EndRun TECHNOLOGIES
"Smarter Timing Solutions"

**W H I T E   P A P E R**

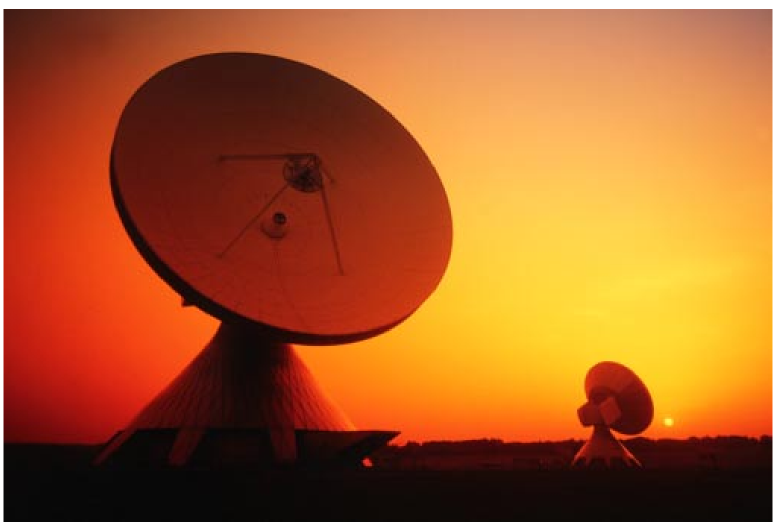
# Satellite Communication *Systems*

## *Frequency Reference Distribution for Earth Stations*

**Large earth stations host communication systems that provide mission-critical, high-bandwidth services to multiple customers. Within these earth stations are many frequency-based devices with independent local oscillators that generate and convert carrier frequencies, and modulate and demodulate data. Locking these oscillators to a common, stable and low-noise frequency reference distribution system is fundamental to minimizing frequency issues and supporting higher data rates. This application note focuses on the important role and benefits of a frequency reference distribution system, design considerations, and best practices to deploy a system that meets large earth station reliability and quality-of-service requirements.**

### IMPORTANCE OF HIGH-RELIABILITY FREQUENCY REFERENCES

Satellite communications are based upon stable, accurate, and low-noise microwave carrier frequencies. In order to provide robust satellite links at high bandwidths with complex digital modulation, a common GPS frequency reference is very important to system reliability.



The role and benefits of a frequency reference system are the same for small and large earth stations but the architecture differs relative to the number of devices to be synchronized. Both systems are based upon GPS-synchronized frequency reference(s). Application note Satellite Communication Systems – GPS Frequency Reference for Earth Stations discusses the high value that a GPS frequency reference with ultra-low phase noise provides to earth station operations.

### HIGH-RELIABILITY FREQUENCY REFERENCE DISTRIBUTION SYSTEM

Large earth station operators have the challenge of providing multiple services to a large number of customers at the highest data rates. The overall volume of data serving critical applications necessitates an infrastructure with a higher level of reliability and redundancy to meet customer availability and quality-of-service requirements.

Earth station quality-of-service is directly related to the frequencies used to carry the payloads through the modulators, demodulators, uplinks and downlinks. The independent local oscillators within these devices are subject to frequency drift and temperature instability that can result in degraded performance and errors. Best practice is to stabilize these oscillators with a phase-locked-loop (PLL) connected to an external GPS-based frequency reference. The frequency output from the GPS reference, that is traceable to the United States Naval Observatory (USNO), provides excellent short- and long-term stability. This enables earth-station devices to correct the local oscillator accuracy and stability by continuously compensating for drift and temperature.

A GPS-based frequency reference requires an exterior-mounted antenna to receive the broadcasted GPS signal. Proper installation requires the antenna to be placed in a location that ensures as clear a view-of-the-sky as possible. Any obstructions such as buildings, large metal objects, other antennas, or even trees, will limit performance. The antenna is connected to the GPS frequency reference with coaxial cable.

Considering the value of the GPS frequency reference to the earth station and the vulnerabilities of the exterior antenna (e.g. lightning) and cable run, best practice involves installing redundant systems. This is accomplished by installing dual-GPS references with a frequency distribution system as illustrated in Figure 1.

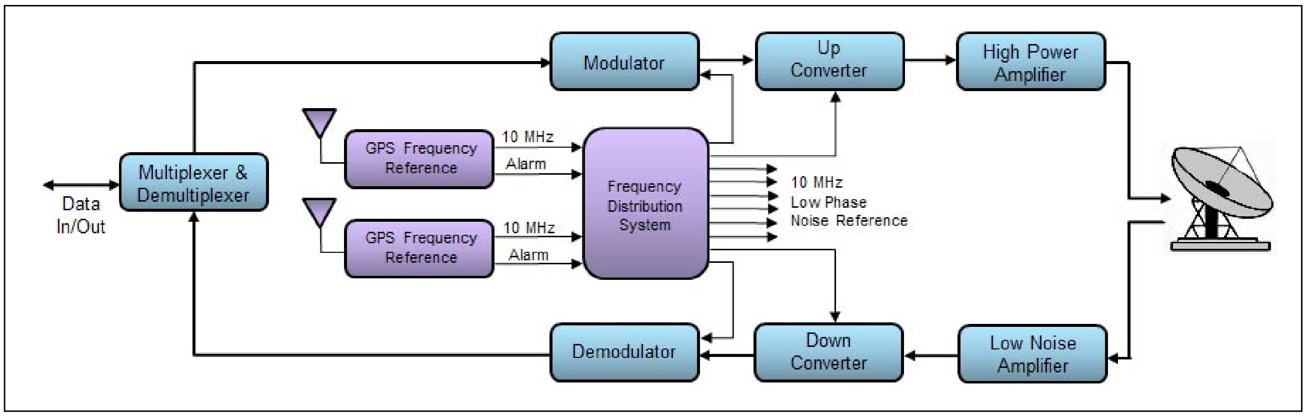



**Figure 1. Dual GPS Frequency Reference and Distribution System**

The frequency distribution system provides multiple outputs (i.e. copies) of the reference signal from one of the GPS references that are connected directly to earth station equipment. The distribution system continuously monitors the operational status and signal levels of the GPS references and automatically switches to the healthy system in event of a fault. Alarms are then generated so that earth station operators can address the cause of the fault. Earth station equipment, however, continues to receive a solid frequency reference from the redundant GPS reference.

## Frequency Reference Fundamentals and Terminology for Distribution System

To understand the benefits of a robust frequency reference distribution system, it is helpful to know some terminology and fundamentals of oscillators, frequency and signal distribution.

*Frequency stability* refers to how an oscillator's resonant frequency varies when averaged over a short- or long-term period. Short-term stability is typically measured in decade intervals from 1-100 seconds and long-term stability in decade intervals from greater than 100 to 100,000 seconds (approximately 1 day) and sometimes over days and weeks. A properly equipped GPS reference with low-phase noise oscillator provides excellent short- and long-term stability, and frequency accuracy.

*Phase noise* is related to the rapid movement of zero crossings of the signal relative to those of an ideal reference standard. The noise is measured relative to the carrier signal power in dBc/Hz at small frequency offsets. Phase noise is one of the most critical noise elements to minimize in earth stations as the noise close to the carrier cannot be filtered, is multiplied and propagates through the system. Ultra-low phase noise in earth station equipment is essential to supporting complex modulation, strong signal-to-noise (S/N) ratios, and respective high data rates. High-quality, oven-controlled, quartz oscillators provide the best low phase noise and short-term stability.

*Additive phase noise* is the level of phase noise added to a signal as it passes through an electronic device or distribution system. In practice each electronic device will contribute some added noise but the levels should be minimal and not significant to the overall system operation. Distribution equipment manufacturers, for example, take care to minimize additive phase noise and specify the noise levels at offsets from the carrier.

*Impedance matching* ensures that the impedances of the signal source output, load input, and transmission cable match as close as possible. A properly impedance-matched system minimizes reflections and standing waves to achieve maximum power transfer and signal integrity.

*Port-to-port isolation* is a property of electronic devices that indicates how well the input and output ports are isolated from interference from other ports. The degree of port isolation, or separation, is measured in dB and typically lessens as the signal frequency increases. It is important that signal faults and anomalies on one output channel are not reflected and disrupt operations on another channel. Within distribution equipment, a port-to-port isolation specification of -100 dB and lower is considered excellent for a 10 MHz frequency reference.

*Coaxial cable* is the most common cable type for distributing RF signals. Coaxial cable has an internal conductor, surrounded by a tubular dielectric material, and a tubular conducting shield. The cable is encapsulated and protected with an outer, insulating sheath. The conductor, shield and dielectric type can vary as well as the characteristic impedance of the cable. High-quality cables should be selected for earth station applications and specifications reviewed to ensure impedance match and adequate signal levels are delivered to receiving equipment. Shielding is also important in maintaining channel-to-channel isolation.

| Coaxial Cable Type | RG-174 | RG-58 | RG-123 | RG-6 | RG-11 |
|---|---|---|---|---|---|
| Attenuation @ 10 MHz | 3.3 dB | 1.4 dB | 1.0 dB | 0.6 dB | 0.4 dB |

**Table 1. Coaxial Attenuation of 10 MHz Signal Per 100 Feet (typical)**

*Attenuation* refers to loss of signal strength and is a key specification for cables used in a frequency distribution system. As a signal is transmitted from a frequency distribution system to earth station equipment, signal strength will be attenuated based upon the cable type, length, and degree of impedance match of the respective equipment. Signal attenuation increases with frequency and varies with cable type. See Table 1 for a comparison of the typical losses a 10 MHz signal experiences with various coaxial cables.

## FDC3302 High-Performance Frequency Distribution Chassis

The EndRun Technologies FDC3302 Frequency Distribution Chassis (FDC) is a high-performance system ideal for distributing low phase noise signals from a GPS frequency standard to multiple earth station devices. The FDC supports dual sine wave inputs, from 100 kHz – 30 MHz, and provides ten high-quality, isolated outputs in an efficient 1U form factor. For applications requiring additional outputs, multiple FDC units can be deployed in a bank arrangement providing over 100 outputs.

Within earth station applications, the spectral purity of the frequency reference is essential to achieving high signal-to-noise (S/N) ratios throughout the system. The FDC uses specialized hardware to ensure an absolute minimum amount of phase noise is added to the reference signal at its input.

The typical level of additive phase noise by the FDC to a 10 MHz reference is shown in Figure 2. Figure 3 illustrates the FDC additive phase noise relative to the Intelsat IESS 308/309 standard when up-converted to 14.5 GHz. Note that minimizing the additive noise provides a larger margin for phase noise contributed by other devices in the earth station.

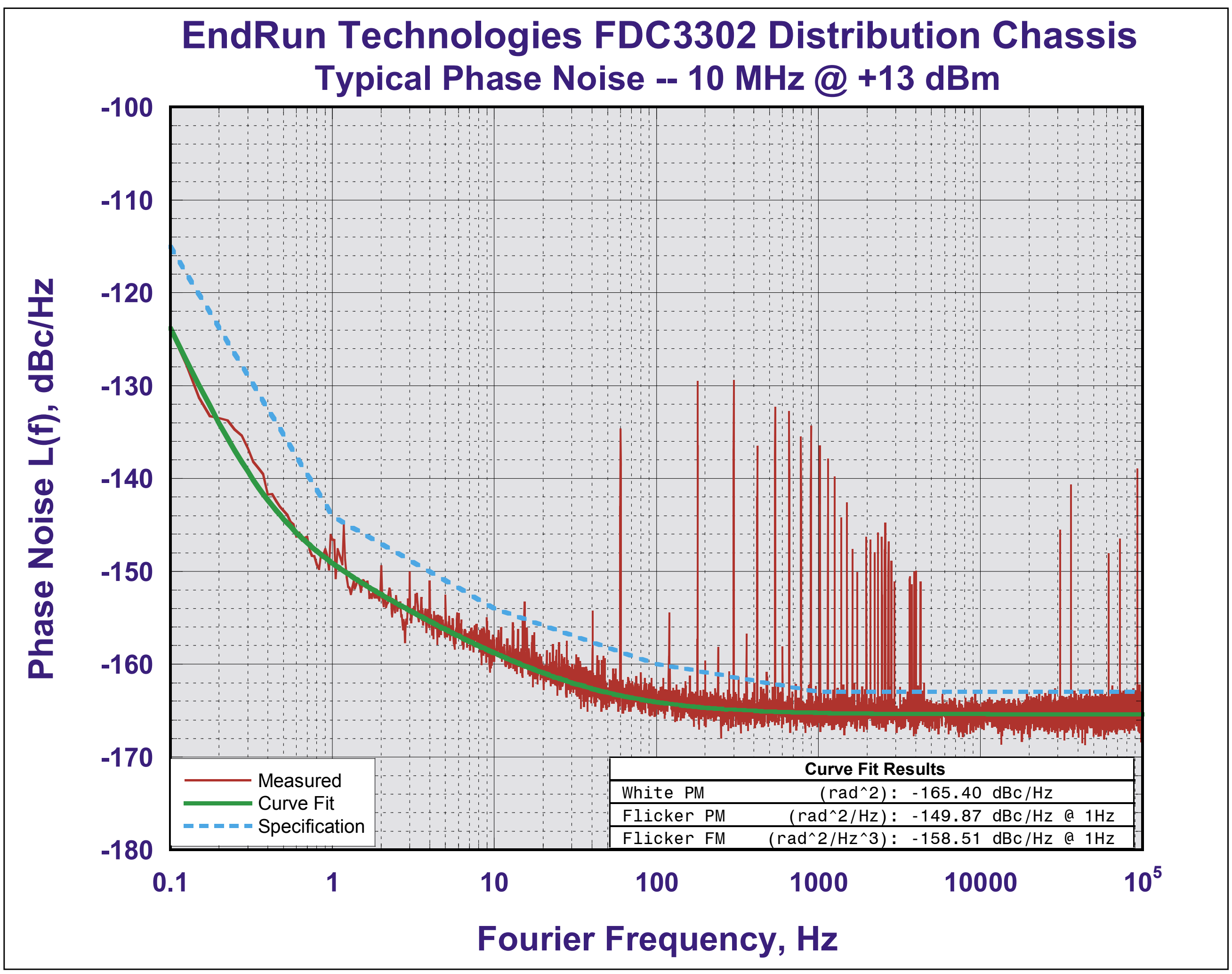



**Figure 2. FDC3302 Typical Additive Phase Noise to 10 MHz Signal**

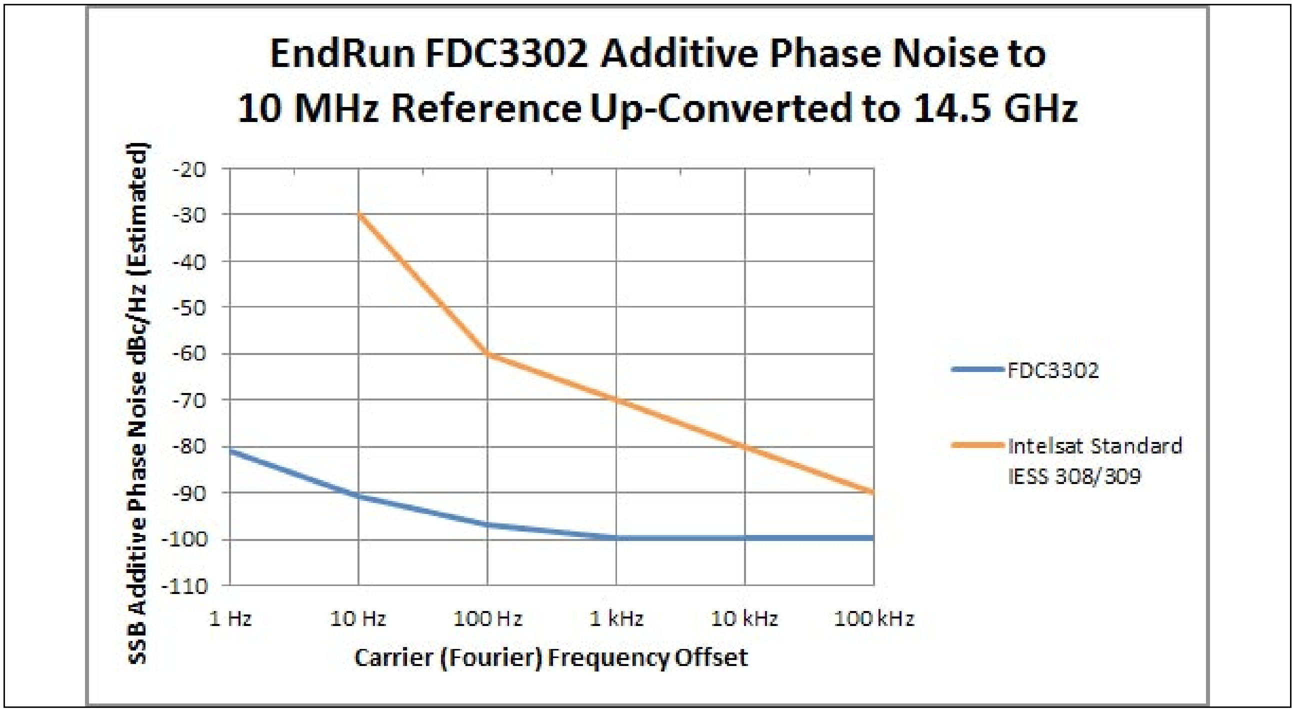



Figure 3. FDC3302 Additive Phase Noise vs. the Intelsat Standard

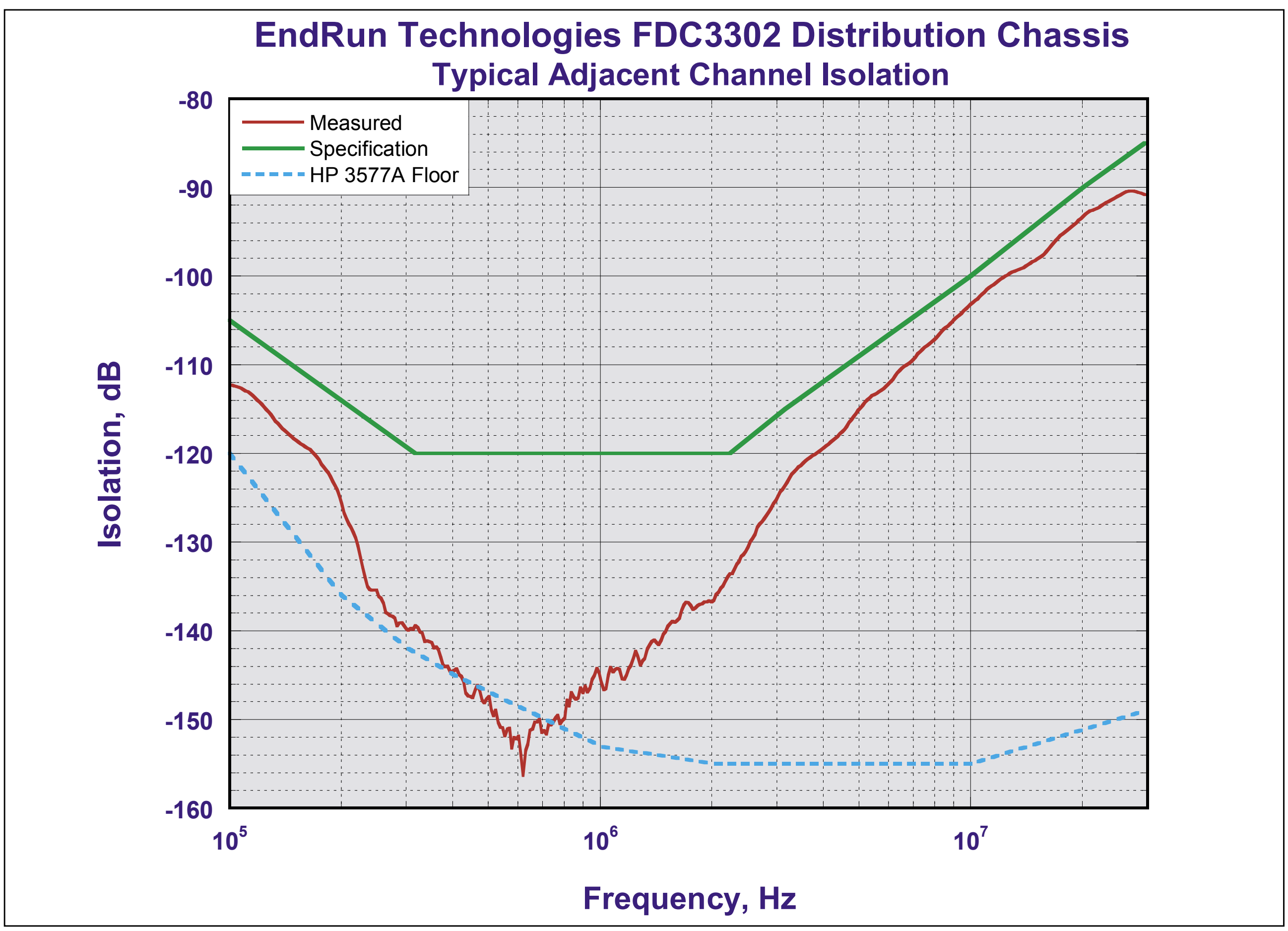



Figure 4. FDC3302 Output Channel Isolation

## FDC3302 Port-to-Port Isolation

The FDC architecture results in industry-leading port-to-port isolation of the input and all ten output channels. Ten discrete broadband output amplifiers are utilized to insure consistent performance of all outputs with minimal cross talk. Figure 4 illustrates the exemplary isolation performance. Note that at 10 MHz frequencies the FDC provides isolation better than -100 dBc. Isolation is a key parameter within earth stations to ensure a fault on one output does not disrupt operation of an earth station device connected to another output channel.

## FDC3302 High-Reliability Operation with Dual GPS Frequency Reference Inputs

The FDC supports dual GPS frequency reference inputs to support large earth station applications as shown in Figure 1. The FDC monitors the 10 MHz reference signal levels at its input as well as the alarm outputs from the GPS frequency references. Should a fault or alarm be detected, the FDC will automatically select the input from the healthy GPS reference to drive its outputs. Upon this condition, the FDC will also assert its alarm output to alert earth station personnel of the fault.

## FDC3302 Port Impedance and Standing Wave Ratio

The FDC is a unity gain frequency distribution system with 50 ohm impedances on all inputs and outputs. The inputs have a standing wave ratio (SWR) specification of <1.1 and the outputs <1.3 at 10 MHz which is an accurate measure of the actual impedance. When connected to devices and cables with exact 50 ohm impedances, reflections and SWR losses are minimal (<0.1 dB).

## System Management and Security

The FDC can be monitored and controlled locally via a dedicated RS-232 serial port and/or remotely via an optional network interface port. Secure network management is supported via Secure Shell (SSH). Complete system status, alarms, and control are available via these interfaces to efficiently and easily manage the unit.

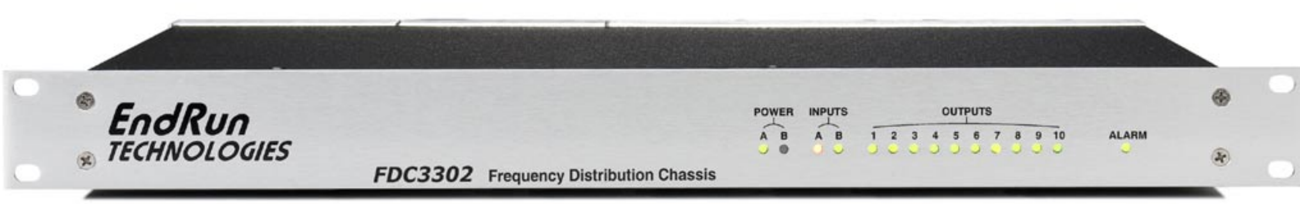
The FDC monitors all the output ports as well as the inputs for signal presence and asserts an alarm if a fault is detected. The status of all ports is easily viewed via the communication interfaces, therefore system operators can monitor the status of all distributed frequency references from one central location. The status of the inputs, outputs, power supplies, and alarms are also displayed for easy viewing on the front panel LEDs.

## Dual Power Supply Option

For high-reliability applications, such as earth stations, the FDC3302 is normally configured with the optional dual power supplies. The FDC continuously monitors the voltage at the output of each of the two internal power supplies. Under normal operation, the Primary A supply is active while the Secondary B supply remains on standby. Should the Primary or Secondary supply fail, the FDC asserts the appropriate alarm and the distribution system continues operating to specification as the power supplies are connected in a diode "OR'd" configuration.

## Summary

Large earth station operations are based upon high-stability, low-phase-noise frequency references. Dual GPS-based frequency references with ultra-low phase noise oscillators and a robust distribution system are fundamental to ensuring earth station up-converters, down-converters, and modems have a common high-quality reference. System interconnects must be established with high-quality, low-loss, impedance-matched cable. Best practice involves deploying redundant frequency references and a fault tolerant distribution system to support reliable earth station operations at maximum data rates with the highest quality of service.




**FDC3302 High-Performance Frequency Distribution Chassis**

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