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# 8C - Small Signal Amplifier Design - Design for Constant Mismatch, Effective Power Gain

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## References

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- [1]\* D.M. Pozar, "Microwave engineering", 3rd Edition, 2005 John-Wiley & Sons.
- [2] R.E. Collin, "Foundations for microwave engineering", 2nd Edition, 1992 McGraw-Hill.
- [3] R. Ludwig, P. Bretchko, "RF circuit design - theory and applications", 2000 Prentice-Hall.
- [4]\* G. Gonzalez, "Microwave transistor amplifiers - analysis and design", 2nd Edition 1997, Prentice-Hall.
- [5] Gilmore R., Besser L., "Practical RF circuit design for modern wireless systems", Vol. 1 & 2, 2003, Artech House.

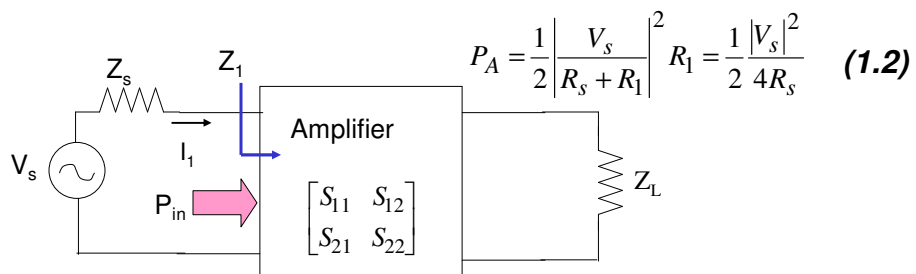
# 1.0 Impedance Mismatch Factor

## Impedance Mismatch Factor (1)

- The Concept of Available Power  $P_A$ .

$$I_1 = \frac{V_s}{Z_s + Z_1} \quad P_{in} = \frac{1}{2} \left| \frac{V_s}{Z_s + Z_1} \right|^2 R_1 \quad (1.1)$$

- From the theory of maximum power transfer, when  $R_1 = R_s$ ,  $X_1 = -X_s$  (or  $Z_1 = Z_s^*$ ) maximum power is transferred from the source to the amplifier. This power is  $P_A$ , the available power from the source.



## Impedance Mismatch Factor (2)

- When  $Z_1 \neq Z_s^*$ , we have an impedance mismatch and  $P_{in} < P_A$ . The input power can be written as:

$$P_{in} = \frac{1}{2} \left| \frac{V_s}{Z_s + Z_1} \right|^2 R_1 = \frac{1}{2} \frac{|V_s|^2}{4R_s} \left[ \frac{4R_s R_1}{|Z_1 + Z_s|^2} \right] = MP_A \quad (1.3)$$

- M is known as the **Impedance Mismatch Factor (IMF)**.

$$M = \frac{4R_s R_1}{|Z_1 + Z_s|^2} \quad (1.4)$$

- The input power to an amplifier is the product of IMF and the Available Power.

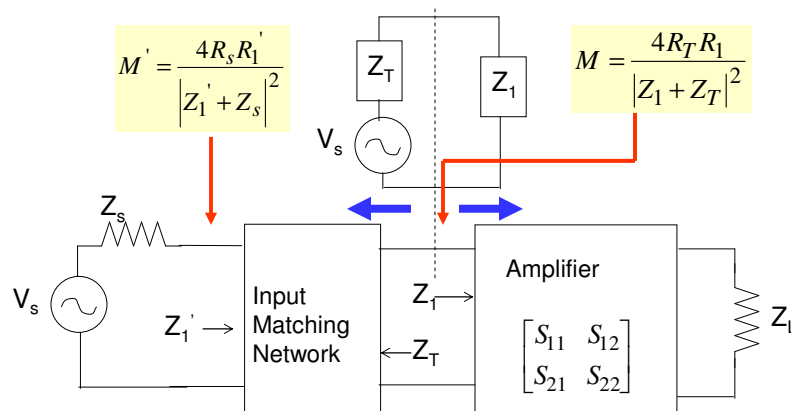
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5

## Invariant Property of Impedance Mismatch Factor (1)

- When a lossless network is inserted between source and port 1, Thevenin equivalent network can be used to find M at both ends of the network.



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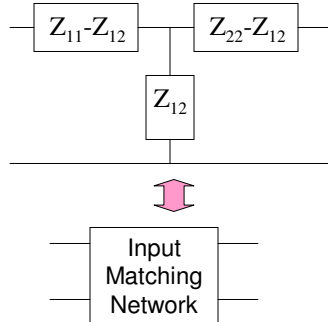
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6

## Invariant Property of Impedance Mismatch Factor (2)

- We can represent the lossless network using Z parameters. And using circuit analysis shows that  $M = M'$ . The details of the proof are shown in Chapter 5, Collin [2].

- Use  to show that



$$M' = \frac{4R_s R_1'}{|Z_1' + Z_s|^2} = \frac{4R_T R_1}{|Z_1 + Z_T|^2} = M$$

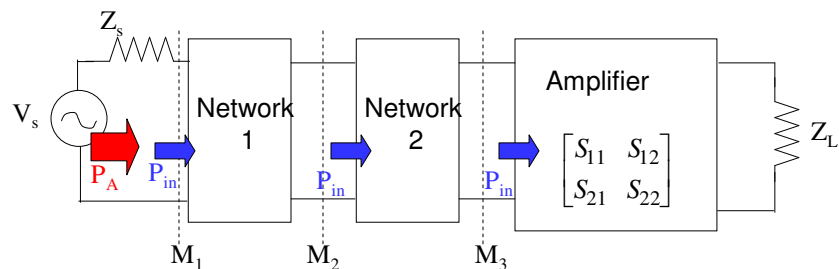
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7

## Impedance Mismatch Factor Summary

- In general when there are N lossless networks connected in cascade:



$$M_1 = M_2 = M_3 \quad (1.5)$$

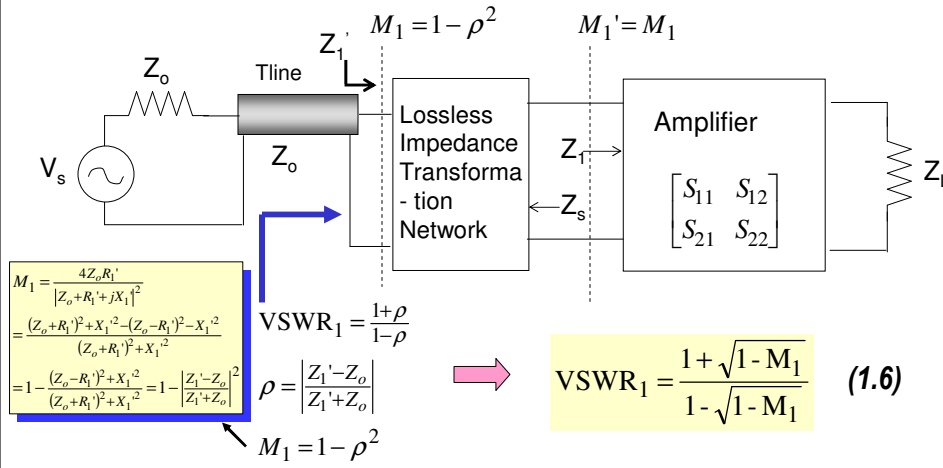
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## Relationship Between M and Input VSWR

- Usually the matching between two networks is specified by the VSWR.



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9

## Input Mismatch and Transducer Power Gain (1)

- A  $VSWR_1$  near unity ensures that most of the power from the source is absorbed by the amplifier. It is equivalent to requiring  $M_1 = 1$ . A  $VSWR_1$  that is greater than unity (or  $M < 1$ ) is termed input mismatch.
- As we have seen in Chapter 7, the actual power gain experienced by a system is  $P_L / P_A$  which is the Transducer Power Gain  $G_T$ .
- From which we conclude that

$$G_T = \frac{(1 - |\Gamma_L|^2) |S_{21}|^2 (1 - |\Gamma_s|^2) (1 - |\Gamma_1|^2)}{|1 - S_{22}\Gamma_L|^2 |1 - \Gamma_1\Gamma_s|^2 (1 - |\Gamma_1|^2)} \quad G_T = \frac{P_L}{P_A} \cdot \frac{P_{in}}{P_{in}} = M_1 G_P \quad (1.7a)$$

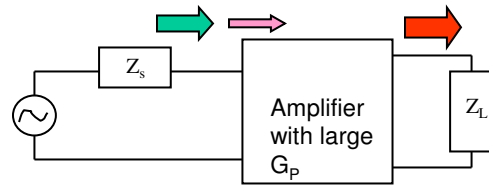
$$G_P = \frac{(1 - |\Gamma_L|^2) |S_{21}|^2}{|1 - S_{22}\Gamma_L|^2 (1 - |\Gamma_1|^2)} \cdot \frac{(1 - |\Gamma_s|^2) (1 - |\Gamma_1|^2)}{|1 - \Gamma_1\Gamma_s|^2} \quad M_1 = \frac{(1 - |\Gamma_s|^2) (1 - |\Gamma_1|^2)}{|1 - \Gamma_1\Gamma_s|^2} \quad (1.7b)$$

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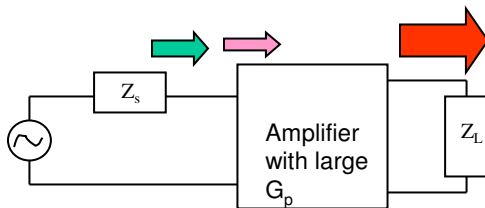
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10

## Input Mismatch and Transducer Power Gain (2)



An amplifier with high  $G_p$  but bad input matching ( $VSWR_{in} \gg 1$ ), low  $G_T$ .



An amplifier with high  $G_p$  and good input matching ( $VSWR_{in} \rightarrow 1$ ), high  $G_T$ .

Bottomline: A proper small-signal amplifier design needs to have high  $G_p$  and Good input matching,  $VSWR_{in}$  close to 1.

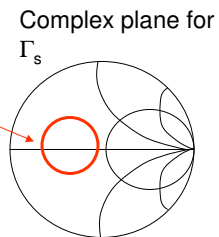
## Input Mismatch and Transducer Power Gain (3)

- In general we could not set  $M_1 = 1$  due to conflicting requirements, for instance factors such as stability, low-noise competes with good matching requirement. A small amount of input mismatch must be tolerated.
- To control the amount of input mismatch, **Constant Input Mismatch Circles** are plotted after the power gain is determined.
- To maintain a certain effective power gain, we usually specify the maximum  $VSWR_1$ . This can be converted into  $M_1$ .
- An amplifier can have a high power gain  $G_p$ , but if the input mismatch factor  $M_1$  is small, only a small amount of power from the source network is absorbed by the input ( $P_{in}$ ). It is this power which is amplified and presented at the output of the amplifier.

## Constant Input Mismatch Circles (1)

$$M_1 = \frac{(1 - |\Gamma_s|^2)(1 - |\Gamma_1|^2)}{|1 - \Gamma_1 \Gamma_s|^2}$$

Fixed



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13

## Constant Input Mismatch Circles (2)

- The radius and center of the Input Mismatch Circle for a particular  $\Gamma_L$  and  $M_1$  is given by Collin [2], Chapter 10:

$$\Gamma_{Scenter} = \frac{M_1 \Gamma_1^*}{1 - (1 - M_1) |\Gamma_1|^2} \quad (1.8a)$$

$$R_{Srad} = \frac{\sqrt{1 - M_1} (1 - |\Gamma_1|^2)}{1 - (1 - M_1) |\Gamma_1|^2} \quad (1.8b)$$

$$M_1 = 1 - \left( \frac{VSWR_{in} - 1}{VSWR_{in} + 1} \right)^2 \quad (1.8c)$$

This circle is also known as **Constant input VSWR circle** in other literatures

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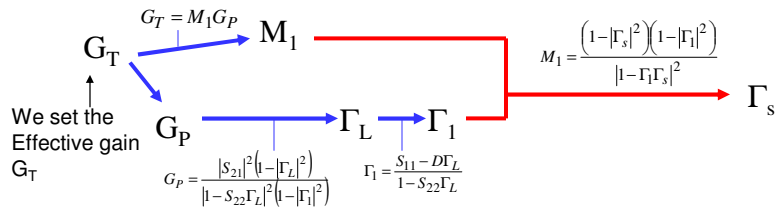
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14

## 2.0 Design for Fixed $G_T$ and Input Mismatch

### Design for Specific Transducer Power Gain $G_T$

- Usually we start by plotting the Constant Power Gain circles and fixing  $M_1$  (this would fix  $G_T$ ). The constant  $G_P$  circles determine the load impedance required.
- Once  $\Gamma_L$  is determined,  $\Gamma_1$  is calculated and we could find the corresponding  $\Gamma_s$  that would give the required  $M_1$ . These values of  $\Gamma_s$  would form a circle, known as **Constant Input Mismatch Circle** on the Smith Chart.
- The approach shown here complements the constant  $G_P$  and  $G_A$  approaches in Chapter 8A.



## Example 2.1

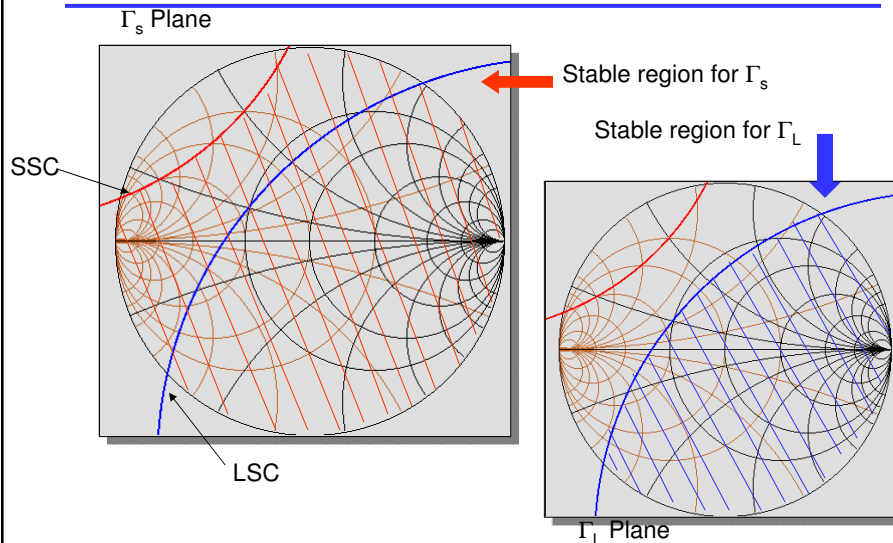
- A FET amplifier has the following parameters:  $S_{11}=0.8\angle-140^\circ$ ,  $S_{12}=0.2\angle30^\circ$ ,  $S_{21}=2.8\angle60^\circ$ ,  $S_{22}=0.2\angle150^\circ$  at 1.5GHz. We would like to use this FET amplifier with  $G_p=10.79\text{dB}$ . Assuming we can tolerate an input mismatch of  $VSWR_{in}=1.6$ , find a suitable load and source reflection coefficients. Also work out the effective power gain of the amplifier.
- **Solution...**
- From S-parameter, the maximum stable gain  $G_{MS}=|S_{21}/S_{12}|=14$ .
- Hence  $G_p=10.79\text{dB}$  or 12 is within this limit.
- $K=0.561 < 1$ , hence the amplifier is conditionally stable.

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17

## Example 2.1 Cont...



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18

## Example 2.1 Cont...

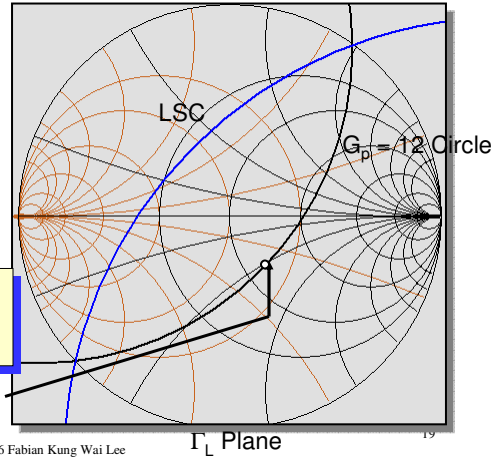
- From  $G_p = 12$ , we plot the constant power gain circle and determine a suitable load reflection coefficient  $\Gamma_L$ .

For  $\Gamma_L = 0.54 \angle -1.48$  Rad:

$$\Gamma_1 = \frac{S_{11} - D\Gamma_L}{1 - S_{22}\Gamma_L} = -0.304 - j0.454$$

This point is chosen as it is sufficiently far away from LSC and not too close to the border of Smith chart

$$\Gamma_L = 0.28 \angle -0.94 \text{ rad}$$



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19

## Example 2.1 Cont...

- For  $VSWR_1 = 1.6$

$$M_1 = 1 - \left( \frac{VSWR_1 - 1}{VSWR_1 + 1} \right)^2 = 0.947$$

$$\text{Radius} = \frac{\sqrt{1 - M_1} \cdot [1 - |\Gamma_1|^2]}{1 - (1 - M_1)|\Gamma_1|^2} = 0.139$$

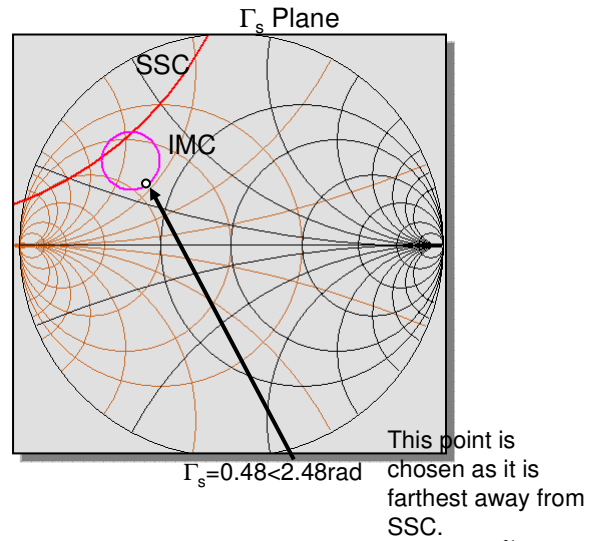
$$\text{Center} = \frac{M_1 \cdot \bar{\Gamma}_1}{1 - (1 - M_1)|\Gamma_1|^2} = -0.475 + j0.401$$

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20

## Example 2.1 Cont...



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21

## Example 2.1 Cont...

- Computing Source and Load impedance:

$$Z_s = Z_o \frac{1 + \Gamma_s}{1 - \Gamma_s} = 19.24 + j14.81$$

$$Z_L = Z_o \frac{1 + \Gamma_L}{1 - \Gamma_L} = 61.71 - j30.79$$

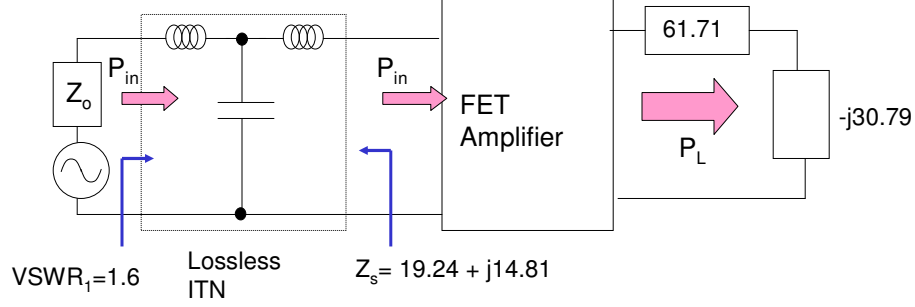
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22

# Example 2.1 Cont...

- The final block diagram:



$G_P = P_L / P_{in} = 12$

What is the best case  $G_T$  ?

Worst case  $G_T$  or Effective power gain =  $M_1 G_P = 12 \times 0.947 = 11.364$