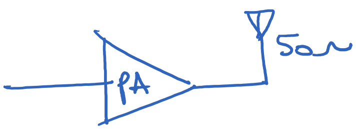
ECE 513- Lecture 27

Thursday, November 29, 2018 9:26 AM

[1] Cripps

Power Amplifiers:

* Tuned power amplifiers
  - ↳ Key component in TX path of wireless communication systems and Radars
  - ↳ Deliver the power required to transmit information to the antenna with high-efficiency and linearity over BWs of 10-20% of the center frequency.

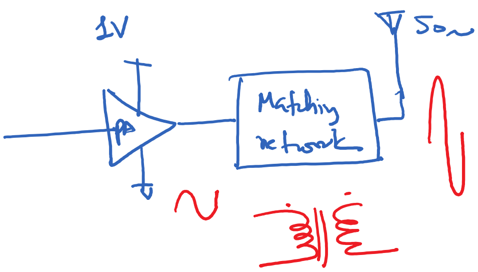


$$P_{out} = 1W \Rightarrow +30\,dBm$$

$$V_{pp} = 2V_{DD}$$

$$P_{out} = \frac{V_{DD}^2}{Z_0}$$

$$V_{DD} = \sqrt{1W \times 50\Omega} = 5\sqrt{2}\ V$$



Johnson's limit

$$V_{DD} \times f_T \simeq 200\,GHz \cdot V \text{ for Silicon}$$

* GaAs HEMT, SiGe HBT (recently), GaN
* Still challenging in CMOS to obtain high TX power and efficiency
* Base station PAs still dominated by GaAs HBTs.
* TWT (Traveling wave vacuum tubes) for very high power applications. i.e. Satellite

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Class-A PA

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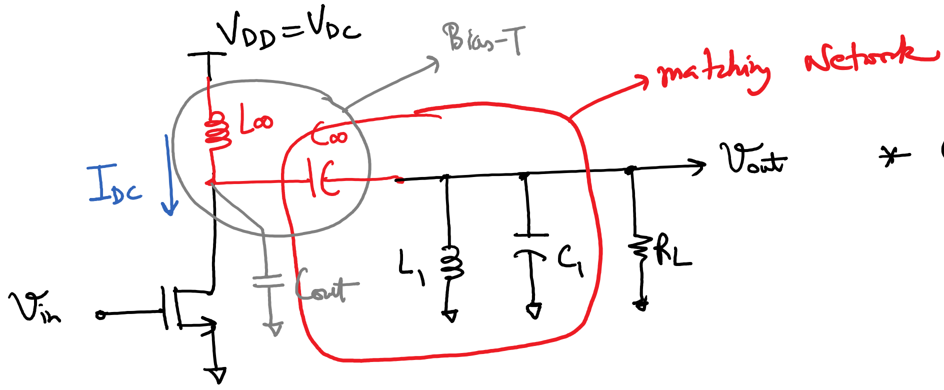

* C_∞, L_1, C_1 form a matching a network that matches transistor R_{out} to the load $R_L = Z_0 = 50\Omega$

* Very large CS transistor operating under large signal conditions with large output swing.

* The drain is biased through a bias-T
  ↳ presents an infinite inductance to V_{DD} and an infinite capacitance towards the load. $X_L = |j\omega_0 L|$
  ↳ is loaded with a parallel RLC tank (R_L, C_1, L) at the frequency of interest.

* Due to strongly nonlinear behavior, a simulation driven design methodology is required for PA design. * [1] Cripps

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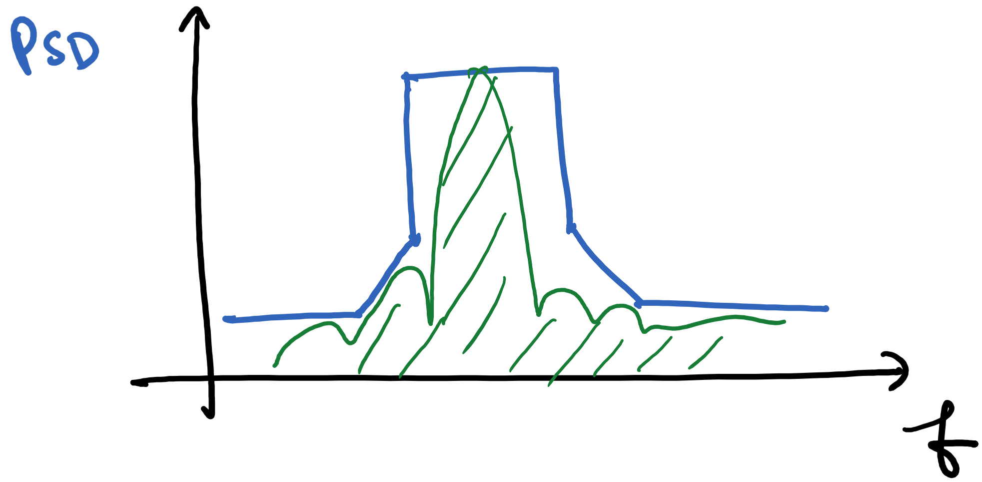
PSD Mask



Tuned PA fundamentals:

Class A–F PAs

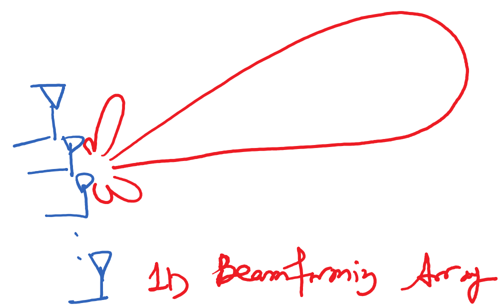
* Each class of PA has different linearity and thus it's hard to compare them

* SiGe BiCMOS

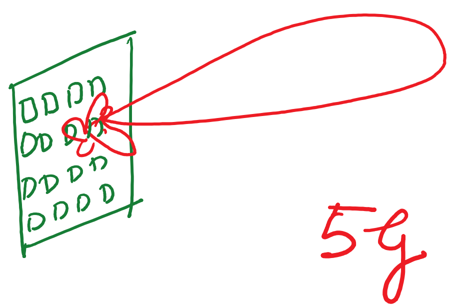
* Output power, P_{out}

* Power gain, G
* Carrier frequency, f
* Linearity (OP_{1dB})

  IP_3, OIP_3



* Power-added efficiency (PAE)
* Power backoff efficiency



* $$FoM_{PA} = P_{out} \cdot G \cdot PAE \cdot f^2$$

To compensate for the 20dB/dec rolloff of the transistor power gain as a function of frequency, a factor of f^2 is included in the FoM.

* Linearity is not included as it's class-dependent.

* Drain-efficiency $\eta_{drain} = \frac{P_{out}}{P_{DC}}$

* Power added efficiency (PAE) $\triangleq \frac{P_{out} - P_{in}}{P_{DC}}$

As the gain $G \to \infty \Rightarrow$ PAE $\to \eta_{drain}$

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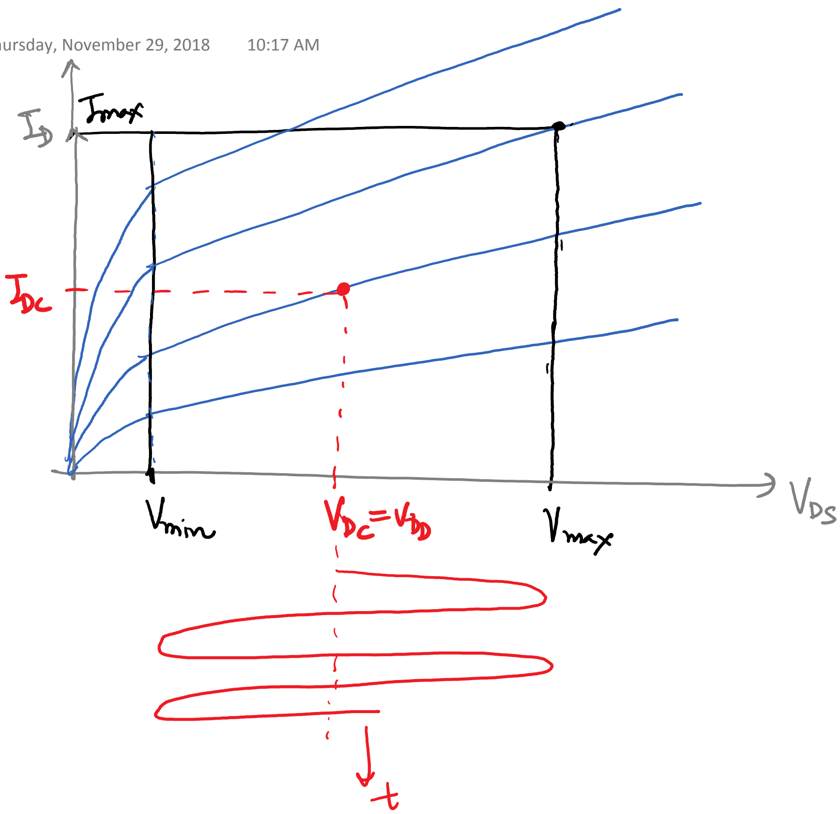


$V_{min} \Rightarrow$ Triode region
$V_{DS,sat}$

$V_{max} \Rightarrow$ maximum allowed V_{DS}
↳ breakdown or reliability concerns

$I_{max} \Rightarrow$ output current going
↳ depends upon the saturation velocity & carrier mobility etc.

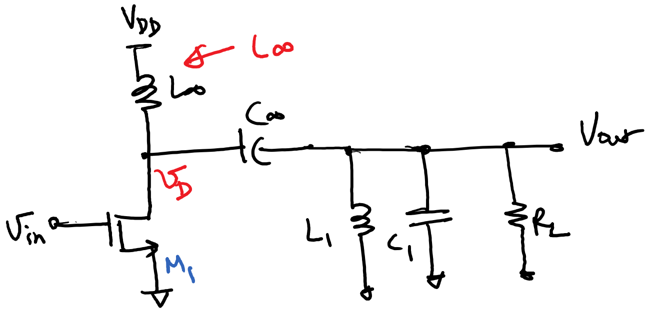
* $I_{max} \rightarrow$ limited by f_T degradation due to high-injection effects and doesn't exceed $2J_{pf_T} \cdot W$

$P_{out} \propto (V_{max} - V_{min}) I_{max}$

and $PAE \propto \left(1 - \frac{V_{min}}{V_{max}}\right)$

* Ideally, we must select the transistor technology with the largest V_{max} and I_{max}

and ideally $V_{min} = 0$ & $R_{on} = 0$
↳ switch resistance

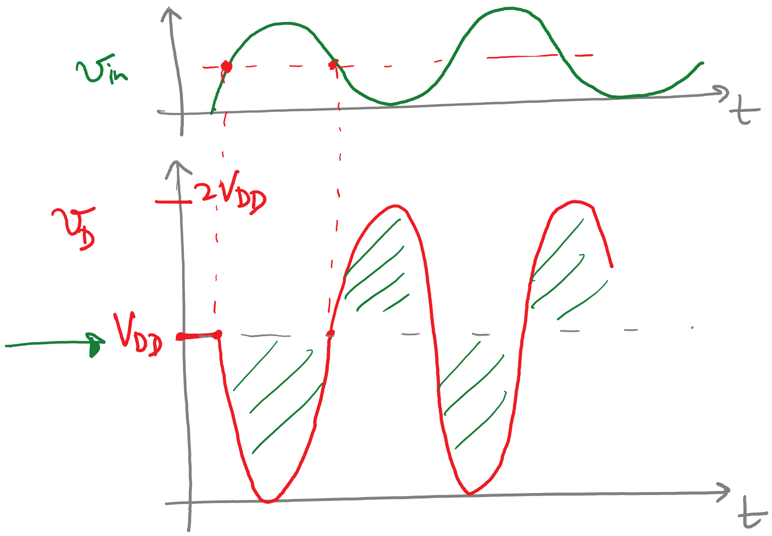


$A_v = -g_{m1} R_L$

$$f_0 = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

$$Q = \omega_0 R_L C_1 = 2\pi f_0 R_L C_1$$

$$BW \Rightarrow \Delta f = \frac{f_0}{2Q}$$



Assume $V_{min} = V_{DS,sat} = 0$

* for ideal inductor, the average (or DC) voltage drop $= \omega L \simeq 0$
  - → average value of $v_D = V_{DD}$.
  - → v_D must swing between 0 and $2V_{DD}$.

* This is only possible because an inductor, rather than a resistor, is connected between the drain & supply.

* at resonance $\omega = \omega_0 = \frac{1}{\sqrt{L_1 C_1}}$

$$P_{out} = \frac{1}{T}\int_0^T \underbrace{V_{DD}\cos(\omega t)}_{v} \cdot \underbrace{\frac{V_{DD}\cos(\omega t)}{R_L}}_{i} \cdot dt$$

$$= \frac{V_{DD}^2}{2R_L T}\int_0^T [1+\cos(2\omega t)]\,dt$$

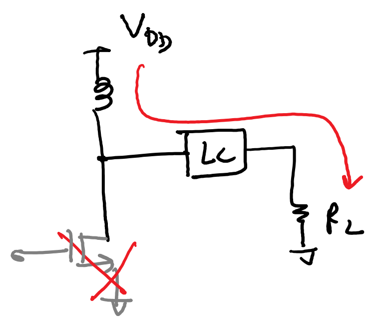
$$= \frac{V_{DD}^2}{2R_L}$$

would have been $\frac{V_{DD}^2}{4R_L}$ for conventional analog amplifier (CS)

+ Power pulled from the supply

$$P_{DC} = V_{DD} \cdot I_{DC} = V_{DD} \cdot \frac{V_{DD}}{R_L}$$

$$= \frac{V_{DD}^2}{R_L}$$



$\Rightarrow$ $\eta = \frac{P_{out}}{P_{DC}} = \frac{1}{2} \Rightarrow 50\%$ efficiency

Class-A drain efficiency

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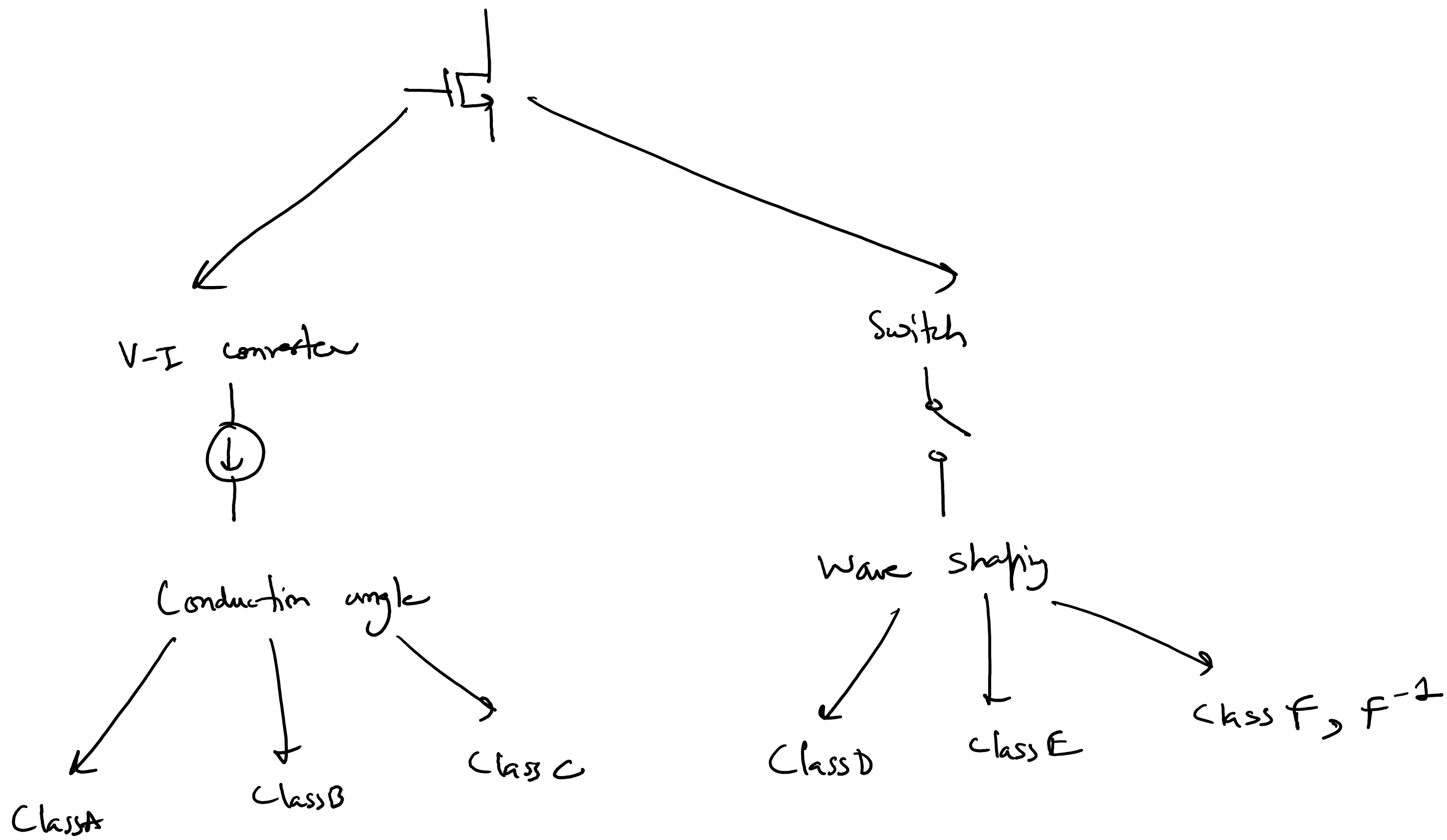
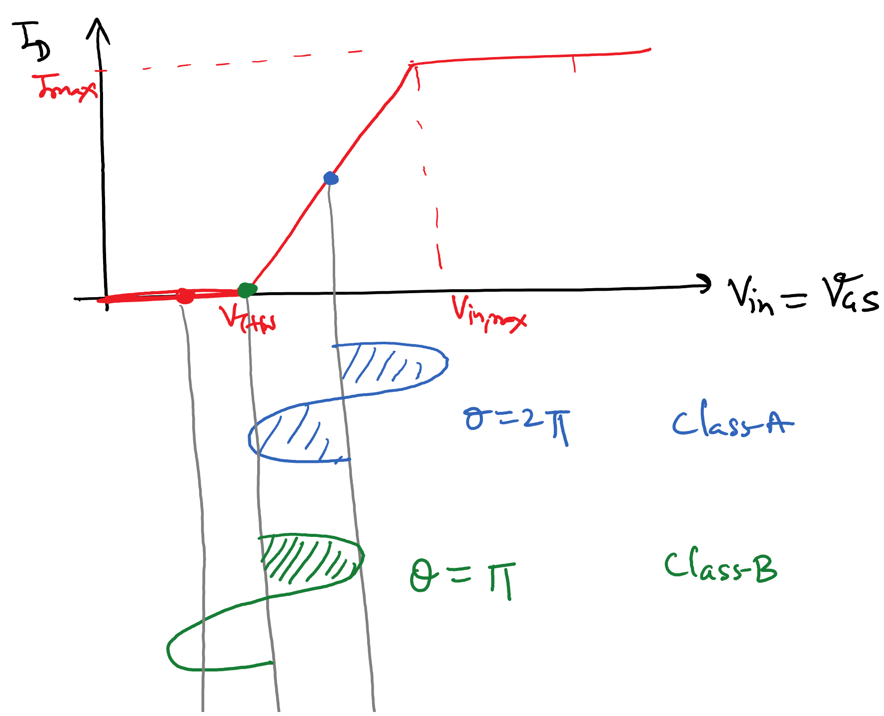
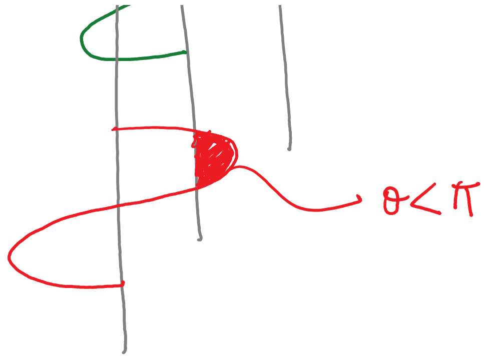
Classes of Tuned PAs







class-c