1.0 INTRODUCTION

Frequency Electronics Inc. (FEI), with principal executive offices in Mitchel Field, New York, is a public corporation traded on NASDAQ under the symbol FEIM. FEI was established in 1962 and is a world leader in the design, development, and manufacture of high-technology frequency generation, timing, and synchronization products for commercial, military, and space applications.

FEI has over 45 years of experience in the design, manufacture and test of space hardware and has produced over 5,000 assemblies for various commercial, scientific and government space systems. Many have demonstrated over 15 years of successful operation in their missions.

Unique critical components such as quartz crystals, rubidium frequency standard lamps and filters, hybrid assemblies, and magnetic components are manufactured at FEI from raw materials to assure the highest reliability and to minimize schedule risk.

Although each space program has its own specific mission requirements (performance, life, environment, etc.), FEI’s approach is to take maximum advantage of its proven in-space experience and utilize qualified electrical and mechanical designs, parts, materials, and processes to the maximum extent possible. Heritage building blocks include power supplies, telemetry and control subsystems, precision oscillators, frequency multipliers, mixers, and amplifiers.

Satellite electronic hardware applications are environmentally challenging and all high-reliability products undergo rigorous qualification and acceptance testing including vibration, thermal shock, temperature, thermal vacuum, EMC, pyrotechnic shock, and radiation.
Some of the basic building blocks of FEI space subsystems are:

- **Optically pumped Rubidium based clocks/oscillators**
  - Examples:
    - MILSTAR
    - AEHF 1, 2, 3
    - GPS

- **Quartz based radiation-hardened ultra-stable clocks/oscillators**
  - Over 500 precision oscillator assemblies have been supplied for space applications
  - Cross-strapped designs with no single point failure
  - Extremely high reliability as demonstrated by clocks on Voyager 1 and 2 launched in 1977 and still operating

- **DRO (dielectric resonator oscillators)**
  - Fixed frequency and electronically tunable configurations

- **CRO (ceramic resonator oscillator)**
  - Fixed frequency and electronically tunable configurations

- **Frequency reference sources for generation and distribution from 1 MHz to 42 GHz**
  - Examples:
    - Reference Signal Generators from 100 MHz to 42 GHz
    - Coherent microwave sources and synthesizers utilizing sigma delta processing (step sizes 1 KHz to 1 MHz)
    - High isolation frequency distribution units from 1 MHz to 1 GHz

- **RF and microwave receivers**
  - Examples:
    - Pilot Receiver: Ka-Band and X-Band
    - Geostationary Communications and Control Segment (GCCS); formally known as WAAS: C-Band down converted to L-Band
    - X-Band down converted to S-Band
    - Defense Support Program: C-Band down-converted to baseband

- **DC to DC Converters**
  - Power outputs to 200w
  - Bus inputs from 20v to 100v
  - Base-plate operating temperature up to 80º C
  - Standard hybrid designs for converter controller and linear regulators
  - Custom magnetic elements fabricated in-house
  - Radiation hardened components and circuits
  - Isolated and non-isolated bus and telemetry signals available

**PROVEN PERFORMANCE**

- Forty-five years of High-Reliability Space Experience
- Over 150,000 Fielded products
- More Than:
  - 5,000 Systems In Space
  - 10,000 RF, Microwave & Other Assemblies
  - 60,000 Quartz Clocks
  - 100,000 Rubidium Clocks
  - 10,000 Sync Systems
  - 4,000 GPS Units

**2.0 SATELLITE PRODUCTS**

- **Power Amplifiers**
  - Examples:
    - 10.29 GHz, +23 dBm
    - 7.3 GHz, +34 dBm
    - 11.1 GHz, +21 dBm
    - C-Band, +40 dBm
    - Ku Band, +36 dBm

- **LNAs (Low Noise Amplifiers)**
  - UHF through Ku-Band

- **Filters**
  - Crystal 1MHz to 150MHz
  - SAW 200 MHz to 1100 MHZ
  - Helical 100MHz to 2GHz
  - Cavity 1GHz to 39GHz
  - Stripline 1GHz to 15GHz

- **Custom hybrids**
  - Build to specification or build to print
  - Analog, RF and microwave functions
  - Low and high power
  - Thin film and thick film technology
  - Eutectic and epoxy chip and substrate mounting
  - Wire and ribbon bonding
3.0 MASTER OSCILLATORS

FEI provides oscillators in various configurations to meet the requirement of the mission: stand-alone, double redundant and triple redundant. All redundant configurations are cross-strapped with no single-point failure. Oscillator assemblies incorporate DC-DC Converters and command/telemetry functions. Many have frequency stepping capabilities with non-volatile frequency storage memory. These oscillators are often incorporated into receivers and other integrates assemblies.

FEI’s Highest Precision Frequency Standard
- Internal DC-DC Converter
- Internal High-Precision VCXO
- $\sigma_y(\tau) = 2E^{-12}/\sqrt{\tau}$
- Long Term Stability < 2E-14/day

Triple Redundant Standard 1, 2, 3
- Triple Redundant Rubidium Atomic Standards
- Triple Redundant Precision Quartz Oscillators
- Double Redundant
- Multiple Frequency RF Synthesizers
- Triple Redundant DC/DC Converters
- Triple Redundant Mil-Std-1553B Serial Interface
- $\sigma_y(\tau) = 2E^{-12}/\sqrt{\tau}$
- Long Term Stability < 2E-14/day

Dual Redundant Ultra Stable Quartz Clock and High Isolation Distribution Assembly
- Dual Redundant DC-DC Converters
- Short Term Stability: 1E-13/1 sec
- Long Term Stability < 2E-8/10 years

Triple Redundant OCKO
- Triple Redundant DC-DC Converters
- Short Term Stability: 1E-12/1 sec
- Long Term Stability < 2E-7/10 years

Triple Redundant Ultra Stable Quartz Clock and 60 Output High Isolation Distribution Assembly

Rubidium Master Oscillator
- Total of 19 systems delivered
- Excellent performance in space
- Aging Rate: 3E-14/day
- Internal High-Precision VCXO and DC-DC converters
- $\sigma_y(\tau) = 8E^{-12}/\sqrt{\tau}$
- Long Term Stability < 2E-14/day
## 4.0 MICROWAVE FREQUENCY SOURCES

<table>
<thead>
<tr>
<th>Program</th>
<th>Type</th>
<th>Output Frequency</th>
<th>Long Term Frequency Stability</th>
<th>Spurious Signals (dBC)</th>
<th>Phase Noise (dBc/Hz)</th>
<th>DC Power (Watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fixed Frequency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIL</td>
<td>Direct</td>
<td>3.24 GHz, 4.13 GHz, 5.4 GHz, 6.48 GHz</td>
<td>1 x 10^-7</td>
<td>-85</td>
<td>-65 @ 10 Hz; -135 @ 100 kHz</td>
<td>20</td>
</tr>
<tr>
<td>MIL</td>
<td>Direct and Indirect</td>
<td>2.4 GHz through 14.5 GHz (six units)</td>
<td>1 x 10^-7</td>
<td>-70</td>
<td>-55 @ 100 Hz; -115 @ 100 kHz (14.5 GHz)</td>
<td>9</td>
</tr>
<tr>
<td>COMM</td>
<td>Direct and Indirect</td>
<td>2.4 GHz through 10.5 GHz (six units)</td>
<td>1 x 10^-7</td>
<td>-75</td>
<td>-42 @ 0.1 Hz; -120 @ 100 kHz (10.5 GHz)</td>
<td>10</td>
</tr>
<tr>
<td>COMM</td>
<td>Direct</td>
<td>1.50 GHz, 2.55 GHz, 3.30 GHz</td>
<td>1 x 10^-6</td>
<td>-80</td>
<td>-60 @ 10 Hz; -135 @ 100 kHz</td>
<td>8</td>
</tr>
<tr>
<td>DoD</td>
<td>Direct</td>
<td>100 MHz, 400 MHz, 500 MHz</td>
<td>5 x 10^-6</td>
<td>-100</td>
<td>-106 @ 10 Hz; -155 @ 100 kHz; -172 @ 1 MHz</td>
<td>4</td>
</tr>
<tr>
<td>DoD</td>
<td>Direct, Selectable Outputs</td>
<td>5.5 GHz – 16 GHz</td>
<td>5 x 10^-6</td>
<td>-90</td>
<td>-70 @ 10 Hz; -140 @ 100 kHz</td>
<td>19</td>
</tr>
<tr>
<td>DoD</td>
<td>Direct</td>
<td>20.5 GHz</td>
<td>5 x 10^-7</td>
<td>-70</td>
<td>-60 @ 10 Hz; -140 @ 100 kHz</td>
<td>4</td>
</tr>
<tr>
<td>COMM</td>
<td>Direct</td>
<td>(4) L-Band, (2) Ku-band</td>
<td>1 x 10^-7</td>
<td>-60</td>
<td>-130 @ 100 kHz</td>
<td>15</td>
</tr>
<tr>
<td>COMM</td>
<td>Direct</td>
<td>(6) L-Band, (2) Ku-band</td>
<td>1 x 10^-7</td>
<td>-60</td>
<td>-121 @ 25 kHz</td>
<td>20</td>
</tr>
<tr>
<td>MIL</td>
<td>Direct and Indirect</td>
<td>128 MHz, 480 MHz</td>
<td>1 x 10^-7</td>
<td>-90</td>
<td>-150 @ 100 kHz</td>
<td>25</td>
</tr>
<tr>
<td><strong>Tunable Frequency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIL</td>
<td>Indirect, 10 kHz steps</td>
<td>170 MHz to 260 MHz</td>
<td>5 x 10^-7</td>
<td>-75</td>
<td>-70 @ 10 Hz</td>
<td>1.8</td>
</tr>
<tr>
<td>COMM</td>
<td>Indirect, 100 kHz steps</td>
<td>1487 MHz to 1491 MHz</td>
<td>1 x 10^-7</td>
<td>-75</td>
<td>-65 @ 1 Hz; -95 @ 100 Hz; -145 @ 100 kHz</td>
<td>8</td>
</tr>
<tr>
<td>COMM</td>
<td>Indirect, 5kHz steps</td>
<td>4.25 GHz to 5.25 GHz</td>
<td>1 x 10^-7</td>
<td>-60</td>
<td>-40 @ 100 Hz; -95 @ 100 kHz; -125 @ 1 MHz</td>
<td>15</td>
</tr>
</tbody>
</table>

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**TUNABLE FREQUENCY SOURCES**

**Dual Redundant Tunable Frequency Generators**

- Dual Redundant DC-DC Converters
  - 100 KHz; Steps for 1487 MHz to 1491 MHz
  - 10 KHz; Steps for 170 MHz to 260 MHz
  - 5 KHz; Steps for 4.25 GHz to 5.25 GHz
- Synthesizer Tunable in Steps of 1 KHz to 1 MHz
- Excellent Phase Noise

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**L-Band Synthesizer Phase Noise**

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**Dual Tunable L-Band Synthesizer**
### FIXED FREQUENCY SOURCES

**Output Frequencies 1 Hz to 42 GHz**

- Dual Redundant Fixed Frequency Generator
- Dual Redundant DC-DC Converters
- Output Frequencies
  - 3.24 GHz, 4.13 GHz
  - 5.4 GHz, 6.48 GHz

- Multiple Frequency Local Oscillator
  - Fully redundant with internal cross-strapping
  - Dual Redundant DC-DC Converters
  - Output Frequencies
    - 1 Hz to 42 GHz
    - 2 @ 7084 MHz, 2 @ 6950 MHz
    - 2 @ 2457 MHz, 2 @ 1000 MHz
    - 8 @ 750 MHz, 6 @ 150 MHz
    - 2 @ 20 MHz, 2 @ 3.88 MHz
  - All Outputs Coherent with Internal 50 MHz OCXO Except for 3.88 MHz

### 5.0 OTHER SATELLITE RF COMPONENTS

<table>
<thead>
<tr>
<th>Unit</th>
<th>Frequency</th>
<th>Qty</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNA</td>
<td>L-Band</td>
<td>700</td>
<td>Low in-band ripple, 35 types</td>
</tr>
<tr>
<td></td>
<td>Ku-Band</td>
<td>4</td>
<td>1.1 dB NF</td>
</tr>
<tr>
<td>Up/Down Converters</td>
<td>Ka-C</td>
<td>4</td>
<td>44 GHz – 5 GHz</td>
</tr>
<tr>
<td></td>
<td>Ku-UHF</td>
<td>5</td>
<td>Low Passband Ripple</td>
</tr>
<tr>
<td></td>
<td>UHF-Ku</td>
<td>5</td>
<td>Low Passband Ripple</td>
</tr>
<tr>
<td></td>
<td>Ku-X</td>
<td>12</td>
<td>Low Spurious Signals</td>
</tr>
<tr>
<td></td>
<td>X-Ku</td>
<td>12</td>
<td>Low Spurious Signals</td>
</tr>
<tr>
<td>Receivers</td>
<td>C-Band</td>
<td>4</td>
<td>Triple Conversion to baseband</td>
</tr>
<tr>
<td></td>
<td>C-Band</td>
<td>2</td>
<td>CR and T</td>
</tr>
<tr>
<td></td>
<td>X-S Band</td>
<td>2</td>
<td>NF = 1.6 dB</td>
</tr>
<tr>
<td></td>
<td>C-S Band</td>
<td>1</td>
<td>NF = 1.2 dB</td>
</tr>
<tr>
<td></td>
<td>Ka-Band</td>
<td>2</td>
<td>Pilot receiver</td>
</tr>
<tr>
<td></td>
<td>X-Band</td>
<td>2</td>
<td>Pilot receiver</td>
</tr>
<tr>
<td></td>
<td>C-L Band</td>
<td>2</td>
<td>GPS Dual channel NF = 1.8 dB</td>
</tr>
<tr>
<td>CRO - DRO</td>
<td>14.16 GHz</td>
<td>5</td>
<td>PLDRO, 80 MHz reference</td>
</tr>
<tr>
<td></td>
<td>13.77 GHz</td>
<td>5</td>
<td>Free-running</td>
</tr>
<tr>
<td></td>
<td>2.55 to 3.30 GHz</td>
<td>12</td>
<td>PLDRO, 25 MHz reference two frequencies</td>
</tr>
<tr>
<td></td>
<td>1.00 to 1.80 GHz</td>
<td>12</td>
<td>PLDRO, 25 MHz reference three frequencies</td>
</tr>
<tr>
<td></td>
<td>4.8 to 14.5 GHz</td>
<td>30</td>
<td>PLDRO, 10 MHz reference six frequencies</td>
</tr>
<tr>
<td></td>
<td>8.2 GHz to 10.5 GHz</td>
<td>20</td>
<td>PLDRO, 10 MHz reference three frequencies</td>
</tr>
<tr>
<td></td>
<td>2.4 to 2.8 GHz</td>
<td>20</td>
<td>PLC RO, 10 MHz reference three frequencies</td>
</tr>
<tr>
<td></td>
<td>5 GHZ</td>
<td>2</td>
<td>PLDRO, 10.23 MHz reference two frequencies</td>
</tr>
</tbody>
</table>
6.0 RECEIVERS

**Dual Receiver**
- *Triple Redundant Precision Oscillators*
- C-Band Receivers down-converted to L-Band
- **INPUT FREQUENCY (GHz)** 6.0
- **NOISE FIGURE (dB)** 1.2
- **RECEIVER GAIN (dB)** 67 – 82 selectable
- **L NA GAIN (dB)** 52
- **BANDWIDTH (MHz)** 75
- **TEMPERATURE RANGE (°C)** -25 TO +67
- **DC POWER (WATTS)** 27
- **RELABILITY** 1250 FITS (15 years)
- **GROUP DELAY (nsec)** 0.40
- **OIP3 (dBm)** +22

**Triple Redundant 30 GHz Pilot Receiver**
- **TRIPLE REDUNDANT OCXO**
- **TRIPLE REDUNDANT 30 GHz PILOT RECEIVERS**
- **TRIPLE REDUNDANT DC-DC CONVERTERS**
- **SHORT TERM STABILITY: 1E-12/1 SEC**
- **CLOCK PHASE LOCKED TO GROUND BASE OR PILOT SIGNAL**

**Dual Redundant Receiver**
- **INPUT FREQUENCY: 8.8 GHz**
- **OUTPUT FREQUENCY: 2.2 GHz**
- **BANDWIDTH: 150 MHz**
- **NOISE FIGURE: 1.6 dB**
- **INTERCEPT POINT: +30 dBm**
- **DC POWER: 11 WATTS**
- **WEIGHT: 3.2 Kg**
Over the last five decades, FEI has supplied high-stability time and frequency generators, low-noise receivers, DC-DC Converters, and integrated RF assemblies to the major satellite manufacturers. The products described in this brochure represent only a small sample of the thousands of satellite products produced by FEI.

As a world leader in high-reliability satellite components and systems, FEI has in-place engineering and management resources to ensure a successful program. Critical design analyses are performed by experienced circuit, thermal, and mechanical engineers using the latest computerized simulation programs. FEI maintains a large inventory of screened active and passive components and our experienced parts specialists carefully review each program requirement to minimize schedule risk.

FEI will supply a comprehensive solution for all of your satellite needs addressing hardware specifications, command, telemetry, and bus interface requirements, and lots more. It’s no wonder that so many satellite manufacturers around the world choose FEI for their most critical high-rel requirements.

7.0 IN-HOUSE RESOURCES

- Technical staff is in place to execute space programs with over 1000+ years of space/high-reliability experience
- All Critical Analyses Performed In-House
  - Worst Case
  - Component Stress
  - Thermal
  - Radiation
  - Structural
  - Reliability/FMECA
  - EMC
  - Phase noise and spurious signals
- Environmental Tests Performed In-House
  - Thermal Cycling
  - Thermal Vacuum
  - Vibration
  - Conducted Susceptibility
- Critical Manufacturing In-House
  - Full machine shop with three CNC machines
  - Personnel certified by NASA and IPC instructors
  - Workmanship to NASA-STD-8739.2 and .3

8.0 CONCLUSION

Over the last five decades, FEI has supplied high-stability time and frequency generators, low-noise receivers, DC-DC Converters, and integrated RF assemblies to the major satellite manufacturers. The products described in this brochure represent only a small sample of the thousands of satellite products produced by FEI.

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