Some Review and Noise Properties

- Objectives today:
  - Some Comments about Exam 1
  - Giant Gas Science Report Results
  - Back to Goldstone...
  - System Noise & Temperature
    - Gain
    - Loss
    - Translating up and down
    - Antennas... (might be next time)
    - Receivers...
Next, demonstrate how the pointing error vector may be drawn on the deadband diagram below for the following two example real-time error vectors:

H–Earth offset error vector \( \mathbf{e}_{H-E} = 0.5 \angle 345^\circ \text{ mrad} \)

Sum error vector \( \mathbf{S} = \mathbf{C} + \mathbf{N} + \mathbf{W} + \mathbf{M} + \mathbf{E} = 0.9 \angle 285^\circ \text{ mrad} \)

Finally, compute the pointing error loss for \( |Z| = \theta \) (mrad):

\[ L(\theta) = -0.26 \text{ mrad} \] (to 2 digits)
\[ \{ d = 1, \ AR = +4, \ \tau = 45^\circ \} \]

where \( d \) = degree of polarization, \( AR \) = axial ratio, \( \tau \) = tilt angle is received by an Earth antenna polarized LHCP. Compute the polarization loss at the Earth antenna:

\[ L = 5.76 \]

(use 2 decimal points)
Exam 1 Curve

NE
A
B
C
D
E

Grad
A
B
C
D
E

+6 to exam
Form 1: Jupiter Science

Please review the Jupiter movie at http://www.amazon.com/gp/product/B006I0GYV8
Answer the questions below. (Short, not long answers, using complete sentences.)
This report is to be done on an individual basis, team efforts will have points subtracted.
There are several variations of the forms. You must use the Form # assigned to you by Connect.

* Required

Email address *

johnson@wmich.edu

Enter Your name *

1 Prof. Dean R. Johnson
Scientists in the Jupiter Movie

Provide rows of information for five presenters in the movie (exactly as shown below).
1) Andy Ingersol (can't use this example!)
2) Planetary Scientist, CALTECH
3) Studies weather

1) Presenter's Name 2) Title 3) What they do *

1) John Spencer
2) Planetary Scientist, SRI
3) Studies Io

Add individual feedback

1) Presenter's Name 2) Title 3) What they do *

1) Torrence Johnson
2) Planetary Scientist NASA/JPL
3) Runs robotic program
Remaining Questions from Movie

Answer the following questions, one row per question part (exactly as shown below).
1) Answer to first part of question
2) Answer to second part of question
3) etc.

State the purpose of the Galileo mission. * _____ / 6

Study Jupiter's magnetic storms. Study different features presented by Jupiter's moons.

State three physical characteristics of Jupiter (use 3 rows) * _____ / 6

1) Largest planet in solar system/62 moons/Solar system vacuum cleaner
2) Strong Magnetosphere
3) No solid surface/Atmosphere is mostly ammonia, H2S & water.
Jupiter Report

Questions about the Juno mission from Eyes on Solar System

Answer the following questions, one row per question part (exactly as shown below).
1) Answer to first part of question
2) Answer to second part of question
3) etc.

How long did Juno fire its engines to insert itself in an orbit about Jupiter? *

1) 35 minutes

1) What is Juno’s HGA covered with and 2) describe why it is used and when it designed to be used? *

1) The HGA is covered by insulating blankets.
2) The blankets shield Juno’s HGA from heat produced by the Sun’s harsh light while Juno is in the inner solar system.
Questions from lectures/Yuen document

Answer the following questions, one row per question part (exactly as shown below).
1) Answer to first part of question
2) Answer to second part of question
3) etc.

For an aperture antenna in Fig. 8-5, why does nt fall off with decreasing edge illumination? *

Because there is more loss based upon a tapered illumination than a uniform illumination. More edge tapering implies less uniform and more loss.

What kind of aperture illumination do antennas that use a subreflector design (such as on Voyager) provide? *

Uniform illumination
Aperture Gain
For an aperture antenna in Fig. 8-5, why does $n_1$ rise with decreasing edge illumination? *

The spillover efficiency ($n_1$) rises with decreasing edge illumination because there is less radiation to spillover at the edge.

What is the primary advantage of an antenna with uniform illumination over one with tapered illumination? *

It generates larger power in the main beam.
Jupiter Report

Report Quality: Will measure any one or more of the following: spelling, grammar, followed instructions including short complete sentences, individual effort, etc. (leave blank below)

Add individual feedback
Form 4: Saturn Science

Please review the Saturn movie at http://www.amazon.com/gp/product/B006I0GYVA
Answer the questions below. (Short, not long answers, using complete sentences.)
This report is to be done on an individual basis, team efforts will have points subtracted.
There are several variations of the forms. You must use the Form # assigned to you by Connect.

* Required

Email address *

johnson@wmich.edu

Enter Your name *

4 Prof. Dean R. Johnson
Scientists in the Saturn Movie

Provide rows of information for five presenters in the movie (exactly as shown below).
1) Andy Ingersol (can't use this example!)
2) Planetary Scientist, CALTECH
3) Studies weather

1) Presenter's Name 2) Title 3) What they do *

1) Bonnie Burrati
2) Planetary Scientist NASA/JPL
3) Studies Enceladus.

Add individual feedback

1) Presenter's Name 2) Title 3) What they do *

1) Chris McKay
2) Research Scientist NASA Ames Research Center
3) Studies Enceladus
State the purpose of the Cassini mission. *

To study the planet Saturn and its system; taking detailed observations of Saturn and its ring system. Explore Titan and Enceladus.

<table>
<thead>
<tr>
<th>Add individual feedback</th>
</tr>
</thead>
</table>

State three physical characteristics of the rings of Saturn (use 3 rows) *

1) Very thin, as tall as a one or two story building.
2) Made of billions of particles, ranging between grains of sand to small apartment buildings
3) 200,000 miles across, rotates at 20,000 - 40,000 mph

| Add individual feedback |
Saturn Report

Questions about the Cassini mission from Eyes on Solar System

Answer the following questions, one row per question part (exactly as shown below).
1) Answer to first part of question
2) Answer to second part of question
3) etc.

1) Explain the "High-gain to RAM" maneuver necessary for Cassini to begin its grand finale, plunging into the space between Saturn and its innermost ring for the first time. 2) How much space (km) is in that empty gap? *

1) The spacecraft is instructed to orient itself so that its HGA is facing towards the direction Cassini is moving.
2) 1500 mile = 2400 km

Add individual feedback

What moon of Saturn contributed the most to trajectory changes in Cassini? *

Titan
Saturn Report

Questions from lectures/Yuen document

Answer the following questions, one row per question part (exactly as shown below).

1) Answer to first part of question
2) Answer to second part of question
3) etc.

What is the effect of increasing tapering (ET) on the main beam of the aperture antenna described in Fig 8-10? *

A small decrease in the power (approximately 5 dB)

Add individual feedback

What mission (that has been discussed in class) has an antenna that would necessarily have the smallest surface leakage efficiency n7? *

The mesh antenna of Galileo.
Far-field patterns based on the aperture distribution (8.2-17) for different edge tapers and $n = 1$; $k = 2\pi/\lambda$, $a$ = antenna radius, $\theta$ = off-boresight angle. (Patterns are normalized to the peak of the 0 dB edge taper case.)
Saturn Report

Questions from lectures/Yuen document

Answer the following questions, one row per question part (exactly as shown below).

1) Answer to first part of question
2) Answer to second part of question
3) etc.

What is the primary advantage of an antenna with tapered illumination over one with uniform illumination? *

Less power is in the sidelobes with tapered illumination than with uniform illumination, as shown in Fig 8-10 or 11.

Add individual feedback

Does increasing k (kappa) in Fig. 8-6 increase or decrease the random surface error efficiency for an aperture antenna? *

Increasing kappa decreases n2.
Fig. 8-6. Correction factor $\kappa$ as a function of the surface $\text{rms}$ (in the normal to the surface direction) $\delta_{\text{rms}}/\lambda$ for different $f/D$ values
70 m Antenna at Goldstone
Goldstone Antenna Features
Goldstone Antenna System Diagram

Fig. 2.7. Receiving system noise temperatures are defined at specific locations: Feedhorn aperture at reference location 1, receiver input at reference location 2, receiver output at reference location 3.

Fig. 2.15. Calibration 2: DSN LNA noise temperature calibration configuration.
Fig. 2-8. Goldstone 70-m antenna XTR cone X-band feedhorn aperture reference location 1.
Goldstone Antenna LNA

Fig. 2-12. Goldstone 70-m antenna XTR cone X-band HEMT amplifier.
Noise & Temperature

*Vol 10 Low-Noise Systems in the Deep Space Network, Ch 2 - Macgregor S. Reid*

Thermal or Johnson [9] noise power density is given by

\[ N = k \ T_p \ \left[ \frac{J}{K} \right] \left[ \frac{K}{Hz} \right] = \left[ \frac{J}{Hz} \right] \]

where

- \( N \) = noise power density, W/Hz
- \( k \) = Boltzmann’s constant = \( 1.38065 \times 10^{-23} \), J/K
- \( T_p \) = resistive termination physical temperature, K
Connecting a resistive source to the input a noiseless amplifier

\[ G_{RCV} \]

\[ T_e = 0 \]

Receiver

\[ N_i \]

\[ P_0 \]

\[ N_o = k \ T_p \ BG \]

provides amplifier output noise power \( N_o \),

where \( G = G(f) \) = available power gain, ratio

\[ B = (1 / G_m) \int G(f) \, df \]

\( G_m = \) maximum available power gain
System operating noise temperature \((T_{op})\) is given by

\[
T_{op} = \frac{P_o}{kBG} \left[ \frac{W}{\frac{\lambda}{\kappa}} \right] = [\kappa]
\]

where

\(P_o = \) receiver output noise power, \(W\)

System operating noise temperature arises from multiple contributions:

\[
T_{op} = T_{sky} + T_{ant} + T_{feed} + T_{LNA} + T_f
\]

Fig. 2-15. Calibration of DSN LNA noise temperature calibration configuration.
Cosmic Microwave Background (CMB)
Cosmic Microwave Background (CMB)

CMB discovered accidentally by American radio astronomers Arno Penzias and Robert Woodrow Wilson.
System Noise Operating Temperature

\( T_{op} \) is composed of both an incident input noise temperature and the receiver effective input noise temperature

\[ T_{op} = T_i + T_e \]

where

\( T_i = \) input source noise temperature, K

\( T_e = \) receiver effective input noise temperature, K

(referred to the input)
Noise, Temperature & Gain

\[ N_i = \frac{kT_i}{G} \]

\[ N_0 = \frac{kT_0}{G} = \frac{kT_i}{G} \]

\[ G = \frac{T_0}{T_i} \]

\[ N_0 = G \cdot N_i \]

\[ 290 \text{ K} : N_i = 1.38 \times 10^{-23} \left( \frac{J}{k} \right) \approx 290 \text{ K} \]

\[ N_i = 4 \times 10^{-21} \text{ W} \cdot \text{Hz} = 4 \times 10^{-18} \text{ mW} \cdot \text{Hz} \]

\[ = -203.98 \text{ dB} \]

\[ = -173.98 \text{ dBm} \]

\[ 1 \text{ K} \]

Compute \( N_i \) in dBm

\[ N_0 = \frac{G}{N_i} \]

\[ N_i = ? \text{ dBm} \]
Noise, Temperature & Gain

\[ T_e = \text{effective input temperature} \]
\[ T_e = \frac{T_0}{G} = \frac{900^\circ K}{10} = 90^\circ K \]
\[ T_i + T_e = 290^\circ K + 90^\circ K = 380^\circ K \]
Noise, Temperature & Gain

Frisch equation:

\[ T_e = T_{e_1} + \frac{T_{e_2}}{G_1} + \frac{T_{e_3}}{G_1G_2} \]

Example:

\[ T_{e_1} = 240^\circ \quad T_{e_2} = 600^\circ \quad T_{e_3} = 1200^\circ \]

\[ G_1 = 1000 \]

\[ G_2 = 2 \]

Find \( T_e \)

\[ T_e = ? \] \( ^\circ K \)
Translating Noise Temperatures

For the three separate reference locations 1, 2, and 3 system noise temperatures by definition are

\[ T_{op1} = T_{i1} + T_{e1} \quad \text{where} \quad T_{op1} = LT_{op2} \]

\[ T_{op2} = T_{i2} + T_{e2} \]

\[ T_{op3} = T_{i3} + T_{e3} \]

\[ T_{op2} = \frac{T_{op1}}{L} \]

\[ T_{op3} = GT_{op2} \]

\( G \) (ratio) and \( L \) (ratio) are always equal to or greater than 1.
Gain & Losses

\[ G_i \rightarrow \frac{L}{1} \begin{cases} \text{when } G+L > 1 \\ \text{when } G+L < 1 \end{cases} \]

Example:

\[ T = \frac{1}{2} \]

Given

\[ 96^\circ K \]

\[ T = ? \]
Translating Noise Temperatures

the noise temperature translation equation
between reference locations 1 and 2
separated by a loss $L$, ratio

$$T_{e1} = LT_{e2} + (L-1)T_p$$

Solving for $T_{e2}$

$$T_{e2} = \frac{T_{e1}}{L} - \left(1 - \frac{1}{L}\right)T_p$$

With $T_{op} = T_i + T_e$

$$T_{op1} = LT_{op2}$$

Solving for $T_{i2}$

$$T_{i2} = \left(\frac{T_{i1}}{L}\right) + \left(1 - \frac{1}{L}\right)T_p$$
### Table 2-3. Noise Temperature Equations Summary.

<table>
<thead>
<tr>
<th>Items</th>
<th>Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>General:</td>
<td>( M = \frac{G}{T} )</td>
</tr>
<tr>
<td>(1)</td>
<td>( T_{op} = T_i + T_e )</td>
</tr>
<tr>
<td>(2)</td>
<td>( T_{op1} = LT_{op2} )</td>
</tr>
<tr>
<td>(3)</td>
<td>( T_{i1} = LT_{i2} - (L - 1)T_p )</td>
</tr>
<tr>
<td>(4)</td>
<td>( T_{i2} = T_{i1}/L + (1 - 1/L)T_p )</td>
</tr>
<tr>
<td>(5)</td>
<td>( T_{e1} = LT_{e2} + (L - 1)T_p )</td>
</tr>
<tr>
<td>(6)</td>
<td>( T_{e2} = T_{e1}/L - (1 - 1/L)T_p )</td>
</tr>
<tr>
<td>(7)</td>
<td>( L = (T_p + T_{e1})/(T_p + T_{e2}) )</td>
</tr>
</tbody>
</table>
Antenna Noise Temperatures

\[ T_a = \frac{N_a}{k} \]

where

- \( T_a \) = antenna noise temperature, K
- \( N_a \) = noise power density delivered by the antenna
- \( k \) = Boltzmann’s constant

Antenna noise temperature is given by

\[ T_a = \int_{4\pi} T(\Omega)G(\Omega)d(\Omega) \]

where

- \( T(\Omega) \) = equivalent blackbody temperature of area \( d(\Omega) \) in direction \( \Omega \), K
- \( G(\Omega) \) = antenna gain in direction \( \Omega \), ratio
## Antenna Noise Temperatures

Table 2-2. DSN Goldstone large ground antennas downlink performance for 25-percent weather and zenith antenna-pointing elevation angle.

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Freq. Band</th>
<th>Gain (dBi)</th>
<th>( T ) Noise Temp. (K)</th>
<th>G/T(_{\text{M}}) (dB)</th>
<th>HPBW (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>34-m BWG</td>
<td>S</td>
<td>56.8</td>
<td>36.8</td>
<td>41.1</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>68.0</td>
<td>33.0</td>
<td>52.9</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td>Ka</td>
<td>78.5</td>
<td>31.0</td>
<td>63.6</td>
<td>0.017</td>
</tr>
<tr>
<td>34-m HEF</td>
<td>S</td>
<td>56.0</td>
<td>38.0</td>
<td>40.2</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>68.1</td>
<td>19.8</td>
<td>55.1</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td>Ka</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>70-m</td>
<td>S</td>
<td>63.4</td>
<td>22.0</td>
<td>50.0</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>74.4</td>
<td>20.6</td>
<td>61.3</td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td>Ka</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

The receiving system sensitivity and capability is defined by \( G/T \), where \( G \) is the antenna gain and \( T \) is the overall noise temperature of the entire receiving chain, usually called system operating noise temperature, \( T_{\text{op}} \).
Antenna Noise Temperatures

\[ T_{\text{sky}} = T_{\text{atm}} + \frac{T_{\text{CMB}}}{L_{\text{atm}}} \]

\[ T_{\text{op}} = T_{\text{sky}} + T_{\text{AMW}} \]

*Top* defined at the feedhorn

where

\[ T_{\text{atm}} = \text{noise temperature of the atmosphere} \]

\[ L_{\text{atm}} = \text{loss due to the atmosphere} \]

\[ T_{\text{CMB}} = 2.725, \text{ K} \]

\[ T_{\text{AMW}} = \text{antenna microwave system} = T_{\text{ant}} + T_{\text{feed}} + T_{\text{LNA}} + T_{f} \]

\[ T_{\text{LNA}} = \text{LNA noise temp} \]

\[ T_{f} = \text{follow-up amplifier noise temp} \]

Fig. 2-15. Calibration a: DSN LNA noise temperature calibration configuration.
$T_{\text{sky}} = T_{\text{atm}} + T_{\text{CMB}} / L_{\text{atm}}$

$T_{e1} = T_{\text{LNA1}} + T_{\text{feed1}} + T_{f1}$

$T_{e2} = T_{\text{LNA2}} + T_{f2}$

where

$T_{\text{LNA1}} = L_{\text{feed}} T_{\text{LNA2}}$

$T_{f1} = L_{\text{feed}} T_{f2}$

$T_{\text{feed1}} = L_{\text{feed}} T_{\text{feed2}}$

$T_{\text{feed2}} = \left(1 - \frac{1}{L_{\text{feed}}}\right) T_{P}$

Fig. 2-15. Calibration a: DSN LNA noise temperature calibration configuration.
### Table 2-3. Noise Temperature Equations Summary.

<table>
<thead>
<tr>
<th>Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(9) $T_{op1} = L_{feed}T_{op2}$</td>
<td></td>
</tr>
<tr>
<td>(10) $T_{i1} = L_{feed}T_{i2} - T_{feed1} = T_{sky1} + T_{ant1} + T_{dichroic1}$</td>
<td></td>
</tr>
<tr>
<td>(11) $T_{i2} = T_{i1} / L_{feed} + T_{feed2} = T_{sky2} + T_{ant2} + T_{dichroic2} + T_{feed2}$</td>
<td></td>
</tr>
<tr>
<td>(12) $T_{e1} = L_{feed}T_{e2} + T_{feed1} = T_{LNA1} + T_{feed1} + T_{f1}$</td>
<td></td>
</tr>
<tr>
<td>(13) $T_{e2} = T_{e1} / L_{feed} - T_{feed2} = T_{LNA2} + T_{f2}$</td>
<td></td>
</tr>
<tr>
<td>(14) $T_{feed1} = (L_{feed} - 1)T_p$</td>
<td></td>
</tr>
<tr>
<td>(15) $T_{feed2} = (1 - 1 / L_{feed})T_p$</td>
<td></td>
</tr>
<tr>
<td>(16) $T_{sky1} = L_{feed}T_{sky2}$</td>
<td></td>
</tr>
<tr>
<td>(17) $T_{ant1} = L_{feed}T_{ant2}$</td>
<td></td>
</tr>
<tr>
<td>(18) $T_{feed1} = L_{feed}T_{feed2}$</td>
<td></td>
</tr>
<tr>
<td>(19) $T_{LNA1} = L_{feed}T_{LNA2}$</td>
<td></td>
</tr>
<tr>
<td>(20) $T_{f1} = L_{feed}T_{f2}$</td>
<td></td>
</tr>
</tbody>
</table>