Noise

Design objective: low-noise amplification. Problem: min. noise and max. power do not go hand in hand! (why?)

Trade-offs: noise, stability, gain.

Need design methodology for a compromise between the two.

Problem: low-noise means low current not good for gain!

Many sources of noise:
1) Johnson and 2) shot noise. The first one dominates in resistors and is present even when there is no current. Shot noise associated with current flow and is propor-

GaAs MESFETs generally have better noise performance than SiBJTs (at high frequencies), but many new devices compete.

Problem: low-noise means low current
Some basic concepts and properties:

\[
\text{rms. } u_{n} = \text{const.} = 4P \int_{L}^{L + 1} \frac{I}{1} \int_{0}^{\infty} L \text{ d}t = u_{n} \tag{2}
\]

\[
0 = 4P (\frac{u_{n}}{2}) \int_{L}^{L + 1} \frac{I}{1} \int_{0}^{\infty} L \text{ d}t = u_{n} \tag{1}
\]

Often we break up a device into noiseless part + noise source.

See fig. K1 for resistor.
Microwave transistor amplifiers

In amplifiers, no source on input but some small output voltage power (power) can be measured. 

\[ V_{n} = \frac{K}{B} \sqrt{\frac{f_{L}}{f_{H}}} \] 

Where: \( f_{L} \) is lower frequency, \( f_{H} \) is higher frequency, \( B \) is bandwidth, \( K \) = Boltzmann constant, \( T \) = Temperature (K), and \( R \) = Resistor on input produces additional noise coming from resistor is amplified. 

Total noise power = Amplified noise input power + noise output power produced by output.

\[ P_{n} = \frac{K}{B} \sqrt{\frac{f_{L}}{f_{H}}} \] 

\( T \) = Noise temperature (K) of resistor. 

\( T_{s} \) = Noise temperature of resistor that will produce the same noise power (or voltage). (See input need not be a resistor but we can always find an equivalent.)
Microwave transistor amplifier design

Note: $P_N$ does not depend on value of $R_N$ but only on $T$ and $B$.

\[ M = 19.9 \cdot 10^{-18}, \]
\[ \Lambda N = N \Lambda \left( 1.2 \cdot 10^{-6} \right), \]
\[ \Rightarrow \frac{P_N}{\frac{N}{2} \Lambda} = N P \]

Example: $R_N = 2 MW$, $B = 290 K$, $T = 270 K$:

\[ R_N = 2 \text{ M}, T = 290 \text{ K}, \]
\[ B = 5 \text{ KHz}, \]
\[ \lambda N = 1.2 \cdot 10^{-6} \]
\[ \Rightarrow P_N \approx 1.9 \cdot 10^{-18} \]

Resistor

How much power is generated? Max. available power from the

dependence to reduce noise operate at lower $T$ - $s$

$T$ does not matter, “white noise”

depends only on $B$, not on frequency itself; if $B$ is the same, $t$
Figure of merit for amplifiers: Noise Figure (F or NF) often used.

$$F = \frac{\text{available output SNR}}{\text{available input SNR}}$$

Using different notation:

$$F = \frac{\text{available output SNR}}{\text{available input SNR}} = \frac{\text{total available output noise}}{\text{total available input noise}}$$

Definition: Figure of merit for amplifiers. Noise Figure (F or NF) often used.
Microwave transistor amplifier design

where $\mathcal{J}$ is effective input noise temperature (see Fig. K.3).

\[
\left(8\right) \frac{S_L}{L} + 1 = P \leq V \beta C_L + B^T_L + G^T_L = 1^N P + 2^N P + C = 0^N P
\]

We can also write (define $\mathcal{J}$)

\[
\left(9\right) \frac{C_\gamma^N P}{1^N P} = \mathcal{J}
\]

Also note that second part is reduced by increasing $C$ increased.
Problems arise if $1^N P$ increases as $\mathcal{J}$ is increased.

Also note that second part is reduced by increasing $C$ increased.

We can also write (define $\mathcal{J}$)

\[
\left(9\right) \frac{C_\gamma^N P}{1^N P} = \mathcal{J}
\]

Remember: $P^N$ contains contributions from amplifier and does not
depend on what is on input.

\[
\left(7\right) \frac{V \mathcal{J}^N P}{1^N P} = \frac{V \mathcal{J}^N P}{1^N P} + \frac{1}{V \mathcal{J}^N P + 1^N P} = \frac{V \mathcal{J}^N P}{1^N P} = \mathcal{J}
\]

terminal noise from amp thus add up.

has two components: one from input, the other due to in-
What is the best value of $F$? If input signal is amplified, then magnitude of noise signal increases as well. However, if no new noise is added, $S/N$ ratio on input and output are the same, $F$ is the same. 

Two stage amplifier noise figure:

$P_{N1} + P_{N2} = F_1 + F_2 = P_{N_{tot}}$

Sketch the figure.

Microwave transistor amplifier design
Microwave transistor amplifier design

General conclusion: there is always a compromise between gain and noise.

Obviously, \( F_1 \) and \( F_2 \) are noise figures for each amp stage separately. Where

\[
\frac{C_{2N}}{N_2} + 1 = F_2 \quad \frac{C_{1N}}{N_1} + 1 = F_1
\]
\[
\begin{align*}
(\text{I}4) & \quad \frac{V}{I} + 1 = \frac{I - 1}{I} + 1 = \cdots + \frac{I - 3}{I} + 1\frac{I}{I} + 1\frac{I}{1} = \frac{I}{I} \\
\text{We require that } M_1 > M_2, \text{ for identical amplifiers.}
\end{align*}
\]

\[
\begin{align*}
(\text{I}3) & \quad (M_2 = )\frac{I - 1}{I} > (M_1 = )\frac{I - 1}{I} \\
\text{where } M_1, M_2 \text{ are noise measures for two amplifiers.}
\end{align*}
\]

\[
(\text{I}2) & \quad \frac{I - 1}{I} + \frac{I - 1}{I} = \frac{I - 1}{I} + \frac{I - 1}{I} = \frac{I - 1}{I}
\]

Is it better to put amp1 first or amp2? The overall noise figure F...
Noise figure of a two-port amp can be expressed as:

\[
F = \frac{\frac{1}{2} \left| 0 \lambda + 1 \right| (\frac{1}{2} \left| s \lambda \right| - 1) + \mu_{\text{nw}} \mathcal{J}}{\frac{1}{2} \left| 0 \lambda - s \lambda \right| u_{\text{d}} \mathcal{V}} + \mu_{\text{nw}} \mathcal{J} = \mathcal{J}
\]

After expressing \( s \lambda \), \( s \lambda \), and \( \mu_{\text{nw}} \mathcal{J} \) in terms of their \( 0 \lambda \), \( s \lambda \), and \( \mu_{\text{nw}} \mathcal{J} \) is source admittance that results in minimum noise figure \( F_{\text{min}} \).

\[
0 \lambda s \lambda + 0 \lambda = 0 \lambda \quad \text{is source admittance, two-port,}
\]

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0 \lambda s \lambda + 0 \lambda = 0 \lambda \quad \text{is source admittance, two-port,}
\]
Microwave transistor amplifier design

Noise parameters $F_{min}$, $F_{min}$ are given by transistor manufacturer.

$F_{min}$ is function of operating current and frequency.

$$ 0 \left| \frac{\text{A}}{0 \text{A} + 1} \right| \left( F_{\text{min}} - 0 = \text{s} \left| \right| \right) = u, I $$

$F_{min}$ is determined when $0 = s \left| \right| \text{how is that done?}$

$0 \left| \right| = s \left| \right| \text{determined when } u, I \text{ is observed in noise-figure meter.}$

$0 \left| \right| = s \left| \right| \text{is varied (using tuner on input terminals)}$

$0 \left| \right| = s \left| \right| \text{coeff. is varied (using tuner on input terminals)}$

$0 \left| \right| = s \left| \right| \text{source rel. coeff.}$

$0 \left| \right| = s \left| \right| \text{disconnect amp.}$

$0 \left| \right| = s \left| \right| \text{and find the source rel. coeff.}$

$0 \left| \right| = s \left| \right| \text{(how is that done?)}$

$0 \left| \right| = s \left| \right| \text{is observed in noise-figure meter.}$

$0 \left| \right| = s \left| \right| \text{determined by:}$
\[
\frac{\frac{z}{2} N + 1}{(z|0,1| - 1)^{\frac{z}{2} N} + \frac{z}{2} N} = \frac{z}{2} N + 1
\]

This represents circles with \( \frac{z}{2} N \) as parameter.

\[
\frac{z(\frac{z}{2} N + 1)}{(z|0,1| - 1)^{\frac{z}{2} N} + \frac{z}{2} N} = \frac{\frac{z}{2} N + 1}{z|0,1| - \frac{s}{z}}
\]

which, after some manipulation, leads to

\[
\frac{z|0,1| + 2}{\frac{U_{\text{circ}}}{U_{\text{noise}}} - \frac{s}{z}} = \frac{z|s,1| - 1}{z|0,1| - \frac{s}{z}} = \frac{z}{2} N
\]

Noise figure parameter (for a given noise figure \( \frac{z}{2} N \))

(time permitting derive eqs. for noise circles)
Example 4.3.1

different $I_s$ in Fig. 4.3.3, max. gain and min. noise figure are obtained for $F = F_{\text{min}}$, but $N_i / 0.5$, $R_{\text{F min}} = 0$, i.e., circle at $P = 0$, i.e., circle at $L = 0$. Typical set of const. noise figure circles in Fig. 4.3.2. $P = \frac{V_{\text{MM}}}{s}$. DB obtained when $L = 0$. Centers of other circles are on line from origin with zero radius. Centers of other circles are on line from origin $L = 0$. $P = \frac{V_{\text{MM}}}{s}$, $R_{\text{F min}} = 0$, i.e., circle at $P = 0$, i.e., circle at $L = 0$. Example 4.3.1
Microwave transistor amplifier design

Unilateral case

$G_u = \frac{1 - |\Gamma|_1^2}{|1 - S_{ii}|_2^2}$

$G_{ru} = \frac{1 - |\Gamma|_1^2}{|1 - S_{ii}\Gamma|_2^2}$

For general analysis write $G_u = G_s \cdot G_d$. For general analysis write $G_s, G_d$ as $G_s$ constant gain circles drawn directly in the S-chart with noise figure circles (sketch the block diagram for amp). Remember

\[ G_s = \frac{1 - |\Gamma|_1^2}{|1 - S_{ii}|_2^2} \]

\[ G_{ru} = \frac{1 - |\Gamma|_1^2}{|1 - S_{ii}\Gamma|_2^2} \]
Microwave transistor amplifier design

For example, looking at Fig. 4.3.3, gain is obtained for

\[ (24) \]

\[ \frac{(\frac{\gamma D}{\eta} - 1) |Z_S|^2 |S|^2 - 1}{|Z_S|^2 |B|^2} = \frac{2\Lambda}{\eta} + 2\Omega^\Lambda = \frac{\gamma p}{\eta} \]
Bilateral case

Example 4.3.1.

Unconditionally stable, but just barely. Also, not unilateral.

Calc. \( \Delta = \frac{h_{211}}{h_{111}} \).  \( h = 1.012 \).

Using some program like UM-MADV get the table:

<table>
<thead>
<tr>
<th>DB Center Radius</th>
<th>3.0</th>
<th>2.9</th>
<th>2.8</th>
<th>2.7</th>
<th>2.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>dBCenterradius</td>
<td>0.437166°</td>
<td>0.437166°</td>
<td>0.437166°</td>
<td>0.437166°</td>
<td>0.437166°</td>
</tr>
</tbody>
</table>

Microwave transistor amplifier design
For relatively large changes in $\frac{S}{N}$, noise figure does not change all that much. E.g. $F = 2.6$ dB increase from all that much. E.g.

$F_{\text{min}} = 2.5$ dB (see table) results in a change of 0.2 dB (see table). For relatively large changes in $\frac{S}{N}$, noise figure does not change.
Next step: design the matching network.

\[ \forall \phi = I \phi \Leftrightarrow \] output

Because of cons. match on

\[ 12 \text{ dB}, \quad \| I \| = \frac{1}{\forall \phi} \Leftrightarrow \]

\[ \begin{align*}
(\lfloor S \rfloor, I) f &= \sqrt{\frac{\lfloor T \rfloor - 1}{\lfloor S \rfloor}} \sqrt{\frac{\lfloor S \rfloor - 1}{\lfloor T \rfloor}} = \forall \phi \\
(\lfloor S \rfloor, I) f &= \sqrt{\frac{\lfloor T \rfloor - 1}{\lfloor S \rfloor}} \sqrt{\frac{\lfloor S \rfloor - 1}{\lfloor T \rfloor}} = d \phi
\end{align*} \]

Plug \( I, L, \| I \| \) into formulas for \( \forall \phi, \quad d \phi \)
Microwave transistor amplifier design

\[ \lambda = \frac{5.34 \text{ cm}}{\text{f} \text{f \epsilon}} \]

\[ A = 0.42, B = 1.2, V/\text{W} = 6.1 \text{ W/Ohm} \]

which leads to \( I = 1.97 \) and

\[ V/\text{W} = 0 \text{ ohm} \]

which must be found for given \( Z_0 \) (after calc.

eg. for \( \text{ff \epsilon} \), \( \text{V/\text{W}} \) must be found for given \( Z_0 \)

From figures \( \text{V/\text{W}} < I \). To use

\( \text{to find lengths}: \) need \( \lambda \).

Frequency \( = \text{f GHz} \).

To find lengths: need \( \lambda \). Frequency \( = \text{f GHz} \).

Real part: \( Z = \frac{0.8}{50} \)

Imaginary part: add the \( -j \) part. By using short circuited stub

\[ \approx \frac{50 \lambda}{50 \cdot 50/2.8} = \frac{50}{300} \]

Then add some reactance/susceptance to get to \( 0.3 \) from 0. Then use \( \lambda \) and \( \text{trans} \).

\[ \approx 0.36 + 0.14 \text{ Ohm} \]

Starting from origin (source is 50 Ohm)

Coming to \( I \):
Show Fig. 4.36 and 4.37.

matched simultaneously on input and output,忆 wicked to get the minimum noise figure. Reason: not conjugately
dB. Since we calculated $\mathcal{G}_A = 11$ dB, some gain was sac-
ificed to get the minimum noise figure. Reason: not conjugately
and output.

How much could we get out in terms of gain? Calc. $\mathcal{G}_{\text{max}} = 15$

Show Fig. 4.3.5.

(i.e., its $Z^0$) or by changing the length of the short circuited stub.

(b) The rest of the matching network is split up in order to provide
some tuning capability, e.g., by changing the width of O-C stub

(a) soldering area provided by a tr. Line with $Z^0 = 50Ω$.

Output matching network: transform $Z_L = 50Ω$ to $Z_L = 0.8447Ω$.
Additional complication: if potentially unstable, stability must be checked. Another example: 4.3.2.

Microwave transistor amplifier design

Note:

Microwave Circuit Design II
Microwave transistor amplifier design

Three bias points (Q): minimum noise, linear power output, maximum gain (explain names). For compromise between noise and gain, use linear power output.

VSWR = 2.238, $Q = 10.5$, $F = 3.14$ dB. Calculating matching and performance for three design points: minimum $F$, max. gain, max. output power (fig. 4.3.9).

Fig. 4.3.11 and 4.3.12. What happens as input changes from $I_s$ to $I_d$? Fig. 4.3.10 shows that for straight line, the point chosen is around mid-way.$VSWR = 3.28$, $F = 3.14$ dB. For results see fig.

Microwave Circuit Design II
Microwave transistor amplifier design

Potentially unstable case: ex. 4.3.4.

- For $F_{\text{min}}$, $G_A = 8.9 \text{ dB}$, and $\text{VSWR}_{\text{in}} = 0.9$. 
- Improvements? Get more gain at the expense of $F$, say $F = 10.5 \text{ dB}$, but $F = 1 \text{ dB}$. 
- Now $\text{VSWR}_{\text{out}} = 6.41$ (what about $\text{VSWR}_{\text{out}}$?). 
- To reduce $\text{VSWR}_{\text{out}}$, sacrifice some $\text{VSWR}$ on output, but also increase gain $G_A$. 

Say pt. $c$ (fig. 4.3.13) $\text{VSWR}_{\text{in}} \leftarrow 3.91$. (no info on $C_L$) Given: $G_A$ (why?). 
- Const. $\text{VSWR}_{\text{out}}$ circles help choose $T$. Pick up, 
- $\text{VSWR}_{\text{in}} = 6.41$ (what about $\text{VSWR}_{\text{out}}$?). 
- For $F_{\text{min}}$, $G_A = 9.9 \text{ dB}$, and $\text{VSWR}_{\text{in}} = 0.9$. 
- Improvements? Get more gain at the expense of $F$, say $F = 10.5 \text{ dB}$, but $F = 1 \text{ dB}$. 
- Now $\text{VSWR}_{\text{out}} = 6.41$ (what about $\text{VSWR}_{\text{out}}$?). 
- To reduce $\text{VSWR}_{\text{out}}$, sacrifice some $\text{VSWR}$ on output, but also increase gain $G_A$. 

First find $\text{VSWR}_{\text{out}} = 27.27$ (14.36 dB). Construct stability circle(s),
In the end use computer for optimization. See appendix CAD 4.

the best compromise. \( V_A \) and \( V_{SWR} \) (in) at those points, 4) select a point that gives

\( I_{SW} \) on S-chart, 2) break it up with 3-4 points, 3) calculate \( M \),

and \( I_{SW} \) and some trial and error procedure will not the case, then some guess-

\( V_A \) is large, minimizing each stage \( F \) (how?) and

Note on multistage amp: minimizing \( M \) (noise measure) is re-

quiried. As long as \( V_A \) is large, minimizing each stage \( F \) (how?)

\( I_{SW} \), obviously, some trial and error procedure re-

\( E_X. 4.3.5 \) illustrates design using \( V_A \) instead of \( C_\text{d} \) and for spec-

Microwave transistor amplifier design
Final \( F \)

Since there is plenty of gain, only the first stage influences the

\[
\frac{\Delta V_2}{I} - \frac{\Delta V_3}{I} + \frac{\Delta V_2}{I} = \text{Final} F
\]

For \( F \), take into account the gain of previous stages, e.g.,

For \( GA \), sum up the gains of every stage (in dB).

Calculating overall \( GA \) and \( F \), Ex. 4.3.6.