ECE 202A Nov. 8, 1989

General Comments about (unilateral) Matched amplifier design.

If unilateral

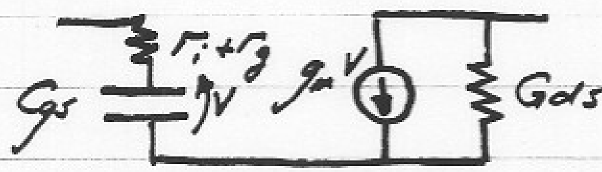
$$G_T = \frac{P_{Load}}{P_{AVS}} = G_S |S_{21}|^2 G_L$$

$$= \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2} |S_{21}|^2 \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2}$$

$$G_{MAX} = \left(\frac{1}{1-|S_{11}|^2}\right) |S_{21}|^2 \left(\frac{1}{1-|S_{22}|^2}\right)$$

⇒ Concept of Matching on input & output to attain G_{max}.

Lets look @ G_{max} for a highly simplified device model:



(no r_s, no C_{gd})

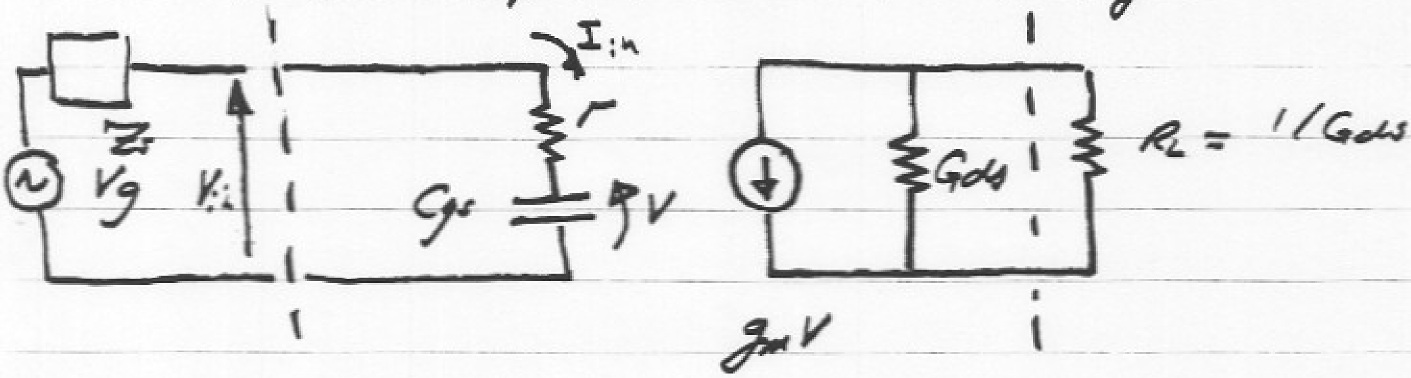
This is the simplest model for a FET to have non-infinite f_{max}.

$$G_{max} = \frac{P_{AVA}}{P_{in}} = \frac{P_{Load}}{P_{in}} \text{ \underline{if} output is matched}$$

P_{AVA}: available output power

P_{in}: power absorbed in input

Match output:



$$P_{LOAD} = \left((g_m V) \times \tfrac{1}{2}\right)^2 R_L = \frac{g_m^2}{4\,G_{ds}} \cdot |V|^2$$

$$P_{in} = |I_{in}|^2 r .$$

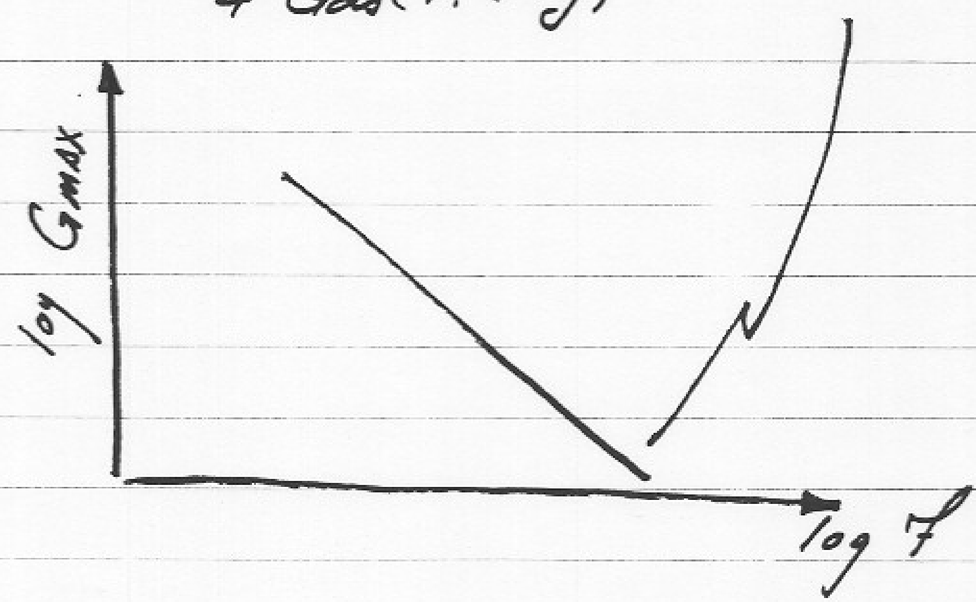
$$\text{But } \ |V|^2 = |I^2| / \omega^2 C_{gs}^2$$

$$\Rightarrow \ \frac{P_{LOAD}}{P_{in}} = \frac{P_{AVA}}{P_{in}} = G_{MAX} = \frac{g_m^2}{4\,G_{ds}} \, \frac{1}{\omega^2 C_{gs}^2} \, \frac{1}{r}$$

$$G_{max} = \frac{g_m^2 / \omega^2 C_{gs}^2}{4\, G_{ds}(r_i + r_g)} = \frac{g_m^2 / (2\pi f)^2 C_{gs}^2}{4\, G_{ds}(r_i + r_g)}$$

but $f_T = g_m / 2\pi C_{gs}$

$$G_{MAX} = \frac{f_T^2 / f^2}{4\, G_{ds}(r_i + r_g)} = 1 \text{ when } f = \frac{f_T}{2\sqrt{G_{ds}(r_i + r_g)}}$$



so $G_{max} = \dfrac{f_{max}^2}{f^2}$ where $f_{max} = \dfrac{f_T}{2\sqrt{G_{ds}(r_i + r_g)}}$

This in general can be carried out (with much more pain) for the more complete device models:

<u>Recall</u>

FET:

$$f_{max} \cong \frac{f_T}{2\sqrt{(r_g + r_s + r_i)\, G_{ds} + 2\pi f_T r_g C_{gd}}}$$

BJT:

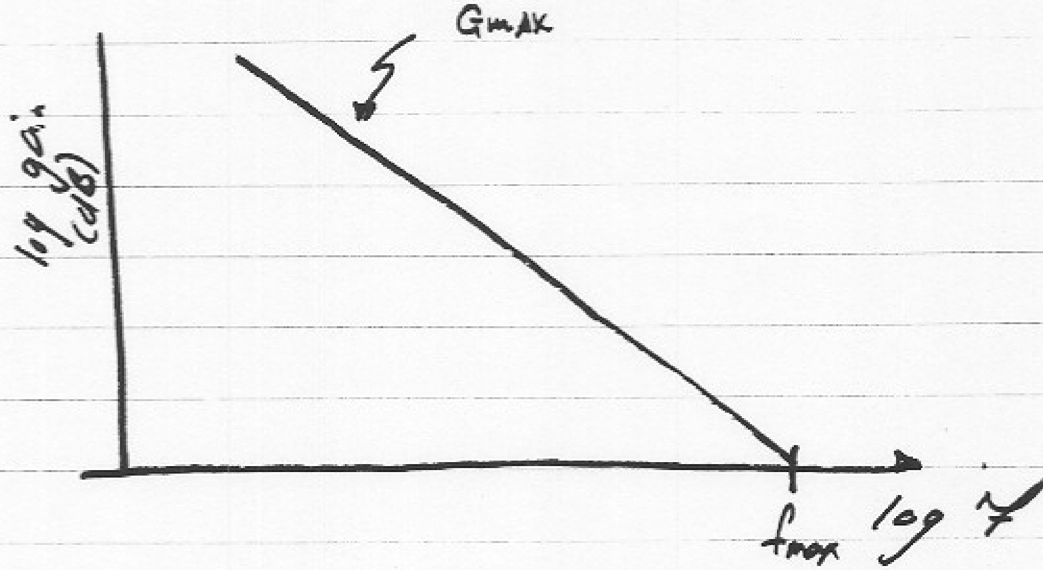
$$f_{max} \cong \frac{f_T}{2\sqrt{(r_e + r_{b'b})/r_{ce} + 2\pi f_T r_{b'b} C_{bc}}}$$

$$\cong \sqrt{\frac{f_T}{8\pi r_{b'b} C_{bc}}}$$

Again, be aware that these are only approximate expressions based on "typical" parameters.

If you put the device model into Touchstone, it will plot <u>G_{MAX}</u>

so, with our unilateral device model : 



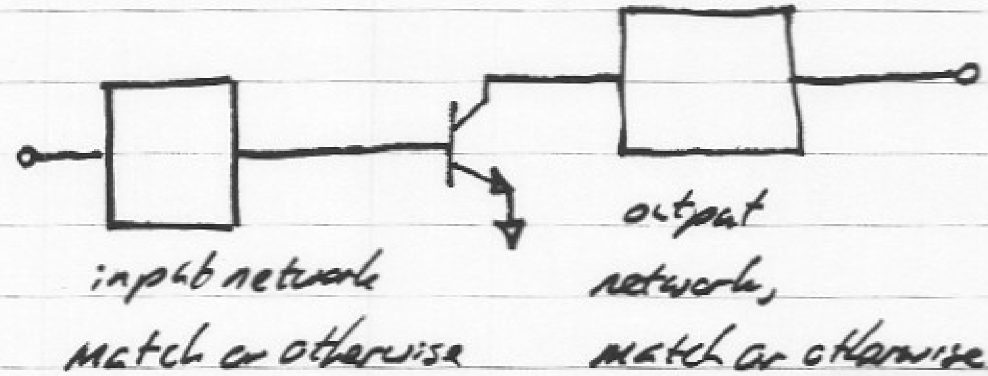
$$G_T = \frac{1 - |\Gamma_S|^2}{|1 - S_{11}\Gamma_S|^2} \, |S_{21}|^2 \, \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$

$$G_T = G_{MAX} \cdot \frac{(1 - |S_{11}|^2)(1 - |\Gamma_S|^2)}{|1 - S_{11}\Gamma_S|^2}$$

$$\cdot \frac{(1 - |S_{22}|^2)(1 - |\Gamma_L|^2)}{|1 - S_{22}\Gamma_L|^2}$$

$$= G_{MAX} \text{ if } \quad \Gamma_S = \Gamma_{in}^*, \quad \Gamma_L = \Gamma_{out}^*$$

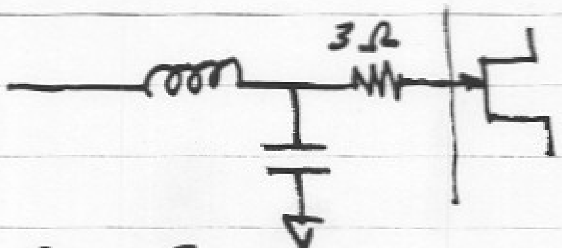
So: picture of amplifier circuit of <u>any</u> type, but no feedback.



overall power gain must be $\leq G_{max}$

Is equal to G_{max} <u>if</u> input & output are matched using <u>lossless</u> matching networks.

why not lossy networks?



$G < G_{max}$ because $P_{in\,device} = P_{gen} - P_{resistor}$

$< P_{generator}$.

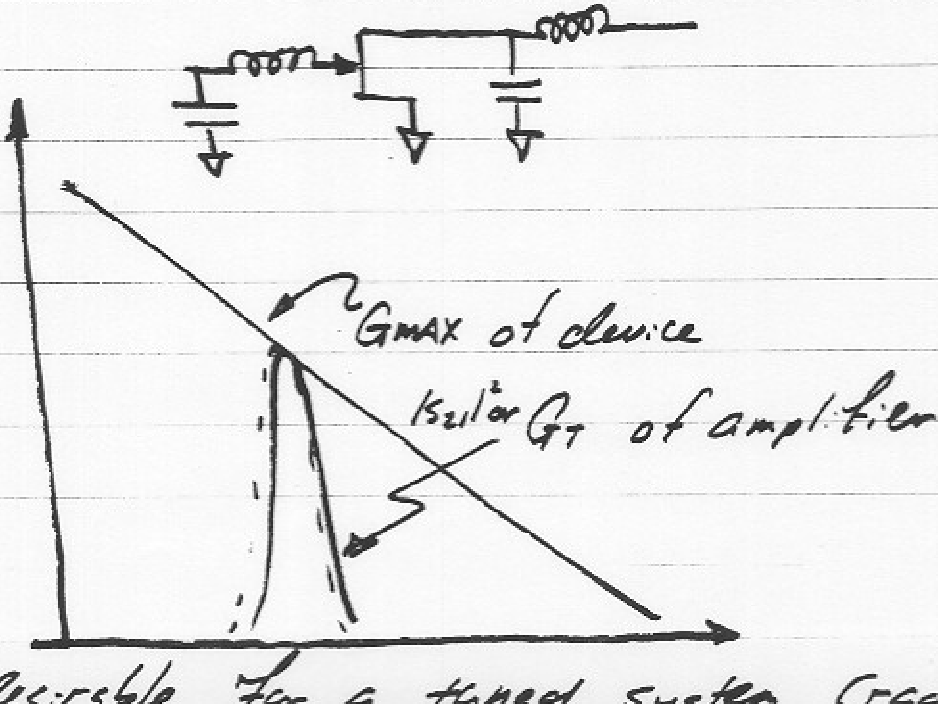
so, amplifiers fail to attain G_{MAX} because:

1) They fail to match on both input & output

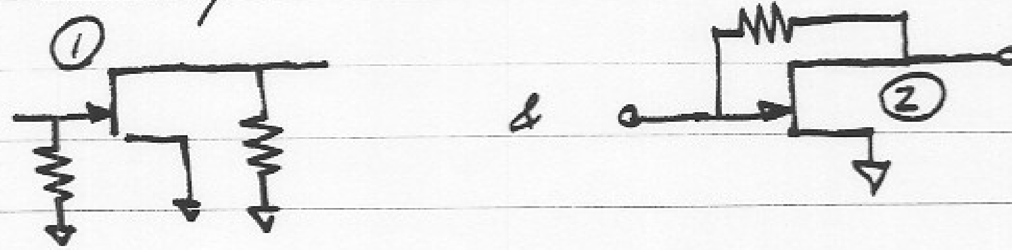
2) They use lossy elements (resistors) to attain a match.

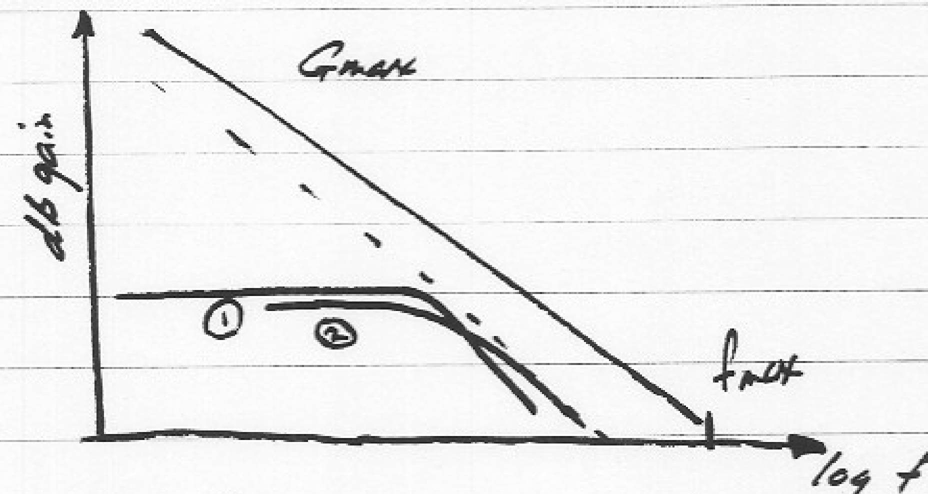
or both.

ex: matched amplifier



This is desirable for a tuned system (radio receiver, etc) ex: resistively-terminated and feedback amplifiers.

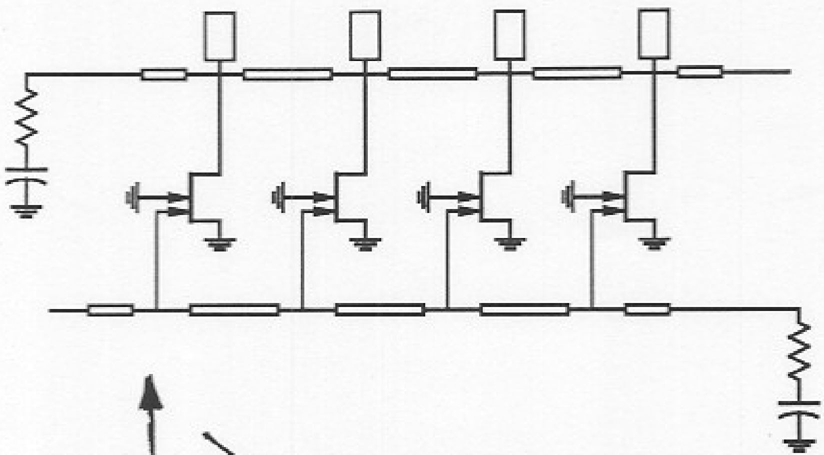


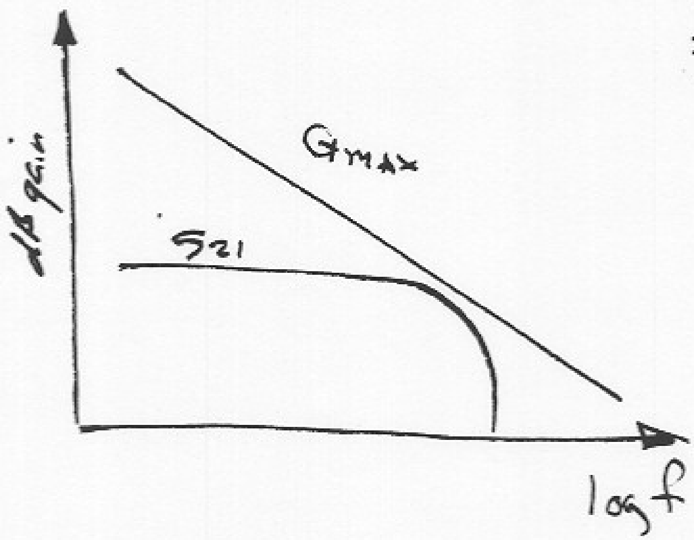


The gain-frequency curve clearly has to lie under the GMAX curve. In fact, the gain-frequency curve may be constrained <u>well</u> below this by the $(f_T/f)^2$ line, or even lower.

⇒ Flat gain, but at the expense of performance far below the fundamental limit (GMAX) of the device.

Ex: Travelling-wave Amp





So a general question is "how well are we using the available power gain of the device?"

Real-World issues:

Cost - related to die area. Here the TWA, "optimum" in one sense, is really lousy. Eats die area. F.B. Amps win due to small area.

Parameter sensitivity: Here TWA's & F.B. Amps do well, but Tuned amps (i.e. "optimum") do badly.

Stability The engineer's nightmare. Need to watch with all designs. F.B. amp probably best.

Noise Performance, Power output: Very important, but discuss later.

also Power supplies, power consumption