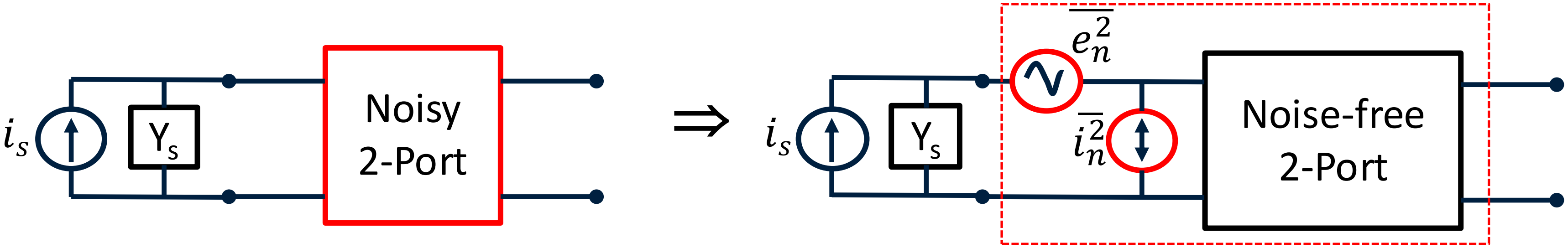
Lecture 5: Noise Factor

ELEC 404

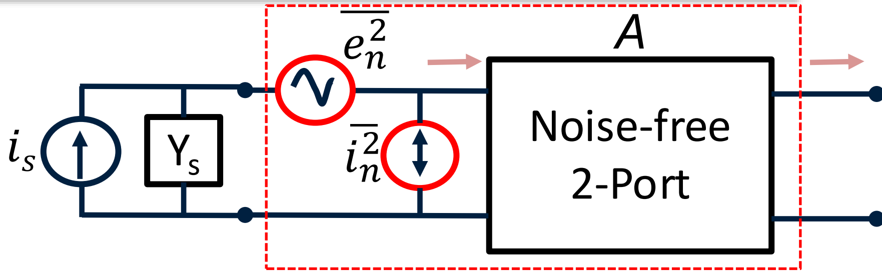
Acknowledgement: *The Design of CMOS Radio-Frequency Integrated Circuits.* T. Lee

Classical 2-Port Noise Theory



- **Why both e_n and i_n?**
  -
  -
  - **For any arbitrary Ys, both contribute**
- **e_n and i_n may be correlated with each other**
- **i_s considered independent (uncorrelated) from e_n and i_n.**

Noise Factor



- **Noise current input to the 2-port network**

$$i = [i_s + (i_n + e_n Y_s)\frac{Y_{in}}{Y_s + Y_{in}}$$

- **Noise Factor:**

$$F = \frac{Total\ output\ noise\ power}{Output\ noise\ power\ due\ to\ source\ only} = \frac{\overline{i_{no,total}^2}}{\overline{i_{no,source}^2}} = \frac{\overline{v_{no,total}^2}}{\overline{v_{no,source}^2}}$$

$$F = \frac{\overline{|i_s + (i_n + e_n Y_s)|^2}\left|\frac{Y_{in}}{Y_s + Y_{in}}\right|^2}{\overline{|i_s|^2}\left|\frac{Y_{in}}{Y_s + Y_{in}}\right|^2} = \frac{\overline{i_s}^2 + \overline{|i_n + e_n Y_s|^2}}{\overline{i_s}^2} = 1 + \frac{\overline{|i_n + e_n Y_s|^2}}{\overline{i_s}^2}$$

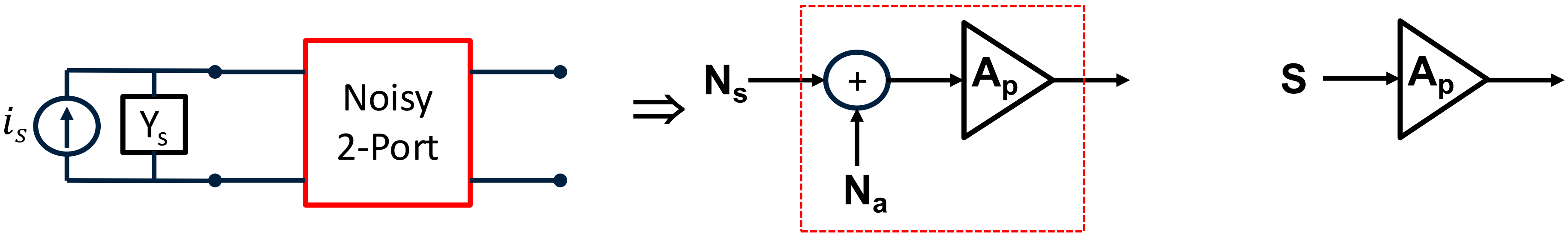
$$F = 1 + \frac{\overline{|i_u + e_n (Y_s + Y_c)|^2}}{\overline{i_s}^2} = 1 + \frac{\overline{i_u}^2 + \overline{e_n}^2 |Y_s + Y_c|^2}{\overline{i_s}^2}$$

$$\overline{|X + Y|^2} = \overline{(X + Y)(X + Y)^*} = \overline{|X|^2} + \overline{|Y|^2} + \overline{XY^* + YX^*} = \overline{|X|^2} + \overline{|Y|^2} + \overline{2Re(XY^*)}$$

Noise Factor – Some Comments

- e_n, i_n, and i_u, Y_c may be difficult to calculate and measure
- Referring voltages and currents to output (or input) port at high frequency easier → F or NF is a popular metric.
- Noise Figure, NF = 10$\log_{10}$(F) in dB
- F is defined with respect to a source impedance.

Noise Factor as SNR Ratio



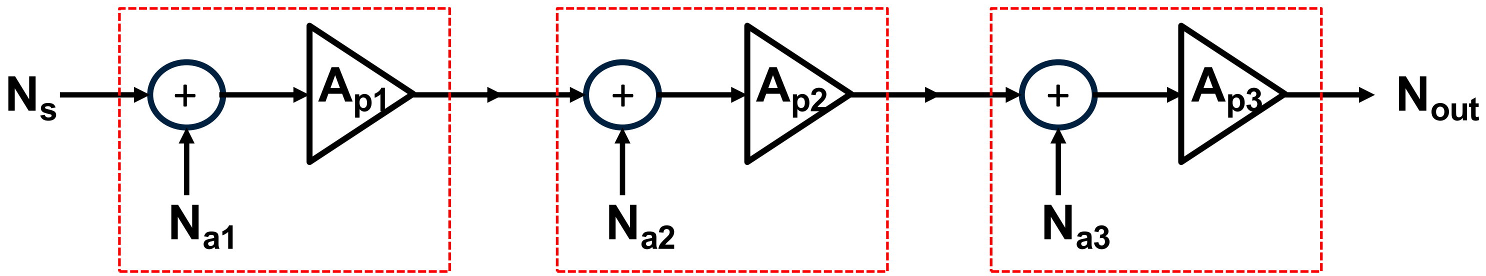
- N_a= Input-referred noise power of the amplifier
- A_p = Available power gain of the amplifier

  = Power that the amplifier would deliver to a conjugate-matched load

$$F = \frac{Total\ noise\ power}{noise\ power\ due\ to\ source\ only} = \frac{N_a + N_S}{N_s} = \frac{A_p(N_a + N_S)}{A_p N_s}$$

$$F = \frac{SNR_{in}}{SNR_{out}}$$

Cascaded Network Noise Factor



- **Assume all input and output impedances equal**

$N_{out,total} =$

$N_{out,s} =$

$$F = 1 + \frac{N_{a1}}{N_s} + \frac{N_{a2}}{N_s A_{p1}} + \frac{N_{a3}}{N_s A_{p1} A_{p2}} = 1 + (F_1 - 1) + \frac{F_2 - 1}{A_{p1}} + \frac{F_3 - 1}{A_{p1} A_{p2}}$$

- **First few stages must be low noise**
- **Loss in first few stages *amplifies* noise**