6. Back to the Earth: Ground Station & User Terminal

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Other Services may need different Network Architectures (broadcasting)
Architecture of a Large Network Gateway (Ground) Station

- Main Reflector
- Subreflector
- Radio Beam to and from Satellite
- Waveguide
- Multiplexer
- Signal Modulation and Translation to Carrier Frequency
- Generator
- Filters
- Emergency Batteries
- Down Converters
- Station Control Center
- Demodulation to Produce Sub-Carrier Groups
- Microwave Link
- Microwave Link (Incoming and Outgoing)
- Low Noise Amplifier
- Driver Amplifier
- Receiver Feed and Filter
- Transmitting Feed Horn
- Folded Radio-Frequency Optics
- Dip. Ingegneria dell'Informazione
- University of Pisa, Italy

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Earth Station Architecture/Functions (Narda/Miteq)

Typical Earth Station Configuration

- HPA’s
- Up Conv.
- Carrier Up Converter
- Level Control Module 70/140 MHz
- ModeMS 70/140 MHz

Uplink

- Antenna
- Actuators
- Tracking System
- Sensors
- Beacon Receivers
- Control / Monitoring

Downlink

- MITEQ
- Non-MITEQ
- LNA’s
- Power Splitters
- Synthesized Down Converter
- ModeMS 70/140 MHz

- Modulators For each carrier
- 70MHz/140MHz L-Band
- Down Conv.
- De-Modulators
- Data Input/Output

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Main Functions

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1:1 Redundant HPAs

1:1 PHASE COMBINED HPA SYSTEM

BUC REDUNDANT SYSTEM

DELAY MATCHED COAXIAL CABLE

400W HPA AC/DC POWER SUPPLY

DELAY MATCHED WAVEGUIDE

MONITOR & CONTROL

WAVEGUIDE HYBRID COMBINER

MONITOR & CONTROL

DELAY MATCHED WAVEGUIDE

400W HPA AC/DC POWER SUPPLY

HPA Alarms, Switch Drive

FPRC-1100 CONTROLLER

RS485 M/C

OUTPUT POWER DETECTOR MODULE

RF OUT

CROSS GUIDE COUPLER

SW1

DUMMY LOAD

HLP

AC/DC POWER SUPPLY

MONITOR & CONTROL

DELAY MATCHED WAVEGUIDE

400W HPA

DELAM MATCHED COAXIAL CABLE

BUC 2

950-1525 MHz INPUT
OPT. 10 MHz REFERENCE INPUT

BUC 1

RCP2-1100 CONTROLLER

RS485 M/C

RS-232 Vcc
47-43 Hz
100W

CONTROLLERS NETWORKED ON RS-485

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“Soft” Redundancy

- All amplifiers are active, and are phase-coherently combined
- If one fails, the other provide slightly increased power
- No switches
• Single Polarization

1:1 System

Redundant LNAs
• Double Polarization

1:2 System

- POL 1 IN (WR42F)
  - TEST IN (-40 dB)
- POL 2 IN (WR42F)
  - TEST IN (-40 dB)
- OFFLINE IN
- PLATE ASSEMBLY
- CONTROLLER
  - CONTROL/STATUS
- LNA 1
  - TRANSMIT REJECT FILTER
  - INPUT CROSSGUIDE COUPLER
- LNA 2
  - TRANSMIT REJECT FILTER
  - INPUT CROSSGUIDE COUPLER
- LNA 3
  - TRANSMIT REJECT FILTER
  - INPUT CROSSGUIDE COUPLER
- POL 1 OUT
  - COUPLED OUT (-20 dB)
- POL 2 OUT
  - COUPLED OUT (-20 dB)
- OFFLINE OUT
There may be more than one RF chain
• User Terminal or User Equipment (UE), much simpler than Gateway Station

![Typical VSAT Domestic User-Teminal Architecture](image)

- **IDU**
  - Satellite Modem
  - L-Band 950 – 1950 MHz
  - 10 MHz Ref., 12 V DC

- **ODU**
  - BUC
  - Feed
  - Block Up Converter
  - LNB
  - Low-Noise Block downconverter
  - Tx 29.50 ~ 31.00 GHz (Ka)
  - Rx 19.7 ~ 21.2 GHz (Ku)

- **Data**
  - 10 MHz Ref., 12 V DC
RX Power Budget/Gain

<table>
<thead>
<tr>
<th>Element</th>
<th>Cumulative G [dB] @ Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMT</td>
<td>-00.40</td>
</tr>
<tr>
<td>LNA</td>
<td>20.00</td>
</tr>
<tr>
<td>AMP</td>
<td>10.00</td>
</tr>
<tr>
<td>IR Filter</td>
<td>-02.00</td>
</tr>
<tr>
<td>Mixer</td>
<td>-12.00</td>
</tr>
<tr>
<td>IF Filter</td>
<td>-01.50</td>
</tr>
<tr>
<td>IF Amp 1</td>
<td>20.00</td>
</tr>
<tr>
<td>IF Amp 2</td>
<td>20.00</td>
</tr>
<tr>
<td>Total (G)</td>
<td>54.10</td>
</tr>
</tbody>
</table>

OrthoMode Transducer (OMT, Duplexer)
Image Reject

- IF passband
- Unwanted image signal
- Local oscillator signal
- Wanted signal

Amplitude / response vs. Frequency

Frequency difference equal to IF
Noise Figure $F$

Represents the degradation of the Signal-to-noise ratio (SNR) caused by the diverse electronic components in a radio frequency (RF) signal processing chain.

$$\text{Input Power}$$

$$SNR_{in} = \frac{S_{in}}{N_{in}}$$

$$G(\text{Gain}) = \frac{S_{out}}{S_{in}}$$

$$\text{Output Power}$$

$$SNR_{out} = \frac{S_{out}}{N_{out}}$$

$$N_{out} \ (\text{Output Noise}) = G \ast N_{in} + N_{DUT} = G \ast F \ast N_{in}$$

$$\frac{SNR_{in}}{SNR_{out}} = \frac{S_{in}/N_{in}}{G S_{in}/G F N_{in}} = F \ , \ F[db] = SNR_{in}[db] - SNR_{out}[db]$$

$$\frac{S_{out}}{N_{out}} = \frac{G \ast S_{in}}{G \ast N_{in} + N_{DUT}} = \frac{S_{in}}{N_{in}} \frac{1}{1 + \frac{N_{DUT}}{G N_{in}}} \quad \Rightarrow \quad F = 1 + \frac{N_{DUT}}{G N_{in}} , \quad N_{DUT} = G N_{in} (F - 1)$$
**Noise Figure $F$**

Represents the degradation of the Signal-to-noise ratio (SNR) caused by components in a radio frequency (RF) signal chain

\[
\frac{SNR_{in}}{SNR_{out}} = \frac{S_{in}/N_{in}}{G_{S_{in}}/G_{FN_{in}}} = F, \quad F_{[dB]} = SNR_{in}[dB] - SNR_{out}[dB] 
\]

If several devices are cascaded, the total noise factor ($F_T$) can be calculated as:

\[
F_T = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1 \cdot G_2} + \frac{F_n-1}{G_1 \cdot G_2 \cdot G_{n-1}} 
\]
RX Noise Computation

<table>
<thead>
<tr>
<th>Element</th>
<th>Cumulative NF [dB] @ Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMT</td>
<td>0.41</td>
</tr>
<tr>
<td>LNA</td>
<td>2.71</td>
</tr>
<tr>
<td>AMP</td>
<td>2.73</td>
</tr>
<tr>
<td>IR Filter</td>
<td>2.74</td>
</tr>
<tr>
<td>Mixer</td>
<td>2.80</td>
</tr>
<tr>
<td>IF Filter</td>
<td>2.82</td>
</tr>
<tr>
<td>IF Amp 1</td>
<td>2.87</td>
</tr>
<tr>
<td>IF Amp 2</td>
<td>2.88</td>
</tr>
<tr>
<td>Total (NF)</td>
<td>2.88</td>
</tr>
</tbody>
</table>

(Remember that for passive devices with loss $L$ dB, then $F=L$)
Noise Figure & Noise Temperature

\[ N_{DUT} = Gk_B T_{DUT} = GN_{in} (F - 1) \]

(Remember that internal noise \( N_{in} \) is always referred to the device input...)

Evaluating noise through the noise temperature(s) gives

\[ N_{in} = k_B T_{ref} \quad \Rightarrow \quad T_{DUT} = T_{ref} (F - 1) \]

And the relation between the Noise Figure \( F \) and the Equivalent Noise Temperature \( T_{DUT} \) is

\[ F = 1 + \frac{T_{DUT}}{T_{ref}} \]

Usually, \( T_{ref} = 290 \, \text{k} \)
Noise Figure & Noise Temperature

Represents the degradation of the Signal-to-noise ratio (SNR) caused by components in a radio frequency (RF) signal chain.

\[ SNR_{in} = \frac{S_{in}}{N_{in}} \]

\[ G(Gain) = \frac{S_{out}}{S_{in}} \]

\[ SNR_{out} = \frac{S_{out}}{N_{out}} \]

\[ N_{out} (Output\ Noisy) = G \cdot N_{in} + N_{DUT} = G \cdot F \cdot N_{in} \]

\[ \frac{SNR_{in}}{SNR_{out}} = \frac{S_{in}/N_{in}}{G_{S_{in}}/G_{F_{in}}} = F, \ F_{[dB]} = SNR_{in}[dB] - SNR_{out}[dB] \]

For cascaded devices, the total equivalent noise temperature \( T_T \) can be calculated as:

\[ T_T = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 \cdot G_2} + \frac{T_n}{G_1 \cdot G_2 \cdot G_{n-1}} \]
An amplifier keeps a constant gain for low-level input signals. At higher input levels, it goes into *saturation* and its gain decreases. The 1 dB *compression point* indicates the power level that causes the gain to drop by 1 dB from its small-signal value.

$$OP_{1dB} = IP_{1dB} + (G)_{dB} - 1 \quad [\text{dBm}]$$

$$IP_{1dB} = OP_{1dB} - (G)_{dB} + 1 \quad [\text{dBm}]$$

If several devices are cascaded, the $P_{1dB}$ can be calculated as:

$$\frac{1}{IP_{total}} = \frac{1}{IP_1} + \frac{G_1}{IP_2} + \frac{G_1 \cdot G_2}{IP_3} + \ldots [\text{dBm}]$$
The 3\textsuperscript{rd}-Order Intercept Point (IP3) relates nonlinear products caused by the third-order nonlinear term to the linearly amplified useful signal.

If several devices are cascaded, the IP3 can be calculated as:

\[
\frac{1}{IP3_{total}} = \frac{1}{IP3_1} + \frac{1}{IP3_2} + \frac{1}{IP3_3} + \ldots \text{[dBm]}
\]

\[
OIP_3 = \frac{IMD_3}{2} + P_{out} \ldots \text{[dBm]}
\]

\[
IIP_3 = OIP_3 - G \ldots \text{[dBm]}
\]
- Oscillator with phase noise:

\[ c(t) = \sqrt{2C} \cos(2\pi f_{LO} t + \theta(t)) \Rightarrow c_{BB}(t) = \sqrt{2C} \cdot e^{j\theta(t)} \]

- rapid, short-term, random fluctuations in the phase of the LO signal, caused by time domain instabilities
Effect of Phase Noise on Data Constellations

QPSK Constellation Diagram

- AWGN only
- AWGN & PN
- PN only
• Oscillator with phase noise:

\[ c(t) = \sqrt{2C} \cos(2\pi f_{LO} t + \theta(t)) \Rightarrow c_{BB}(t) = \sqrt{2C} \cdot e^{j\theta(t)} \]

- rapid, short-term, random fluctuations in the phase of the LO signal, caused by time domain instabilities

<table>
<thead>
<tr>
<th>Offset from the carrier</th>
<th>Analogue DRO (Low-Cost)</th>
<th>Digital DRO</th>
<th>PLL Internal Ref. (Quartz)</th>
<th>PLL External Ref. (10 MHz USO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Hz</td>
<td>Not specified</td>
<td>Not specified</td>
<td>-70 dBC/Hz</td>
<td>-65 dBC/Hz</td>
</tr>
<tr>
<td>1 KHz</td>
<td>-55 dBC/Hz</td>
<td>-65 dBC/Hz</td>
<td>-75 dBC/Hz</td>
<td>-75 dBC/Hz</td>
</tr>
<tr>
<td>10 KHz</td>
<td>-70 dBC/Hz</td>
<td>-80 dBC/Hz</td>
<td>-80 dBC/Hz</td>
<td>-85 dBC/Hz</td>
</tr>
<tr>
<td>100 KHz</td>
<td>-85 dBC/Hz</td>
<td>-100 dBC/Hz</td>
<td>-85 dBC/Hz</td>
<td>-95 dBC/Hz</td>
</tr>
<tr>
<td>1 MHz</td>
<td>-95 dBC/Hz</td>
<td>-100 dBC/Hz</td>
<td>-95 dBC/Hz</td>
<td>-105 dBC/Hz</td>
</tr>
</tbody>
</table>
Anatomy of a Ka-Band VSAT (Professional) Terminal

The transceiver consists of the following sub-systems:

**Waveguide feed**
- Septum polarizer (POL) with OMT
- Diplexers (DPX)

**Low Noise Block-down-converter (LNB)**

**5W Block Up-Converter (BUC)**

**Monitor and Control facility (M&C)**

Key features:

**Integrated Waveguide Feed (POL+OMT+DPX)**

Operation on arbitrary polarizations:
- LHCP or RHCP electronically switchable
- X- or Co-polar electronically switchable

Wideband operation with electronically switchable frequency sub-bands
Anatomy of a Ka-Band VSAT (Professional) Terminal - TX

Waveguide Feed

Transmitter
Anatomy of a Ka-Band VSAT (Professional) Terminal - TX
Anatomy of a Ka-Band VSAT (Professional) Terminal - RX

Receiver
Anatomy of a Ka-Band VSAT (Professional) Terminal - RX
### Typical Requirements of a Universal Ka-Band (5W) Transceiver

<table>
<thead>
<tr>
<th><strong>Receiver Subsystem</strong></th>
<th><strong>Parameter</strong></th>
<th><strong>Value</strong></th>
<th><strong>Comments</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Receive (Downlink) range</td>
<td>19.2 – 21.2 GHz</td>
<td>Commercial &amp; military</td>
<td></td>
</tr>
<tr>
<td>IF output range</td>
<td>950 – 1950 MHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LO frequency</td>
<td>18.25/19.25 GHz</td>
<td>Switchable via M&amp;C</td>
<td></td>
</tr>
<tr>
<td>LO frequency tolerance</td>
<td>0.7 ppm / 3 ppm</td>
<td>In/Ext Auto-detect</td>
<td></td>
</tr>
<tr>
<td>LO phase noise</td>
<td>0.9 deg</td>
<td>1KHz – 1 MHz</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Parameter</strong></th>
<th><strong>Value</strong></th>
<th><strong>Comments</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise figure</td>
<td>1.3 dB</td>
<td></td>
</tr>
<tr>
<td>Conversion gain</td>
<td>60 dB</td>
<td></td>
</tr>
<tr>
<td>Power Consumption</td>
<td>3.6 W</td>
<td>150 mA @ 24 V DC over RX IF supply</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Transmitter Subsystem</strong></th>
<th><strong>Parameter</strong></th>
<th><strong>Value</strong></th>
<th><strong>Comments</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit (Uplink) range</td>
<td>29.0 – 31.0 GHz</td>
<td>Commercial &amp; military</td>
<td></td>
</tr>
<tr>
<td>IF input range</td>
<td>950 – 1950 MHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LO frequency</td>
<td>28.05/29.05 GHz</td>
<td>Switchable via M&amp;C</td>
<td></td>
</tr>
<tr>
<td>LO phase noise</td>
<td>1.3 deg</td>
<td>100 Hz – 100 KHz</td>
<td></td>
</tr>
<tr>
<td>Conversion gain</td>
<td>58 dB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Parameter</strong></th>
<th><strong>Value</strong></th>
<th><strong>Comments</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>RF output spurious</td>
<td>EN 301459 and FCC 47</td>
<td>With 53 dBi antenna</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>62.4 W</td>
<td>1.3 A @ 48 V DC over TX IF supply @ RF full, CW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Feed</strong></th>
<th><strong>Parameter</strong></th>
<th><strong>Value</strong></th>
<th><strong>Comments</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range</td>
<td>19.2 – 31.0 GHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polarisation</td>
<td>RHCP/LHCP &amp; co-/x-polar</td>
<td>Switchable via M&amp;C</td>
<td></td>
</tr>
<tr>
<td>XPD</td>
<td>26 dB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Overall Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transceiver Output Power</td>
<td>5W</td>
<td></td>
</tr>
<tr>
<td>G/T @ 20.2 GHz</td>
<td>17.0 dB/K</td>
<td>30 deg elevation angle</td>
</tr>
<tr>
<td>EIRP @ 30 GHz</td>
<td>50.5 dBW</td>
<td>P1dB</td>
</tr>
<tr>
<td>Polarization</td>
<td>RHCP/LHCP &amp; co-/x-polar</td>
<td>Switchable via M&amp;C</td>
</tr>
<tr>
<td>Tx Band Switching</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Temperature (operational)</td>
<td>-25 to +55 degC</td>
<td></td>
</tr>
<tr>
<td>Temperature (storage)</td>
<td>-40 to +80 degC</td>
<td></td>
</tr>
<tr>
<td>Terminal weight</td>
<td>19.2 Kg</td>
<td>Without transport case</td>
</tr>
</tbody>
</table>

**EIRP** = \( P_0 - Lt + Gt \) ... [dBW]

\[
EIRP = 7 - 0.2 + 43.7 = 50.5 \text{ dBW}
\]

**G/T** = \( Gr - Lr - 10\log(T_{sys}) \) ... [dB/K]

\[
G/T = 40.2 - 0.4 - 22.8 = 17.0 \text{ dB/K}
\]

**Courtesy:** Skyware