EEEN3006J

Wireless Systems

Dr. Declan Delaney

(declan.delaney@ucd.ie)

Beijing Dublin International College

Purpose of this lecture

- As we have seen, wireless signals are often very weak. For this reason, we must use amplifiers to boost the signal.
- In this lecture, we will discuss some aspects of these, in particular of FET and bipolar transistors.

Purpose of this lecture

- Wireless signals are often very weak; powers of pW and smaller are common. We must amplify these signals to make them useful.
- We often require these amplifiers have
  - high gain
  - low noise
  - and high bandwidth

  Difficult combination, especially at high frequencies
- All of this is required at high frequencies.
  - As we will see, we can sometimes design our systems so key steps occur at lower frequencies.

- Most radio frequency systems now use transistors.
  - Gallium arsenide Field Effect Transistors (FETs).
  - Silicon or silicon germanium bipolar transistors (BJTs).
  - Heterojunction bipolar transistors (HBTs).
  - High electron mobility transistors (HEMTs).
- These transistors are cheap, reliable and can be used in discrete or integrated circuits.

- Transistor amplifiers
  - Can be used for frequencies up to 100GHz.
  - Are available in low-noise designs.
  - Can be used up to medium power.

- For high power applications, tube amplifiers are still used, but transistors still being developed.

FET and Bipolar transistors

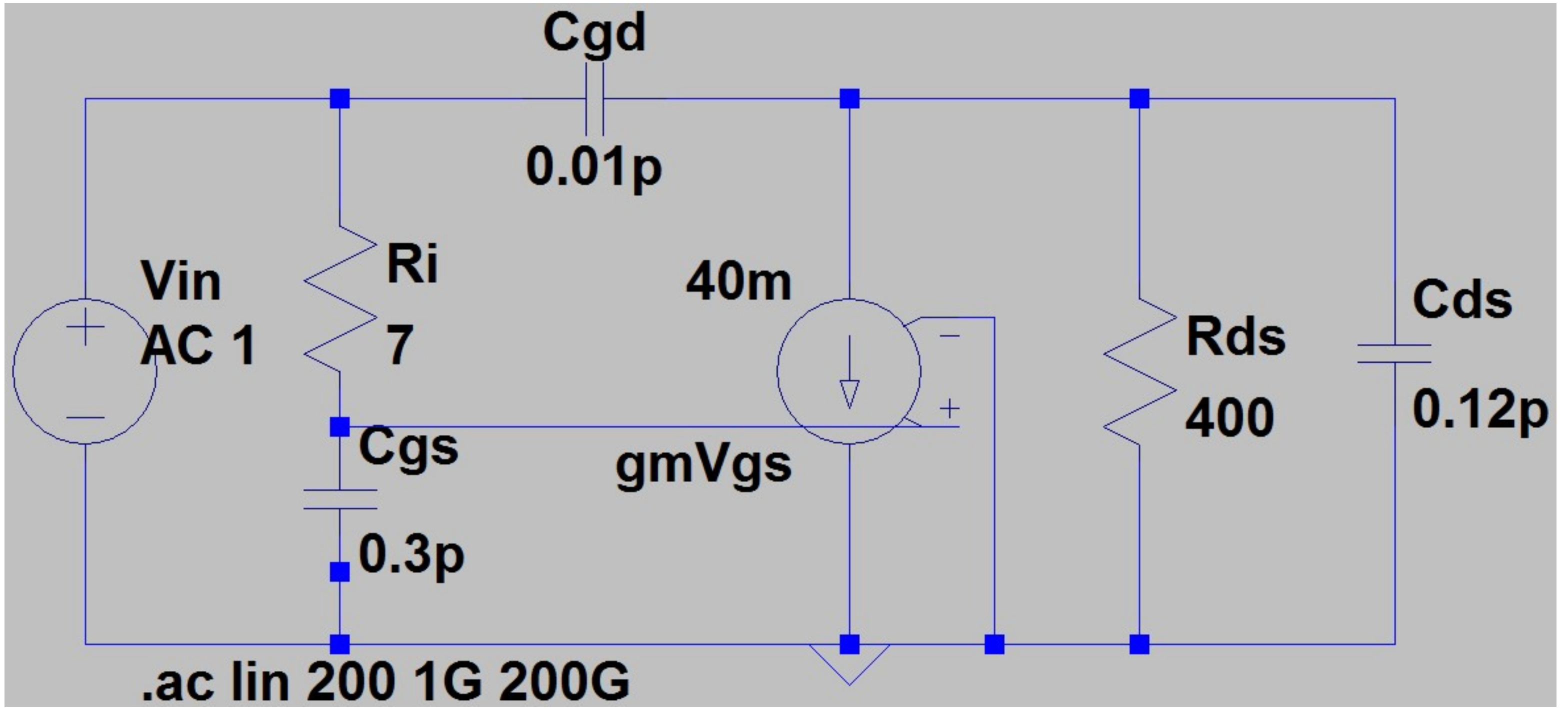
Frequency	GaAs FET		GaAs HEMT		Si Bipolar		GaAs HBT	
GHz	Gain	F_{min}	Gain	F_{min}	Gain	F_{min}	Gain	F_{min}
4	20	0.5			15	2.5		
8	16	0.7			9	4.5		
12	12	1.0	22	0.5	6	8	20	4
18	8	1.2	16	0.9			16	
36			12	1.7			10	
60			8	2.6			7	

The noise figure, F_{min}, describes the cost in dB to the SNR of a signal passing through the amplifier. An ideal amplifier would have a noise figure of 0.

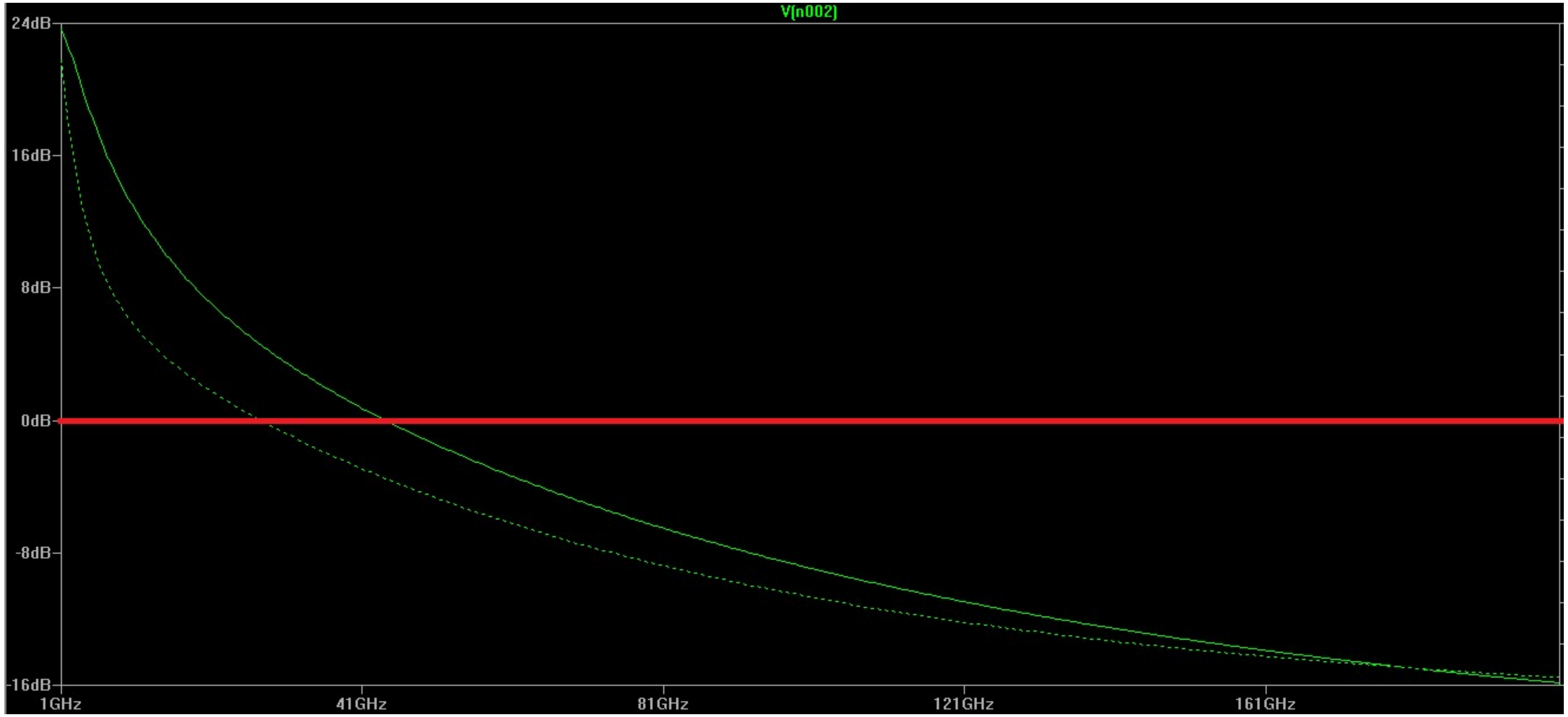
FETs

- Good gain and noise figures make them the device of choice in many applications
  - Especially for frequencies over ~5 GHz.
- GaAs devices used because of high electron mobility compared with Si.
- No shot noise.
- Max frequency limited by gate length.
  - 0.3 microns ~ 100 GHz.

Small signal model (common source)



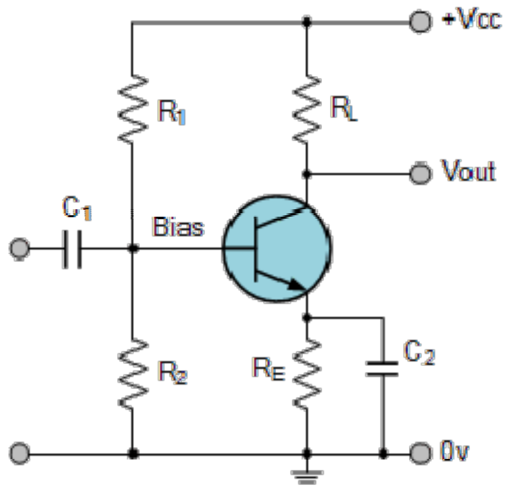
Gain vs Frequency

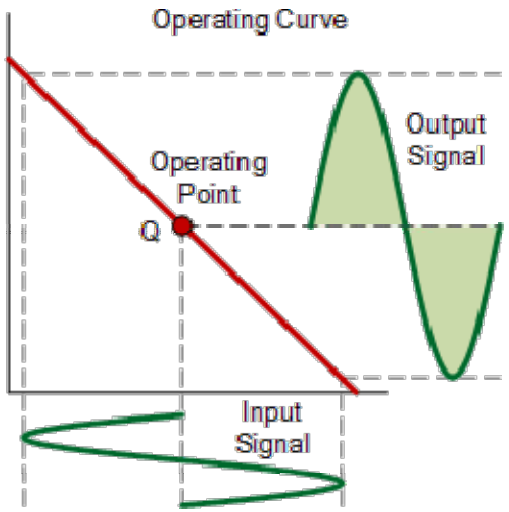


For the parameters in this example, we see that the small signal gain falls to 0 dB (i.e. 1) at ~50 GHz. Above this frequency, it is of no use as an amplifier.

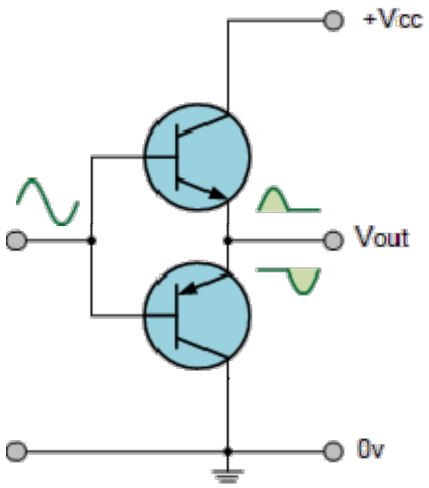
- We must apply a suitable DC bias to the transistor so it is at an appropriate operating point.
- This depends on the class (A, AB, B) and type (FET, bipolar, HBT, HEMT) of the transistor.

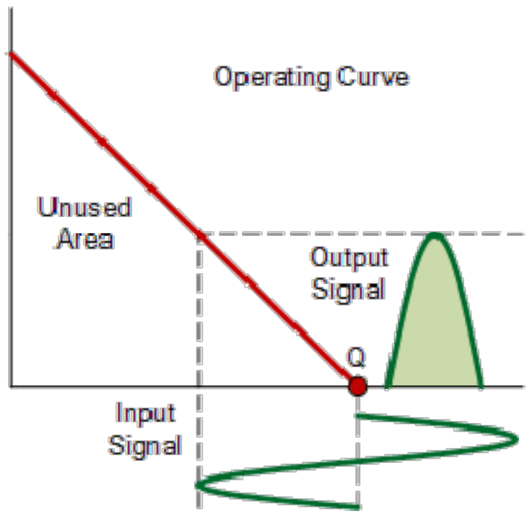
- Class A amplifier



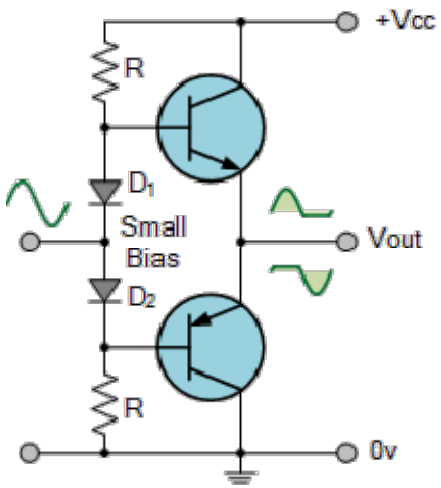


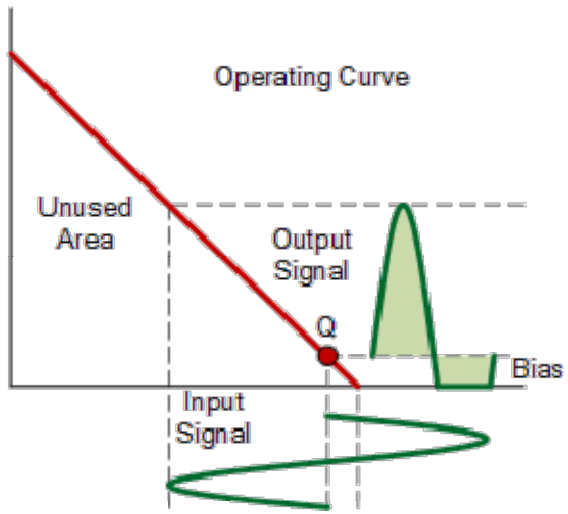
- Class B amplifier



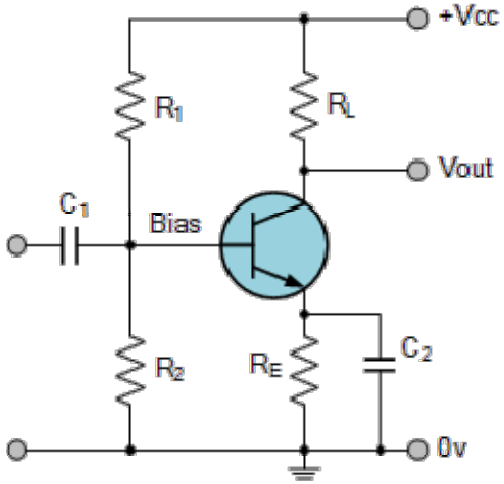


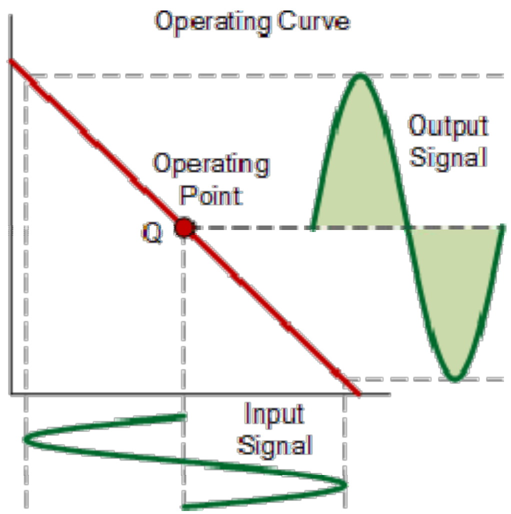
- Class AB amplifier



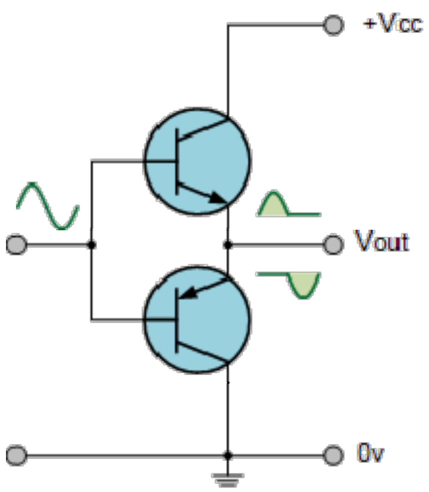


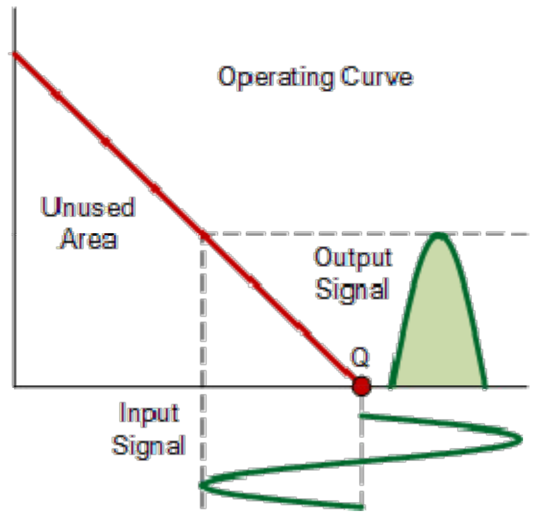
- Class A amplifier – always biased on.



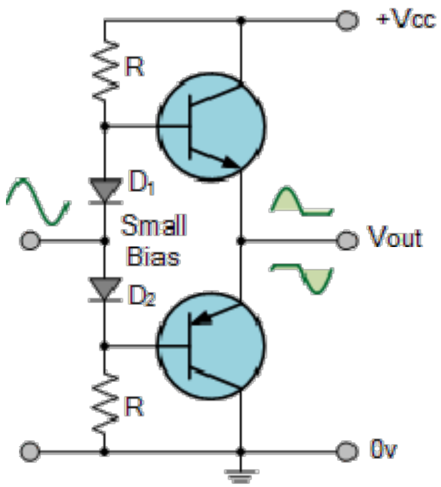


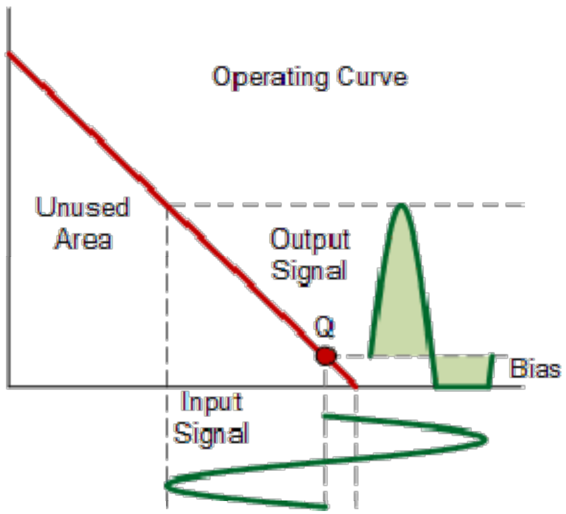
- Class B amplifier – complementary pair of transistors.
  - Trades linearity for better efficiency and lower heating.





- Class AB amplifier – variation of a class B where both devices conduct at the same time around the waveforms crossover point eliminating the crossover distortion problem.





Bipolar transistors

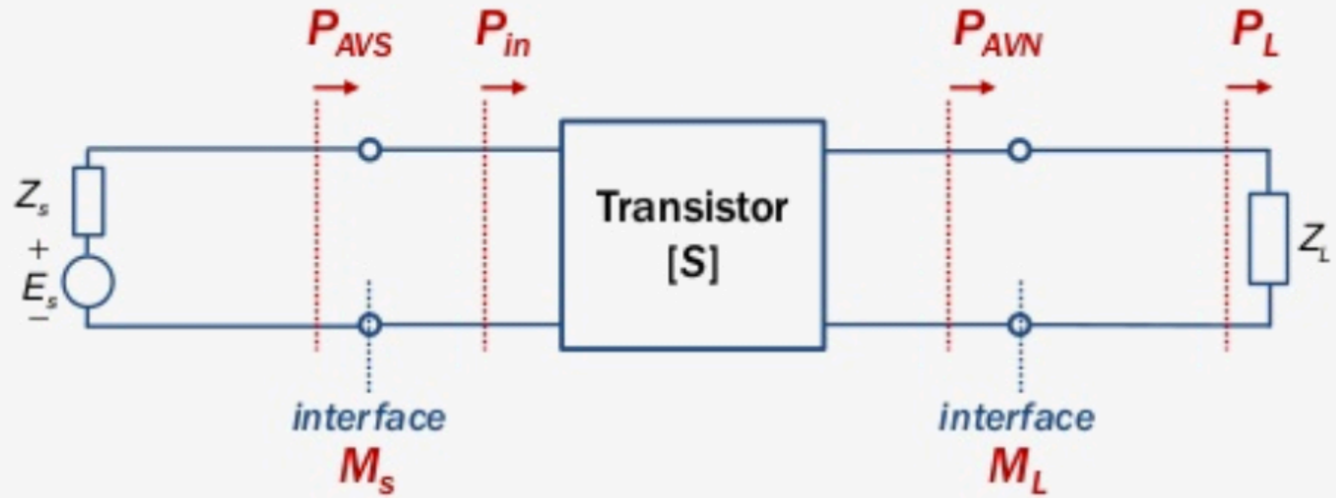
- Usually npn type.
- Often preferred under 4 GHz for higher gain and lower cost.
  - Higher transconductance in small signal model leads to higher gain, but larger capacitances degrade performance at higher frequencies more quickly.
  - Upper frequency limit depends primarily on base length ~ 100 nm.
- Suffer from shot noise – noise figures are higher (i.e. worse) than those of FETs.

2-Port Power Gains

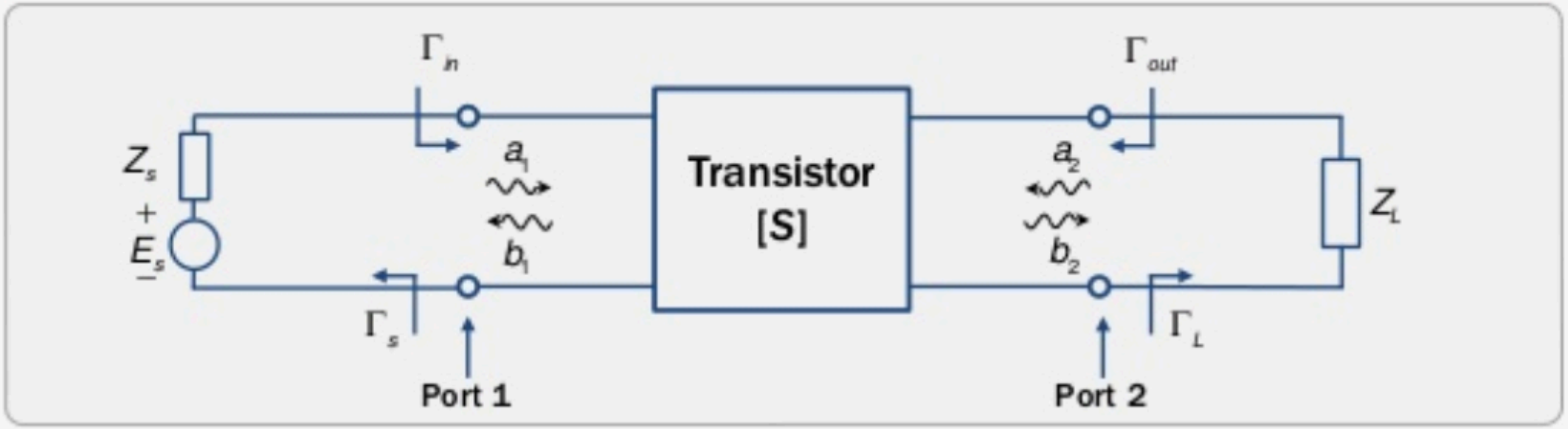
- There are different definitions of gain – power gain, available gain and transducer gain – but they are all the same if the source and load are matched to the input and output impedance of the amplifier.
- The gain can be given in terms of the S parameters and load impedance:

$$G = \frac{|S_{21}|^2(1-|\Gamma_L|^2)}{(1-|\Gamma_{in}|^2)|1-S_{22}\Gamma_L|^2}$$

- where $\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}$ and $\Gamma_L = \frac{Z_L-Z_0}{Z_L-Z_0}$.



- The power gain $G_p = \dfrac{P_L}{P_{in}}$ — From the amplifier input to load
- The transducer power gain $G_T = \dfrac{P_L}{P_{AVS}} = G_p M_s$ — From the source to load — $G_p > G_T$
- The available power gain $G_A = \dfrac{P_{AVN}}{P_{AVS}} = \dfrac{G_T}{M_L}$ — $G_A > G_T$
- When the Input and output are matched: $G_p = G_T = G_A$



- Consider a microwave amplifier with the source and load reflection coefficients Γ_s and Γ_L measured in a Z_o system:

$$\Gamma_s = \frac{Z_s - Z_o}{Z_s + Z_o} \qquad \Gamma_L = \frac{Z_L - Z_o}{Z_L + Z_o}$$

- For the transistor, the input and output traveling waves measured in a Z_o system (this is very practical) :

$$b_1 = S_{11}a_1 + S_{12}a_2$$

$$b_2 = S_{21}a_1 + S_{22}a_2$$

*Dept of EE, NTUT

Stability

- These amplifiers have feedback elements. This means that it is possible for them to oscillate.
- We can define regions of stability in terms of the reflection coefficients, Γ_{in} and Γ_{out}.
- The strongest constraint, called unconditional stability, requires $|\Gamma_{in}|<1$ and $|\Gamma_{out}|<1$.
- There are also conditional stability conditions where stability also depends on the source and load impedances.

Amplifier design using S parameters

- We can use the S-parameters to design for
  - Maximum gain
  - Maximum stable gain and
  - Noise figure
- However, the full analysis based on S-parameters is outside the scope of this course, and this discussion is included here only for your information.
- N.B. The design of power amplifiers is different again, as the small signal model no longer applies.