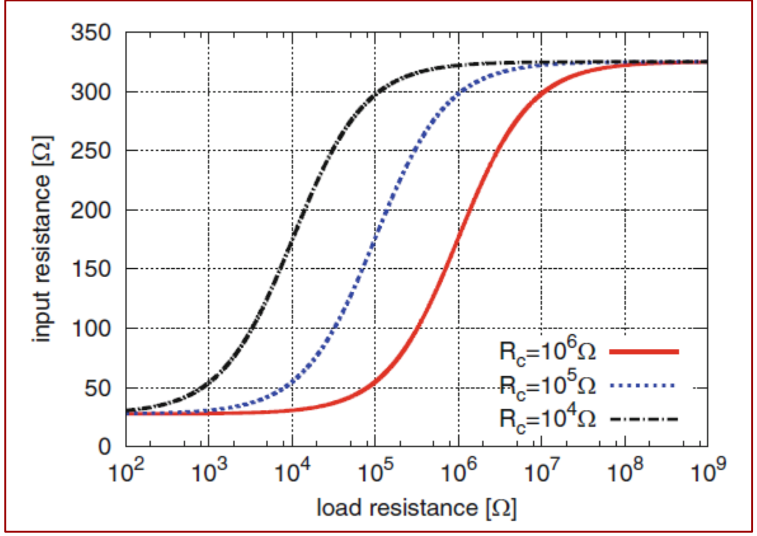
Two extreme cases:

-If $R_L \rightarrow \infty$ (very large), $R_i = R_e + R_b \approx R_b$

-If $R_L \rightarrow 0$ (very small), $R_i \approx R_e$

Recall that in a BJT $\alpha \approx 1$ and $R_b > R_e$

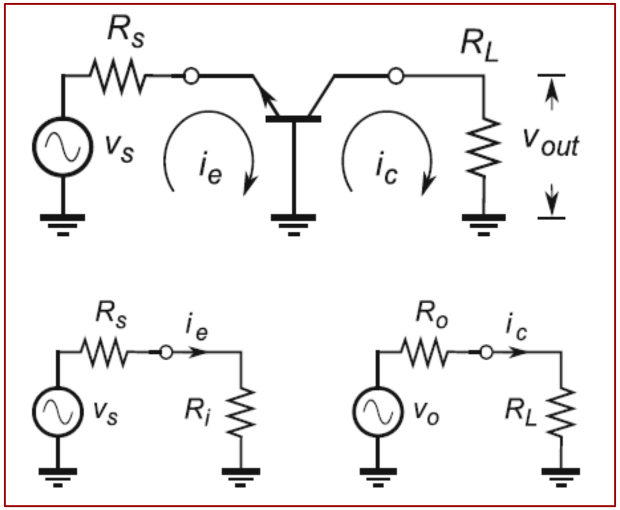
In the example on the right, assumed $R_b = 300\Omega$, $R_e = 25\Omega$, $\beta=100$



Common-Base Amp - Ro

It can be demonstrated that the **output resistance R_o** depends on the source resistance R_s and the internal resistances at emitter, collector, base of the BJT

$$R_o = R_c + R_b - \frac{R_b(R_b + \alpha R_c)}{R_S + R_e + R_b}$$

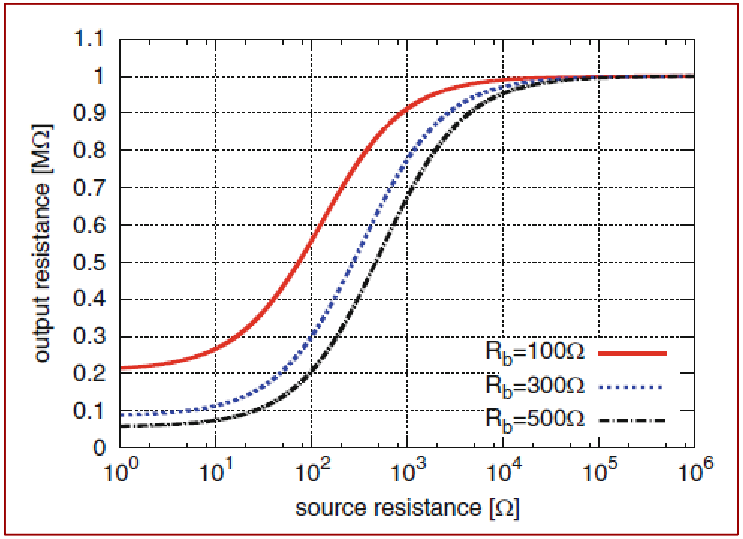


Two extreme cases:

-If $R_s \rightarrow \infty$ (ideal I source), $R_o = R_c + R_b \approx R_c$

-If $R_s \rightarrow 0$ (ideal V source), $R_o \approx R_c \dfrac{R_e + R_b(1-\alpha)}{R_e + R_b}$

Recall that in a BJT $R_c >> R_b > R_e$

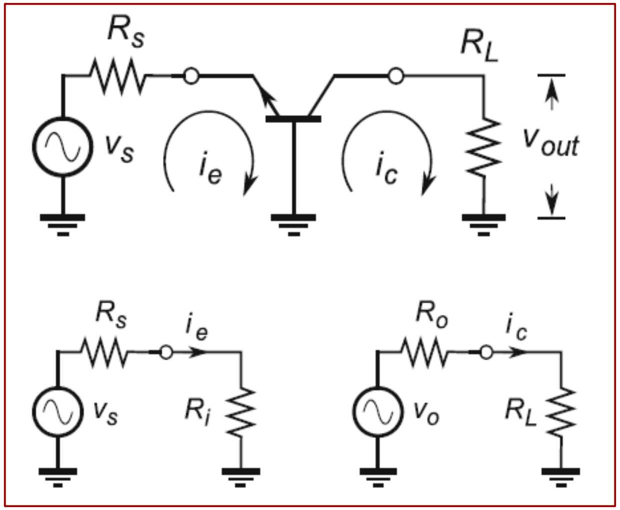


In the example on the right, assumed $R_e = 25\Omega$, $R_c = 1M\Omega$, $\beta=100$

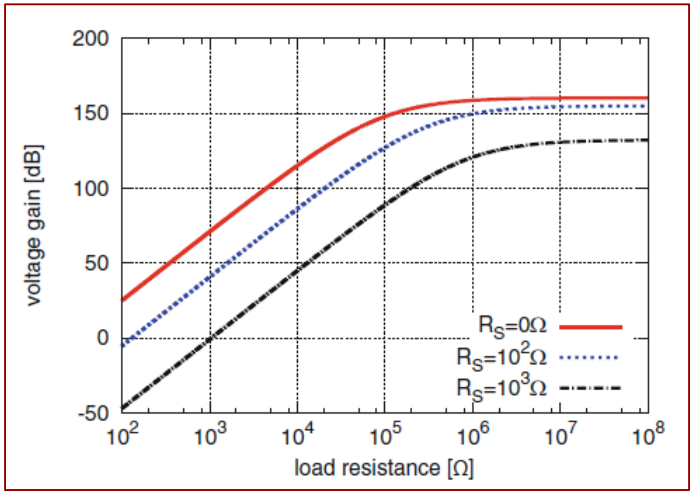
Common-Base Amp - Gain

The **voltage gain Av** is the ratio of Vout over Vs
Combining the previous formulae one can derive
a rather complex expression. Here we provide
The simplified version assuming $R_c >> R_b > R_e$

$$A_v \approx \frac{\alpha R_c R_L}{(R_s + R_e + R_b) R_c - R_b \alpha R_c}$$
$$\approx \frac{R_L}{R_s + R_e + \frac{R_b}{\beta}}$$
$$= \frac{R_L}{R_S + R_i},$$



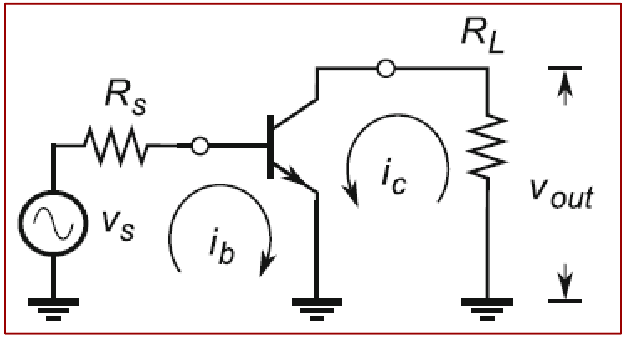
In the example on the right, assumed
$R_e = 25\Omega$, $R_c = 1M\Omega$, $\beta=100$



Common-Emitter Amp - Ri

It can be demonstrated that the **input resistance** $\mathbf{R_i}$ depends (again) on the load resistance R_L and the internal resistances at emitter, collector, base of the BJT

$$r_i = r_b + r_e + \frac{r_e(\alpha r_c - r_e)}{R_L + r_e + (1-\alpha) r_c}$$



Two extreme cases:

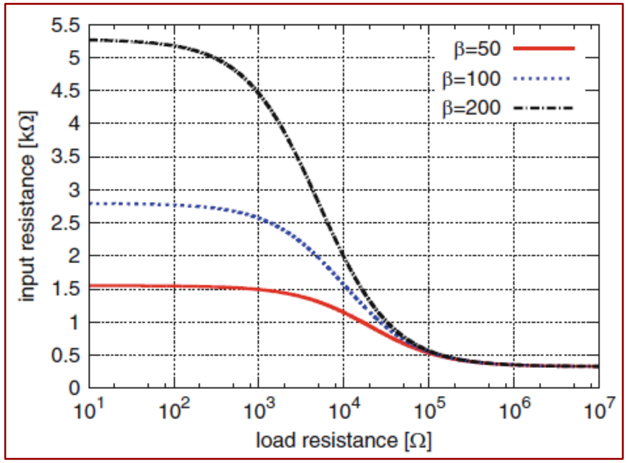
-If $R_L \to \infty$ (unloaded, open amplifier) then $r_i = r_b + r_e \approx r_b$

-If $R_L \to 0$ (shorted load), then R_i tends to $r_b + \beta r_e$

Essentially β has a large effect for small loads

In the example on the right, assumed

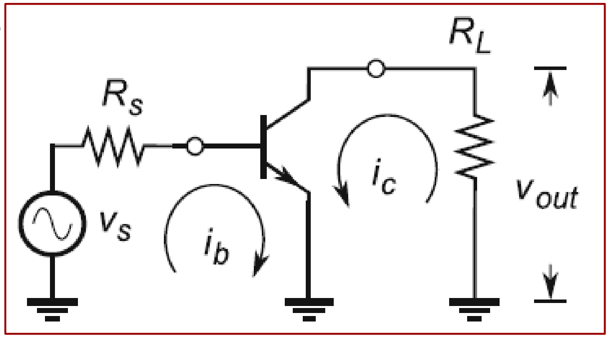
$R_b = 300\Omega$, $R_e = 25\Omega$, $R_c = 1M\Omega$



Common-Emitter Amp - Ro

It can be demonstrated that the **output resistance** $\mathbf{R_o}$ depends on the source resistance R_s and the internal resistances at emitter, collector, base of the BJT

$$r_o = r_e + r_c(1-\alpha) + \frac{r_e(\alpha r_c - r_e)}{R_S + r_b + r_e}$$



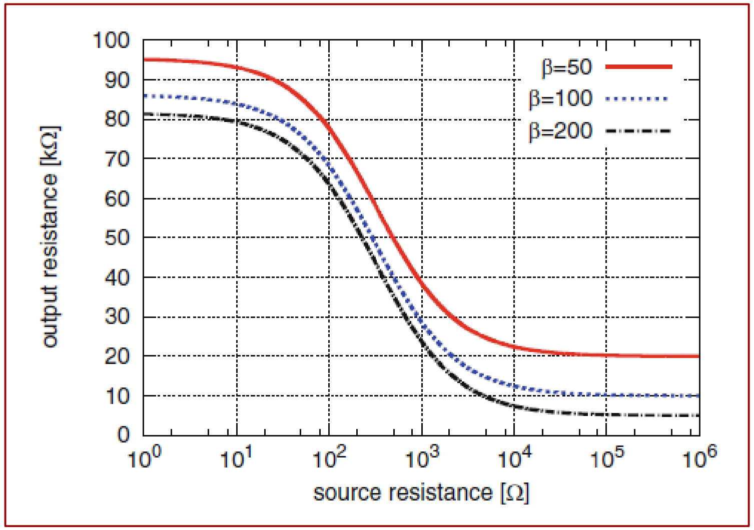
Two extreme cases:

-If $R_s \rightarrow \infty$ (very large), then $r_e + \frac{r_c}{\beta}$.

-If $R_s \rightarrow 0$ (very small), then $r_c \frac{r_e + \frac{r_b}{\beta}}{r_b + r_e} \approx r_c$,

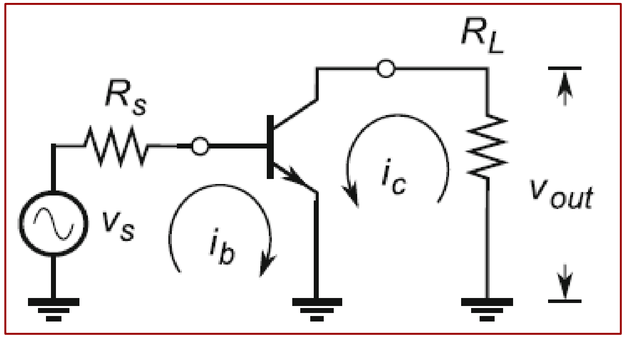
Recall that in a BJT $R_c >> R_b > R_e$

In the example on the right, assumed $R_b = 300\Omega$, $R_e = 25\Omega$, $R_c = 1M\Omega$



Common-Emitter Amp - Gain

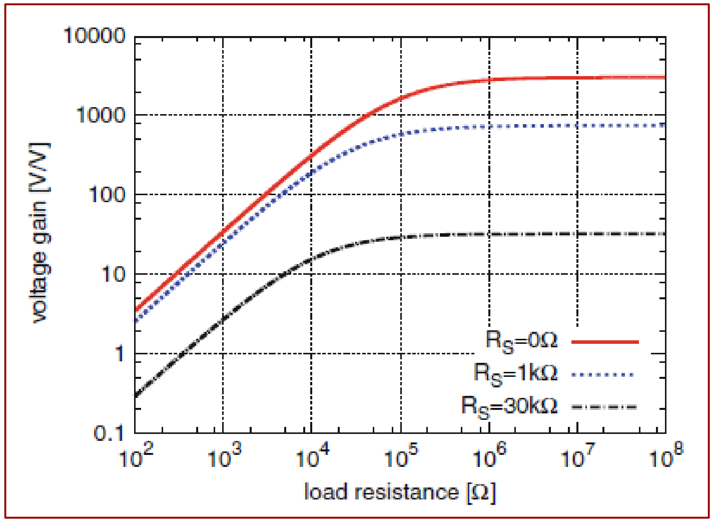
The **voltage gain Av** is the ratio of Vout over Vs Combining the previous formulae one can derive a rather complex expression. Here we provide the simplified version assuming an ideal voltage source ($R_s \approx 0$) and large loads ($R_L \rightarrow \infty$)



$$\boxed{\frac{\alpha r_c}{r_b + r_e} \approx \frac{r_c}{r_b + r_e}}$$

Recall that in a BJT $\alpha \approx 1$

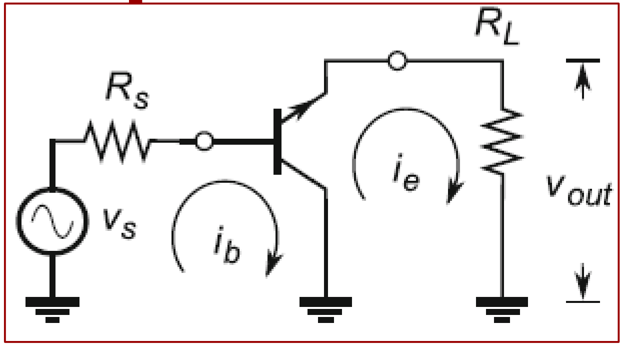
Key point: for large loads and close to ideal voltage sources, the gain is bounded by the ratio of R_C and $(R_E + R_B)$.



In the example on the right, assumed $R_e = 25\Omega$, $R_c = 1M\Omega$, $\beta = 100$

Common-Collector Amp - Ri

It can be demonstrated that the **input resistance R_i** depends (again) on the load resistance R_L and the internal resistances at emitter, collector, base of the BJT



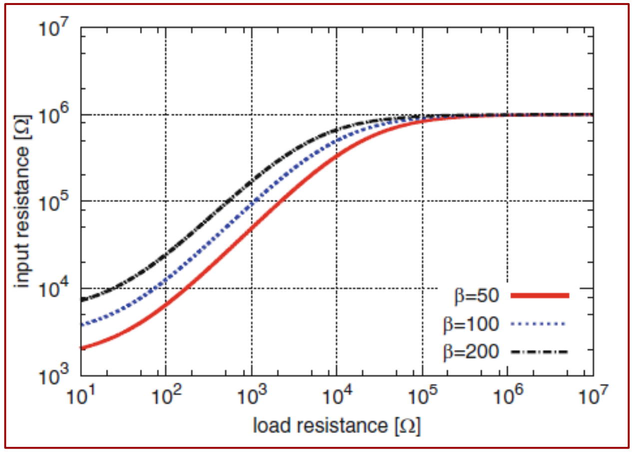
$$\boxed{r_i = r_b + r_c - \frac{r_c^2(1-\alpha)}{r_c(1-\alpha)+r_e+R_L}}$$

Two extreme cases:

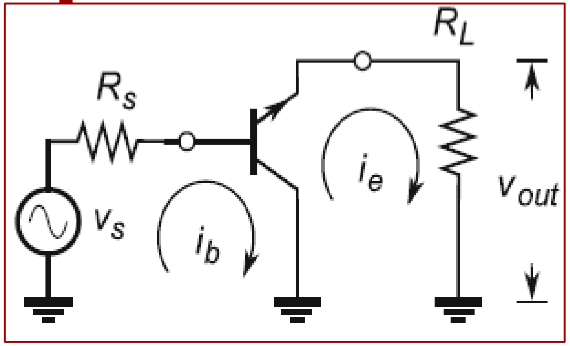
-If $R_L \to \infty$ (unloaded, open amplifier) then $\boxed{r_i = r_b + r_c \approx r_c}$

-If $R_L \to 0$ (shorted load), then R_i tends to $\boxed{r_b + \frac{r_e}{1-\alpha} = r_b + \beta r_e}$

In the example on the right, assumed $R_e = 25\Omega$, $R_c = 1M\Omega$



Common-Collector Amp - Ro



It can be demonstrated that the **output resistance R_o** depends on the source resistance R_s and the internal resistances at emitter, collector, base of the BJT

$$r_o = r_e + r_c(1-\alpha) - \frac{r_c^2(1-\alpha)}{r_b + r_c + R_S}$$

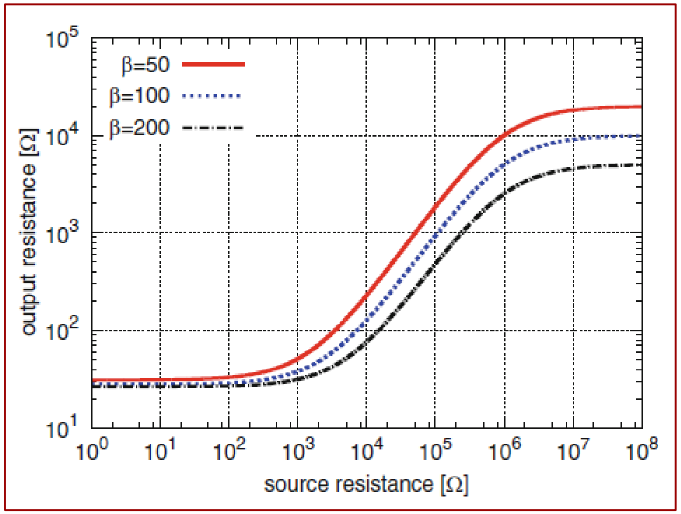
Two extreme cases:

-If $R_s \to \infty$ (very large) then $$r_o = r_e + r_c(1-\alpha) \approx \frac{r_c}{\beta}$$

-If $R_s \to 0$ (shorted load), then $$r_e + \frac{r_b}{\beta} \approx r_e \approx \frac{1}{g_m}$$

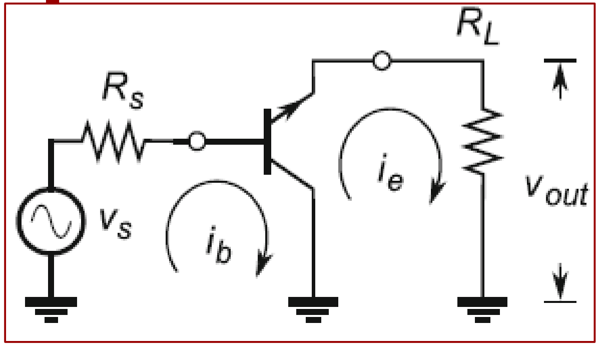
Recall that in a BJT $R_c >> R_b > R_e$

In the example on the right, assumed $R_b = 300\Omega$, $R_e = 25\Omega$, $R_c = 1M\Omega$



Common-Collector Amp - Gain

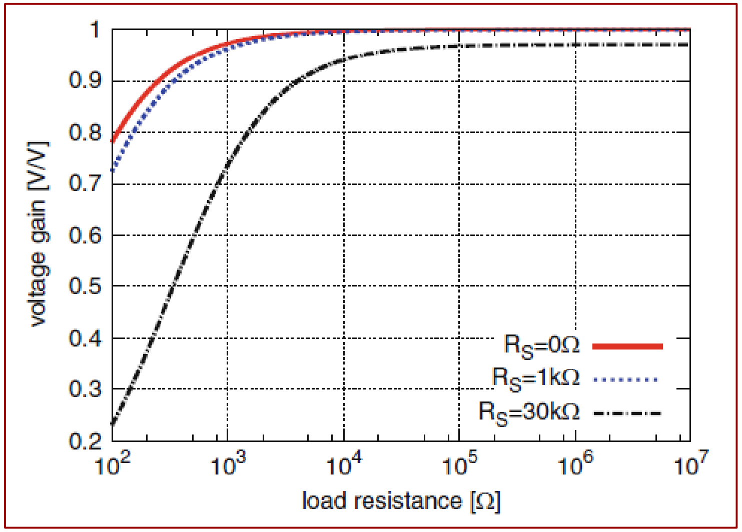
The **voltage gain Av** is the ratio of Vout over Vs Combining the previous formulae one can derive a rather complex expression. Here we provide the simplified version assuming an ideal voltage source ($R_s \approx 0$) and large loads ($R_L \rightarrow \infty$)



$$\frac{R_L}{R_L\left(1+\frac{R_S}{r_c}\right)+R_S(1-\alpha)} \approx \frac{R_L}{R_L+\frac{R_S}{\beta}} \approx 1$$

Assume that R_L is larger than R_s in normal conditions

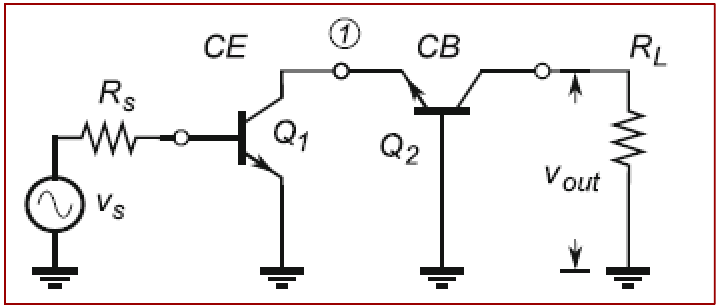
Key point: the gain is very close to 1, so the CC amplifier can be used as "voltage buffer" or impedance converter (high R_i, low R_o)



In the example on the right, assumed $R_e = 25\Omega$, $R_c = 1M\Omega$, $\beta=100$

Cascode amplifier

This is an important configuration made of two-single stage amplifiers, a CE followed by a CB amplifier.



The main characteristics are that the voltage gain **Av** is approximately the same as for a single-stage CE and the output resistance **Ro** is increased significantly compared to both CE and CB in single stage.

So the cascode amplifier can be very suitable for implementing current sources (with ideal output resistance close to infinity).

Note that the cascode also improves the stability, and the rejection of Miller capacitance effects compared to single CE stage (for those curious, see chapter 7.7 of Sobot’s book).

Summary

	Input R_I		Output R_o		Gain Av
	Large R_L	Small R_L	Large R_S	Small R_S	
CB	R_E+R_B	R_E	R_c+R_b	$R_c \dfrac{R_e+R_b(1-\alpha)}{R_e+R_b}$	$\dfrac{R_L}{R_S+R_i}$
CE	$r_i = r_b + r_e \approx r_b$	$r_b + \beta r_e$.	$r_e + \dfrac{r_c}{\beta}$.	$r_c \dfrac{r_e + \dfrac{r_b}{\beta}}{r_b + r_e} \approx r_c,$	$\dfrac{R_c}{R_b+R_e}$
CC	$r_i = r_b + r_c \approx r_c$	$r_b + \dfrac{r_e}{1-\alpha} = r_b + \beta r_e$.	$r_e + r_c(1-\alpha) \approx \dfrac{r_c}{\beta}$.	$r_e + \dfrac{r_b}{\beta} \approx r_e \approx \dfrac{1}{g_m}$	$\dfrac{R_L}{R_L+R_S/\beta}$
Cascode CE+CB	To calculate assuming the R_{in} of CB as load for CE		Much larger than independent single stages		Same as CE single stage

Biasing circuits

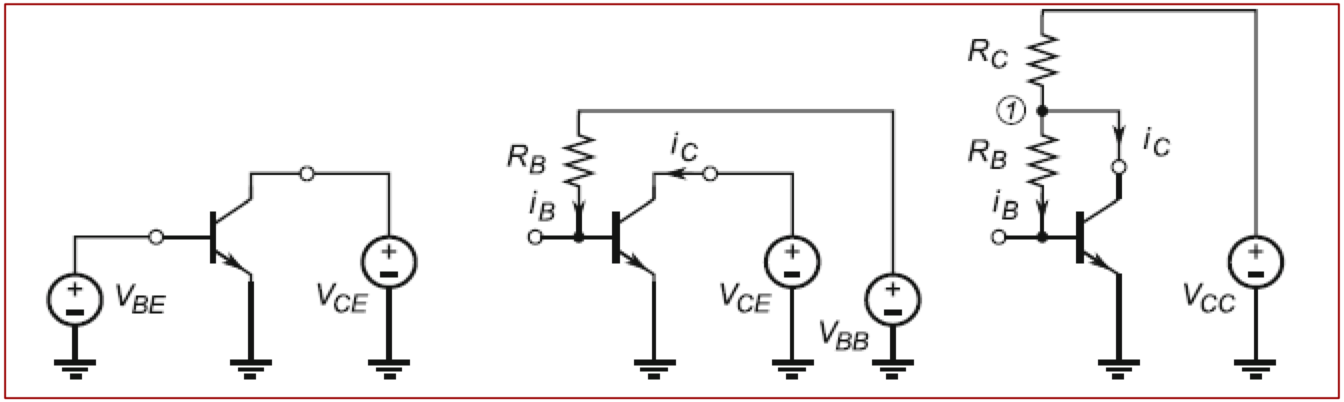
Our circuits so far have neglected the ***biasing*** components, i.e. those needed to provide the BJT with a stable operational point.

We want the BJT to be in the "active" or "constant current source" mode. This means that Ic (collector current) is set by the voltage on the base V_{BE} (or current I_B) through the gain g_m given the voltage on the collector V_{CE} (but without depending on it directly)

So $V_{BE} = R_B I_B$ and $I_C = g_m V_{BE} = \beta I_B$

With the condition $V_{CE} \geq V_{BE}$

This can be modelled by the voltage sources shown below (left), or transforming one into a current source (centre)

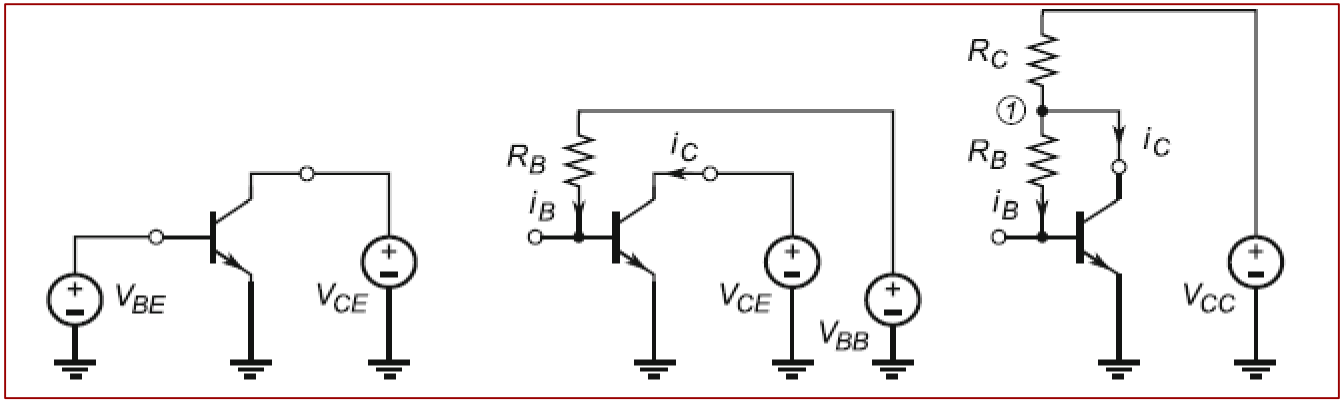


Biasing circuits

However, the BJT characteristics (value of β) change with temperature, aging, imperfections in design. So chosen fixed separate voltages for base and collector is not practical.

What is needed is a ***feedback mechanism***. I_C has to be constant and is controlled by I_B. If a portion of I_C is injected into I_B so that this can oppose the change when I_C tends to increase, then this should work.

Look below (right-hand side). If I_C increases, voltage across R_C increases too. Voltage V_1 is reduced and so is current I_B depending on voltage difference between V_1 and V_B through R_B (Ohm's law). If I_B is smaller, I_C will be also smaller as $I_C = g_m V_{BE} = \beta I_B$



Biasing circuits

So the biasing circuit has two objectives: fixing an operation point for the BJT and ensuring that the feedback mechanism keeps it stable. This can be done by finding the right combination of R_C, R_B and value of β.

Typically, the implementation is different though with the feedback resistor at the emitter (***emitter-degenerated CE amplifier***).

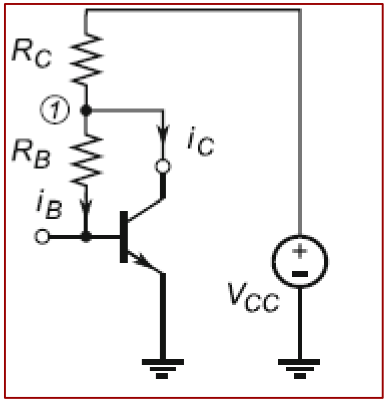
On the source loop $V_{BB} = R_B I_B + V_{BE} + R_E I_E$

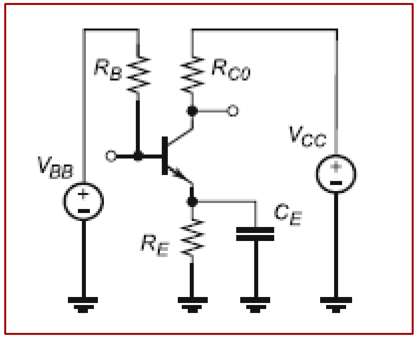
If R_E is close to 0 then $V_{BB} = R_B I_B + V_{BE} = R_B I_c/\beta + V_{BE}$

If R_E is not 0, then $V_{BB} \approx V_{BE} + R_E I_C$ (assume $I_C \approx I_E$ and $R_B I_B$ small)

In other words, I_C depends only on the voltages at base and emitter and on R_E, but not on beta. The BJT is biased.

Note the capacitance C_E to provide a different signal path for AC signals as those should not be affected by the biasing feedback





AC behaviour – Miller capacitance

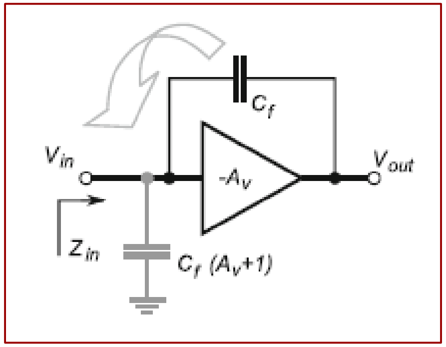
So far we have only analysed DC circuits (low frequency approximation). Let us start with considering the AC circuit shown below.

This is an inverting amplifier where the gain is Av>1 and there is a capacitance C between input and output. If the amplifier is ideal (no input current inside it) one can write $\boxed{i_{in} = \frac{v_{in} - v_{out}}{Z_C} = \frac{v_{in} + A_v v_{in}}{Z_C} = \frac{v_{in}(1 + A_v)}{Z_C}}$ $\boxed{Z_{in} = \frac{v_{in}}{i_{in}} = \frac{Z_C}{1 + A_v}}$

Rearranging the formula we obtain $\boxed{Z_{in} = \frac{1}{j\omega C\,(A_v + 1)} = \frac{1}{j\omega C_M}}$ where $\boxed{C_M = C\,(A_v + 1)}$

C_M is the ***Miller capacitance*** and is the effective capacitance seen at the input of the amplifier by a source. Combined with the source resistance Rs it has a low-pass filter effect, practically limiting the range of frequencies at which our amplifiers can work.

<u>3 conditions for Miller capacitance</u>: inverting amplifier, gain >1, and capacitance feedback between input and output.



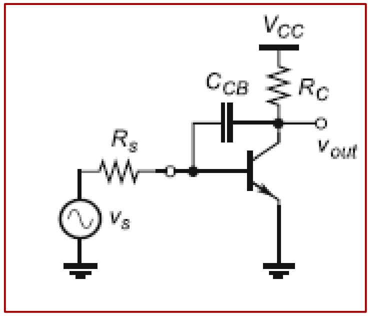
AC behaviour – Miller capacitance

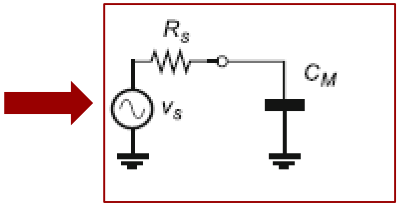
An example. We consider an ideal CE inverting amplifier with voltage gain $|A_v|$ equal to 99. The amplifier is driven by a source with $R_s=50\Omega$ and there is a small capacitance C_{CB} (1pF) between base and collector.
<u>Calculate the range of useful input frequencies.</u>

Useful input frequency??? => the bandwidth of the filter, i.e. those frequencies for which the gain is above the 3dB power threshold.

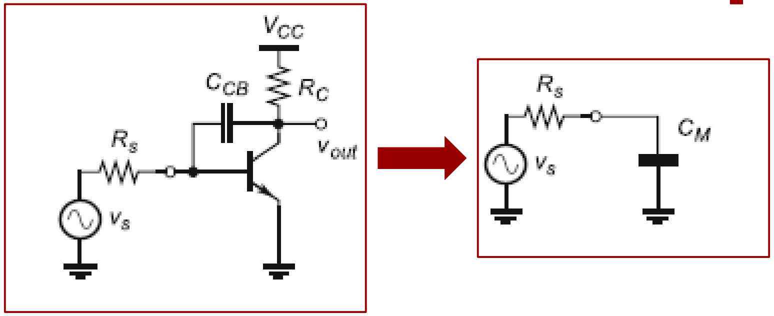
How to approach this??? => use Miller capacitance and construct the LPF equivalent to the original circuit as in the figure below.

Calculate the cut-off frequency using the physical value of the capacitance and then using Miller capacitance. You should get ~ 3.2 GHz and 32 MHz, a really significant difference!





AC behaviour – Miller capacitance



In other words, the Miller effect reduces the bandwidth of our amplifier. This is something to consider when designing RF amplifiers in CE mode.

Note that the capacitance CCB is related to the physical manufacturing of the BJT, and cannot be avoided.

Also, any capacitance in the feedback path between output and input will create Miller capacitance effect (even if it is not a pure capacitor, but an impedance with some capacitive parts).

AC behaviour – RF Tuning

So far we have assumed that amplifiers behave in the same way (same gain, same input/output R) for all frequencies from DC to the Miller capacitance limit.

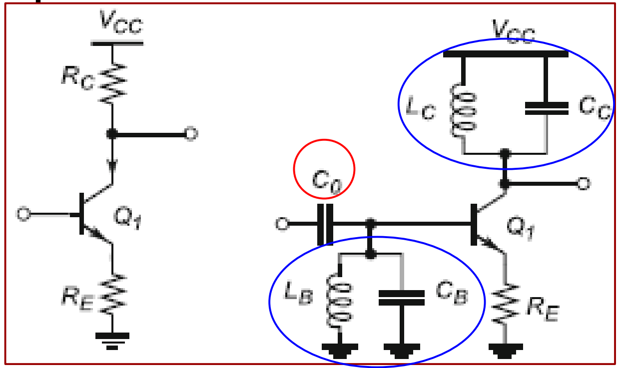
However, we do not need to amplify such a large bandwidth all the time!
It does waste energy and it reduces the SNR (the amplified signals outside the useful bandwidth contribute to the noise floor!).

In other words we need to "**tune**" the input and output of the amplifiers to **match** a specific bandwidth of signal we are interested in, as well as matching the amplifier to the neighbouring components.

The easiest way to do this is adding an *LC resonator* at both input and output of the amplifier.
Ideally an LC resonator let pass only signals at the resonant frequency $\boldsymbol{f_0} = {}^{1}\!/_{2\pi\sqrt{LC}}$ and blocks all other frequencies (ideal band-pass filter).
Resonators will be studied later on more in details.

AC behaviour – RF Tuning

We can look at the circuit below where a CE amplifier is tuned and turned into an RF CE amplifier by adding two resonators (L_BC_B and L_CC_C) at input and output, and a decoupling capacitor C_0 at the input.



<u>So ideally</u>

--C_0 let pass all AC signals but blocks DC biasing

--L_BC_B and L_CC_C are tuned to the same resonant frequency

--L_BC_B and L_CC_C at the resonance behaves like a very high (infinite ideally) resistance. Hence, does not affect the AC signal into the base (input) and acts as large load resistor (output) increasing the gain of the amplifier ($Av = g_m R_L$)

<u>In practice</u>

--L_BC_B and L_CC_C will have an operational band of frequencies around the resonance that can pass, behaving basically as a double narrowband band-pass filter

Note that the tuning can be also applied to other topologies (CB for example)

Summary – Circuit view of amps

What have we seen so far?

- There are 4 model of amplifiers depending on their input and output

- There are 3 key parameters: input R, output R, and voltage gain

- There are 3 main topologies (CB, CE, CC and then cascode) of amplifiers implemented using BJT (or FET transistors)

- The amplifier will need a biasing circuit to fix its DC operating point and set its gain and parameters; the biasing circuit can be omitted when analysing the gain (assume set β)

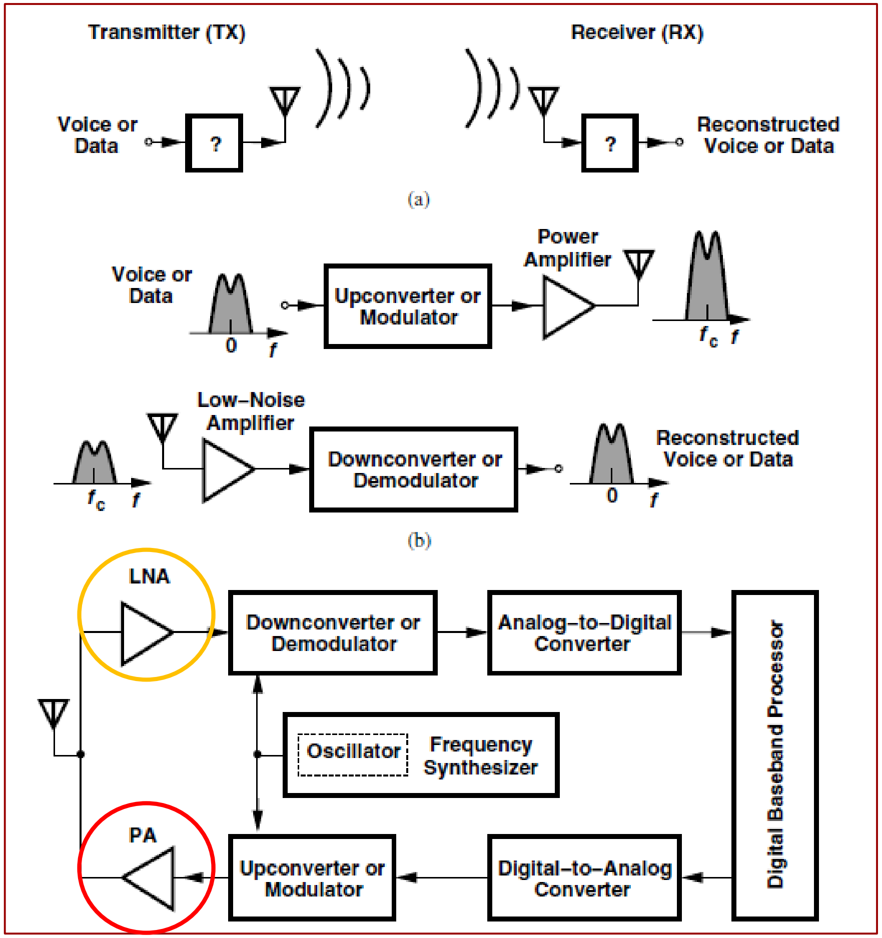
- The behaviour of the amplifier depends on frequency: Miller capacitance effect and RF tuning

System view of amplifiers

We have discussed some (high level) details of the circuits/components to make amplifiers. Now we want to go back and have a "system-level" view. Let us look at the figure (1.4 from Razavi's book).

First of all we note that there are two types of amplifiers: **PA** power amplifiers at the transmitter, and **LNA** low noise amplifiers at the receiver. They will be designed to maximise different metrics of quality, but these metrics will be defined similarly.

We now have a look at such metrics to help engineers choose between amplifiers.



LNA example

A possible LNA from Minicircuits ZX60-3011 – https://ww2.minicircuits.com/pdfs/ZX60-3011+.pdf

Parameters

-frequency
-noise figure
-gain
-gain flatness
-out power @1dB compression
-output 3rd order intercept
-VSWR
-DC supply voltage/current
-input RF power

Coaxial

Low Noise Amplifier

ZX60-3011+

50Ω   400 to 3000 MHz

CASE STYLE: GC957

Connectors	Model	Price	Qty.
SMA	ZX60-3011+	$139.95 ea.	(1-9)

+RoHS Compliant
The +Suffix identifies RoHS Compliance. See our web site for RoHS Compliance methodologies and qualifications

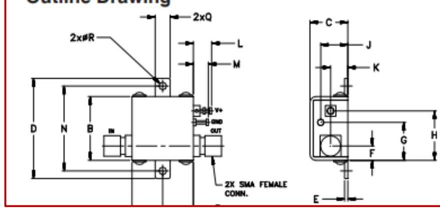
Features
- high dynamic range
- wide bandwidth, 400 to 3000 MHz
- low noise figure 1.5 dB typ.
- 1dB compression, +21 dBm
- medium IP3
- reverse voltage connection protected
- over-voltage transient protected
- low cost
- protected by US patent 6,790,049

Applications
- buffer amplifier
- LO amplifiers for mixers
- cellular
- PCN
- general purpose small signal

Electrical Specifications at 25°C

Parameter	Condition (MHz)	Min	Typ.	Max.	Units
Frequency		400		3000	MHz
Noise Figure	400-1000		1.4	2.5	dB
	1000-1700		1.5	2.5	
	1700-2400		1.7	2.6	
	2400-3000		1.8	2.8	
Gain	400-1000	12	15.0		dB
	1000-1700	11	13.5		
	1700-2400	9	11.5		
	2400-3000	7.5	10.0		
Gain Flatness	400-1000		±.70		dB
	1000-1700		±1.0		
	1700-2400		±1.0		
	2400-3000		±.70		
Output Power at 1dB compression	400-1000	19.5	21.5		dBm
	1000-1700	19.5	21.5		
	1700-2400	18.5	21.0		
	2400-3000	18.0	20.4		
Output third order intercept point	400-3000		31		dBm
Input VSWR			1.7		:1
Output VSWR			1.6		:1
DC Supply Voltage			12		V
Supply Current			120		mA

Outline Drawing



Maximum Ratings

Parameter	Ratings
Operating Temperature	-40°C to 85°C Case -40°C to 60°C ambient
Storage Temperature	-55°C to 100°C
DC Voltage	+6.5 V Min. to 15V Max.
Input RF Power (no damage)	+15 dBm
Power Dissipation	1.12W Typ. at 12V

[1] Other voltages available in the 6.5 to 20V range, please contact factory.
Permanent damage may occur if any of these limits are exceeded.

PA example

A possible Medium PA from Minicircuits ZHL-42 – https://ww2.minicircuits.com/pdfs/ZHL-42+.pdf

Parameters

-frequency

-gain

-gain flatness

-out power @1/3 dB compression

-noise figure

-output 3rd order intercept

-VSWR

-DC supply voltage/current

-input RF power

Same as before!

Coaxial

Amplifier **ZHL-42+**

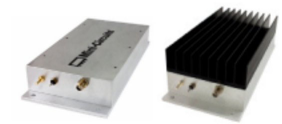
50Ω Medium High Power 600 to 4200 MHz

Features

- wideband, 600 to 4200 MHz
- high IP3, +44 dBm typ.
- high gain, 35 dB min.

Applications

- communication systems
- cellular
- instrumentation
- laboratory



ZHL-42X+ ZHL-42+

CASE STYLE: U36

Connectors	Model
SMA	ZHL-42+
SMA	ZHL-42X+

+RoHS Compliant
The +Suffix identifies RoHS Compliance. See our web site for RoHS Compliance methodologies and qualifications

Electrical Specifications at 25°C

Parameter	Condition (MHz)	ZHL-42+ ▲ZHL-42X+ Min.	Typ.	Max.	Units
Frequency Range		600	—	4200	MHz
Gain	600-4200	35	38	42	dB
Gain Flatness	600-4200	—	±0.8	±1.3	dB
Output Power at 1dB compression	600-4200	+28	+30	—	dBm
Output Power at 3dB compression	600-4200	+29	+31	—	dBm
Noise Figure	600-4200	—	8.5	—	dB
Output third order intercept point	600-4200	—	+44	—	dBm
Input VSWR	600-4200	—	1.5	2.5	:1
Output VSWR	600-4200	—	2.0	2.5	:1
DC Supply Voltage		—	15	—	V
Supply Current		—	—	1.0	A

Open load is not recommended, potentially can cause damage. With no load derate max. input power by 20 dB.

▲Heat sink not included. Alternative heat sinking and heat removal must be provided by the user to limit maximum base-plate temperature to 65°C, in order to ensure proper performance. For reference, this requires thermal resistance of user's external heat sink to be 1.3°C/W max.

Maximum Ratings

Parameter	Ratings
Operating Temperature	-20°C to 65°C
Storage Temperature	-55°C to 100°C
DC Voltage	+20V
Input RF Power (no damage)	+5 dBm

Permanent damage may occur if any of these limits are exceeded.

Amplifier selection metrics

Choosing your amplifier for your design -> need to understand the specs and the metrics to make “your shopping list”

Vendor: Minicircuits

Hide Filter - | All ezsamples | Send to a Friend | Export to Excel

Interface	Category		F Low (MHz)	F High (MHz)	Gain (dB) Typ.	NF (dB) Typ.	P1dB (dBm) Typ.	OIP3 (dBm) Typ.	Voltage (V)	Current (mA)	Connector Type	Options
SMT	Low Noise Amplifiers (NF < 3 dB)	Gain Blocks								≤	N	Bracket
Die	High Power Amplifiers (>2W)	Variable Gain Amplifiers									F	Heat Sink
☑ Connector	Linear Amplifiers (IP3 > +40 dBm)	Dual Matched Amplifiers									BNC	
Plug-in	CATV Amplifiers (75Ω)	Pulse Amplifiers									SMA	
Rack											SMA-N	
											2.92mm	

Model Number	F Low (MHz)	F High (MHz)	Gain (dB) Typ.	NF (dB) Typ.	P1dB(dBm) Typ.	OIP3 (dBm) Typ.	Input VSWR (:1) Typ.	Output VSWR (:1) Typ.	Voltage (V)	Current (mA)	Case Style	Connector Type	Option
LZY-22+	0.1	200	43	8.9	42	52	1.4	4	24	6000	BT1598	SMA	Heat Sink
LZY-22X+	0.1	200	43	8.9	42	52	1.4	4	24	6000	BT1598	SMA	-
ZEL-0812LN	800	1200	20	1.5	8	18	2.5	2.5	15	70	EEE132	SMA	-
ZEL-1217LN+	1200	1700	20	1.5	10	25	2.5	2.5	15	70	EEE132	SMA	-
ZEL-1724LN+	1700	2400	20	1.5	10	22	2.5	2.5	15	70	EEE132	SMA	-

View Full Parametric Table | Reset Table | Hold Shift Key for secondary sorting

Vendor: Analog Devices

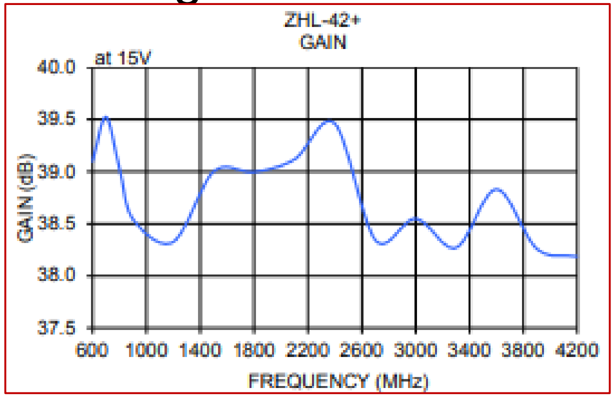
Part#	RF Primary Function	Freq Response RF (min) (Hz)	Freq Response RF (max) (Hz)	Gain (typ) (dB)	OP1dB (typ) (dBm)	OIP3 (typ) (dBm)	NF (typ) (dB)	Device Match	Vs (typ) (V)	Is (typ) (A)	Price (100-499) ($ US)
HMC1040-Die	LNA	20G	44G	21	14	25.5	2.5	Internal	2.5	65m	$34.93 (HMC1040CHIPS)
HMC8325	LNA	71G	86G	21	13	22	3.6	Internal	3	50m	$61.89 (HMC8325)
ADL7003	LNA	50G	95G	14	14	21	5.5	Internal	3	120m	$215.62 (ADL7003CHIPS)

Metrics

We can look at some of the metrics of interest – you may also check https://ww2.minicircuits.com/pages/pdfs/amp3-4.pdf

Frequency range.
Self-explanatory. It is the minimum and maximum frequency between which the amplifier can operate properly with acceptable gain and performances.

Gain and gain flatness.
The power/voltage ratio between output and input, typically measured in dB. It is normally expressed with a typical value, and with its maximum and minimum. The flatness takes into account the fluctuations/variations of the gain as a function of frequency (see the example below for ZHL-42)



Isolation.
It is the ratio between the power measured at the input of the amplifier to the applied power at the output.

Metrics

Noise figure.
Typically expressed in dB, it takes into account the noise introduced/generated by the amplifier. You can consider this as additional noise present at your output signal.

DC voltage and current supply.
This is the DC voltage you need to provide to the amplifier to make it work properly, and the current that the amplifier will draw.
Some amplifiers can work with different supply voltages and in that case they may have different gain/noise curves depending on the supply voltage.
Note that the current drawn can be a first debug indicator for checking the “health” of your amplifier. No current or very high current -> problems!

RF input power.
The maximum amount of power your input signal should have, in order to avoid damaging the amplifier. You may need ***attenuators*** otherwise (components that reduce the signal power)

Metrics

VSWR.

It stands for Voltage Standing Wave Ratio. It can be also expressed with another parameter, the **Return Loss (RL)**, which is the ratio of the reflected power to the incident power at the RF port of an amplifier

$$RL = -20\log_{10}\left|\frac{Vref}{Vinc}\right|; VSWR = \frac{1+10^{-\frac{RL}{20}}}{1-10^{-\frac{RL}{20}}}; \left|\frac{Vref}{Vinc}\right| = \frac{VSWR-1}{VSWR+1}$$

Minimum reflections (extreme case of no reflections at all) -> theoretical value for the RL is infinity, leading to VSWR = 1.

Maximum reflections (total, specular reflections) -> theoretical value for the RL is 0, leading to VSWR to infinity.

Practically you want values as close to 1 as possible. Rule of thumbs.

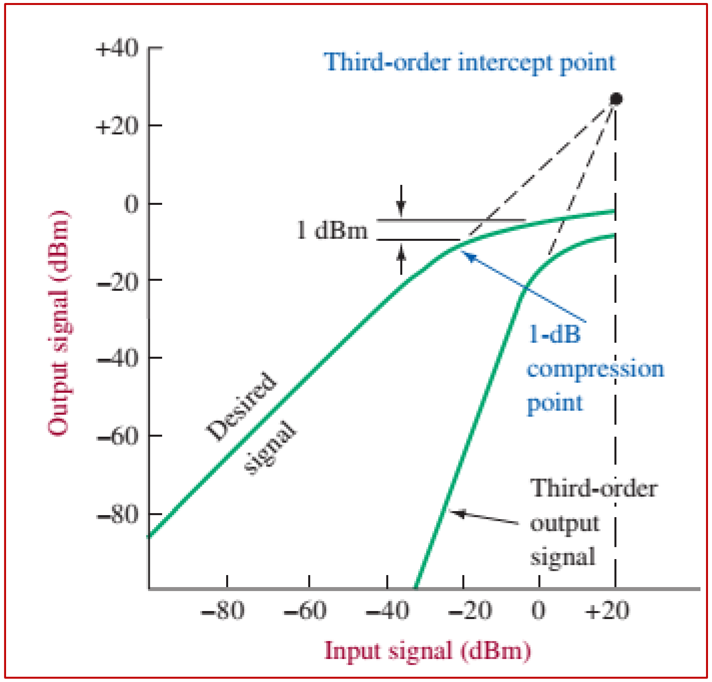
Half voltage reflected -> RL~-13 dB, VSWR ~ 1.5

75% voltage reflected -> RL~-5.7 dB, VSWR ~ 3.13

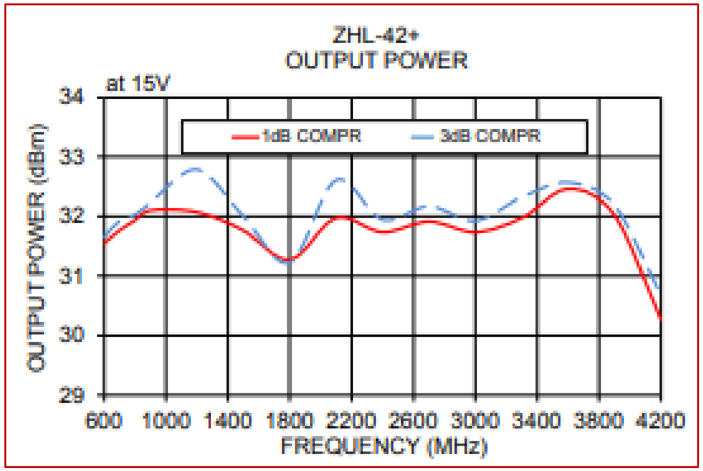
Metrics

Output power. *(see Beasley-Miller book, pp 313-314)*

The output power is typically measured by measuring the output signal at different frequencies and finding the ***1(3)dB compression point***, the point in the output/input relationship where the output is 1(3) dB below the ideal linear trend. That can be considered as the upper limit of the power obtainable from that amplifier.



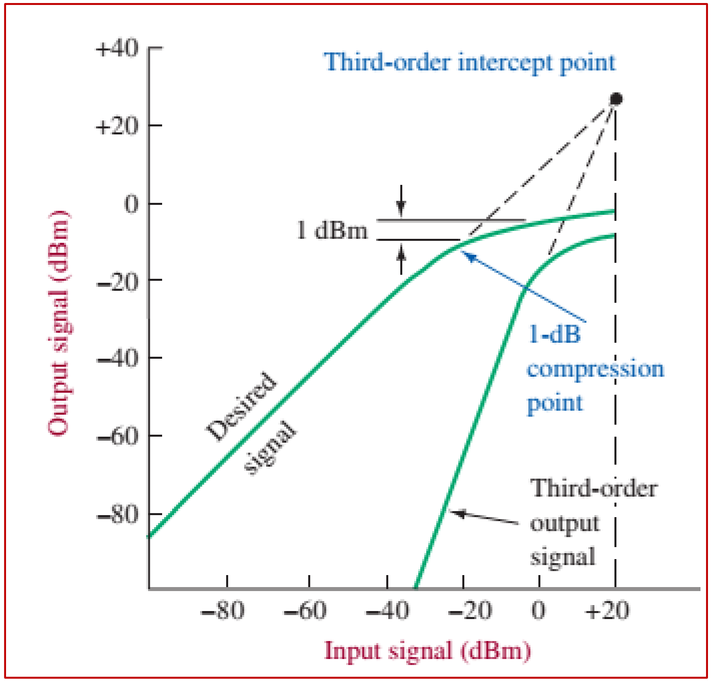
Below an example for the ZHL-42 model



Metrics

3rd order intercept point (OIP3). *(see Beasley-Miller book, pp 313-314)*

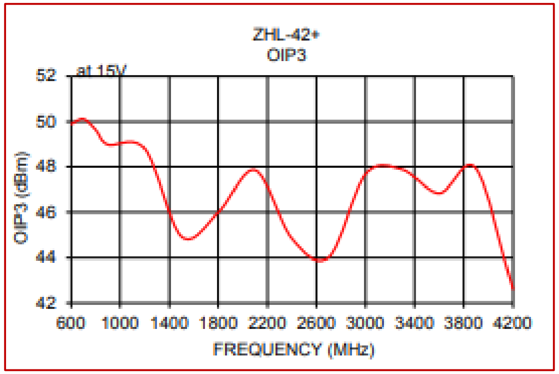
This parameter takes into account how the amplifier rejects intermodulation distortion from ***3rd order products*** generated by mixing stages.



Typically, if we mix signals with two different frequencies (say f_1 and f_2), the ***third order intermodulation products*** at frequency $2f_1 \pm f_2$ and $2f_2 \pm f_1$ can be in the tuned band of the amplifier.

The OIP3 parameter is the output power at the point where the linear extension of the gain of the desired signal and the gain of the 3rd order products intercept. Ideally the higher the better.

Note that it depends on frequency ---------→



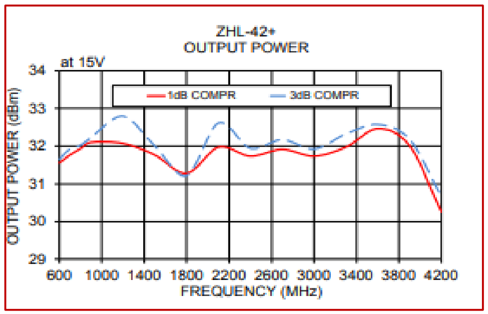
Back to PA and LNA

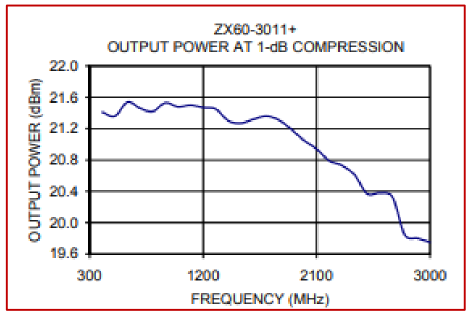
Let us compare three models from Minicircuit – which one would you choose?

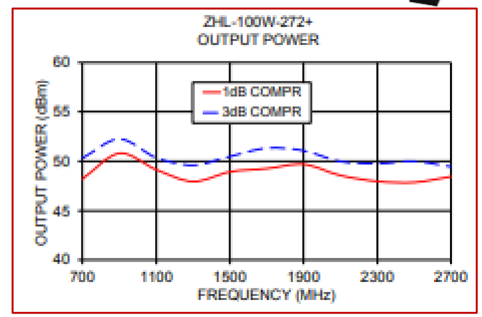
MPA

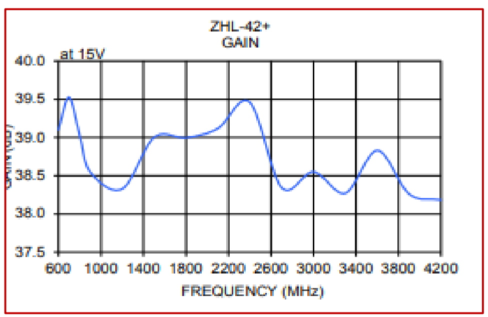
LNA

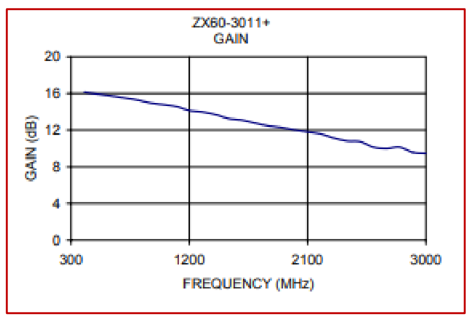
HPA

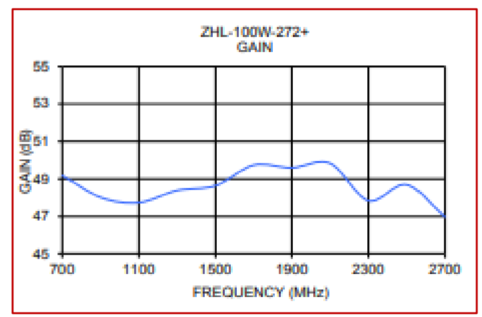




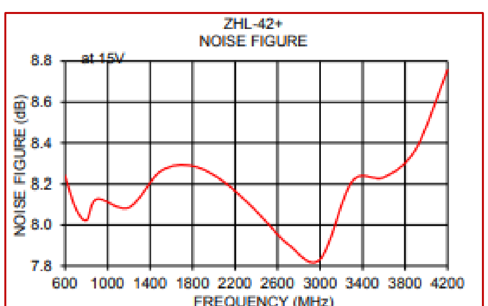


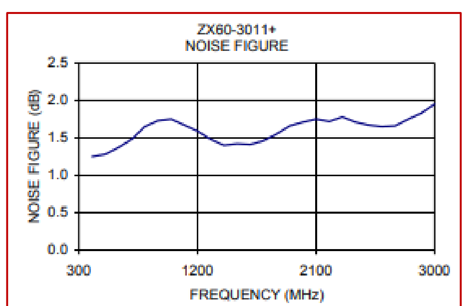


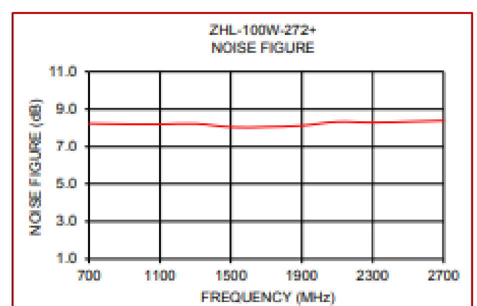




Note the heatsinks!







~$900

~$140

~$8000

Design test

You are asked to find an amplifier for the receiver of a radar system that must operate at C-band (4GHz-8GHz) and low X-band (8-9 GHz).
It is desirable that the amplifier has an output power above 100 mW to drive the Analog-to-Digital converter.

Which one from Mini-Circuit would you buy?
https://ww2.minicircuits.com/WebStore/Amplifiers.html

There may be more than one correct answer!

Would you consider other parameters? Cost constraints? Noise figure? Available gain (i.e. can you actually go above 100 mW output power)?

Summary – System view of amps

What have we seen so far?

- Briefly mentioned the difference between low-noise and power amplifiers
- Some familiarity with datasheets of real amplifiers
- Metrics of quality to describe and compare amplifiers

In future work we will see how amplifiers are used in wider communication systems and how as an engineer you may be asked to select them – Key:
--it may be hard to find the amplifier that satisfies all the requirements
--the amplifier interacts with connected blocks (you need to know what you connect it to)

If you feel curious, you may want to quickly read through pages 135 (AM modulation) and 261 (FM modulation) of the Beasley-Miller book, but we will review that later on in this course