WHITE PAPER

DIFI: Satellite Ground Station Digital Modernization Initiative

Advancing interoperability in digital ground technology with the industry's most powerful RF, application and cybersecurity test platforms

KEYSIGHT

Glossary of Acronyms

BER: Bit Error Rate

BPS: BreakingPoint Software

CD: A DIFI Combiner / Divider

CW: Continuous Wave

DIFI: Digital Intermediate Frequency Interoperability

DUT: Device Under Test

EDIM: Enterprise Digital Intermediate Frequency Multi-carrier

EVM: Error Vector Magnitude

GEO: Geostationary Earth Orbit

GNSS: Global Navigation Satellite Systems

IF: Intermediate Frequency

IFC: Intermediate Frequency Converter

IP: Internet Protocol

IPv4 and IPv6: Internet Protocol version 4 / Internet Protocol version 6

IQ: In-phase and Quadrature

LEO: Low Earth Orbit

MEO: Medium Earth Orbit

NVS: Network Visibility Solutions

QoS: Quality of Service

QSFP+ / QSFP28: Quad Small Form-factor Pluggable / Quad Small Form-factor Pluggable 28

RF: Radio Frequency

SATCOM: Satellite Communications

SDR: Software Defined Radio

SFP / SFP+: Small Form-factor Pluggable / Enhanced Small Form Factor Pluggable

UDP: User Datagram ProtocolVITA-49: VMEbus International Trade Association Standard 49, also known as VITA Radio Transport (VRT) standard

What is DIFI?

DIFI stands for digital intermediate frequency interoperability. The Digital Intermediate Frequency Interoperability (DIFI) standard (IEEE-ISTO Std 4900-2021) was developed to enable interoperability among digital Intermediate Frequency (IF) systems, especially in Satellite Communications (SATCOM). Also known as packetized Radio Frequency (RF), it enables the transmission of digitized In-phase and Quadrature (IQ) data over Internet Protocol (IP) networks, allowing satellite signals to be processed flexibly and remotely. The DIFI standard promotes:

- Vendor neutrality
- IP-based digital IF transport
- Separation of waveform processing and RF hardware

Two key components of the system are the RF/IF Converter (IFC) and the Enterprise Digital Intermediate Frequency Multi-carrier (EDIM) modem, which can be a hardware modem or implemented as a virtual software modem. The IFC receives satellite signals and converts them from radio frequency to an intermediate frequency. It then digitizes and packetizes the signal into IQ data, which can be transmitted over a public or private core network, or even through the cloud. This IQ data is received by the EDIM modem, which demodulates and decodes it for delivery to end users, such as broadcast customers, Global Navigation Satellite Services (GNSS), or military applications.

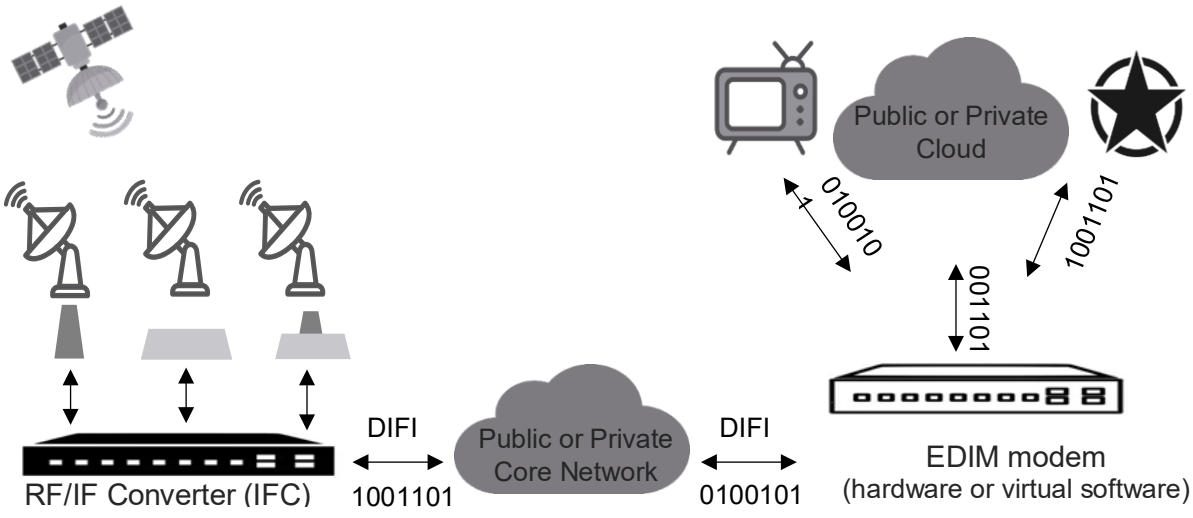


Figure 1. Two key components within the DIFI ecosystem include the IFC and EDIM modem.

The EDIM modem is a critical component of the U.S. Army's modernization initiative and is closely aligned with the DIFI standard. The EDIM modem is mandated to comply with DIFI to ensure interoperability across military and commercial SATCOM systems. DIFI compliance enables the EDIM modem to operate within resilient, scalable, and flexible network architectures, while also supporting long-distance IP-switched fiber connections, up to 40 km, eliminating the limitations of traditional coaxial systems.

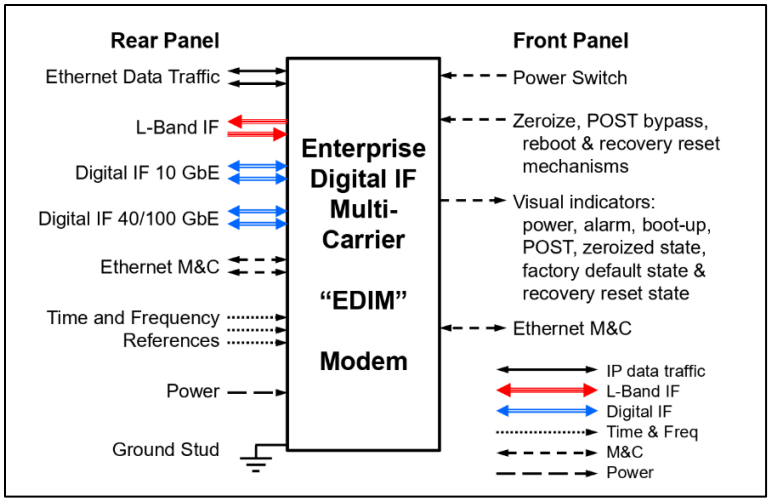


Figure 2. EDIM modem external interface diagram.

The EDIM modem is a multi-channel software-defined modem that operates on multiple, diverse satellite networks simultaneously. EDIM is eight (8) modems in one, operating across multiple networks in different orbital regimes, Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO), simultaneously.

Key Advantages of DIFI

Cloud-based signal processing

Enables advanced demodulation and signal recovery by transmitting raw IQ data and metadata to the cloud, removing the need for on-site processing.

High-fidelity digital signals

Maintains consistent signal quality over long distances, unlike analog signals that degrade with transmission length.

Disaggregated architecture

Separates antenna sites from processing centers, supporting centralized or distributed deployments and flexible resource allocation.

Minimal field infrastructure

Reduces or eliminates bulky satellite headend equipment in the field and streamlines deployment.

Scalable and mobile operations

Supports multi-carrier, multi-mission use cases with easy scalability to meet evolving mission and network demands.

Interoperability and modernization

Facilitates integration across vendors and systems, offering a future-proof, software-defined platform for modern SATCOM needs.

DIFI business sector

This is an emerging technology that's gaining significant traction. In the SATCOM ground segment business chain, we see RF manufacturers producing modems and Intermediate Frequency Converters (IFCs). Key players in this space include Comtech, Kratos, Calian, and ETL. Moving up the value chain, ground station integrators and satellite operators are showing strong interest in DIFI solutions. Additionally, cloud service providers such as Amazon Web Services (AWS), Microsoft and Google are expected to be highly engaged as this technology continues to evolve.

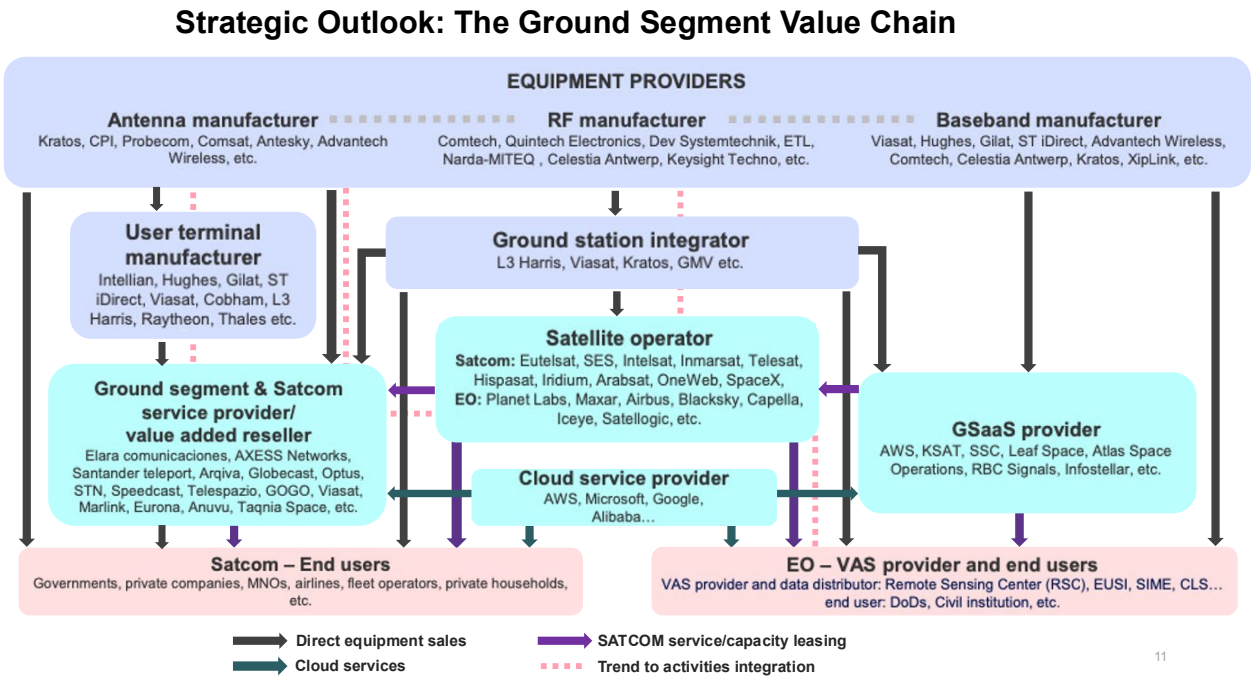


Figure 3. Strategic outlook of the satellite ground segment value chain. Source "Ground Segment Market Prospects 5th Edition, Novaspace 2024, nova.space".

DIFI Packetized RF

The DIFI standard is built upon VITA-49, an established RF packetization protocol. It consists of three primary components:

1. **Context packets** – These are mandatory 150-byte packets that define key signal parameters such as center frequency, bandwidth, and sample rate.
2. **Signal data packets** – These carry the IQ (in-phase and quadrature) data within their payloads. Packet sizes can vary widely, from small 64-byte packets to jumbo frames up to 9000 bytes.
3. **Command packets** – Used for control and configuration purposes within the system.

The protocol operates over User Datagram Protocol (UDP), with support for both Internet Protocol version 4 (IPv4) and Internet Protocol version 6 (IPv6) headers. Signal data packets are aggregated to reconstruct the waveform, enabling flexible and efficient transport of RF signals over IP networks.

VITA-49, also known as the VITA Radio Transport (VRT) standard, is significant because it provides a standardized way to digitize, packetize, and transport RF signals over IP networks. This is especially important in modern communications systems, including SATCOM, radar, and electronic warfare; where flexibility, interoperability, and scalability are critical. By digitizing and standardizing RF transport, VITA-49 enables virtualized ground stations, Software-Defined Radios (SDRs), and cloud-native SATCOM architectures — key trends in modern aerospace and defense systems.

In a packetized RF over IP system, IQ data is transmitted in discrete data packets that, when combined over time, reconstruct the full RF waveform. These packets are accompanied by context packets, which are essential for decoding the IQ data but are not required to appear at a fixed rate. Context packets may be sent as frequently as every other packet or as infrequently as every thousand packets. These packets play a critical role by providing the DIFI device with the necessary metadata, such as sample rate, frequency, and timing information. to correctly interpret the IQ stream. This architecture enables flexible and scalable RF signal transport over standard IP networks.

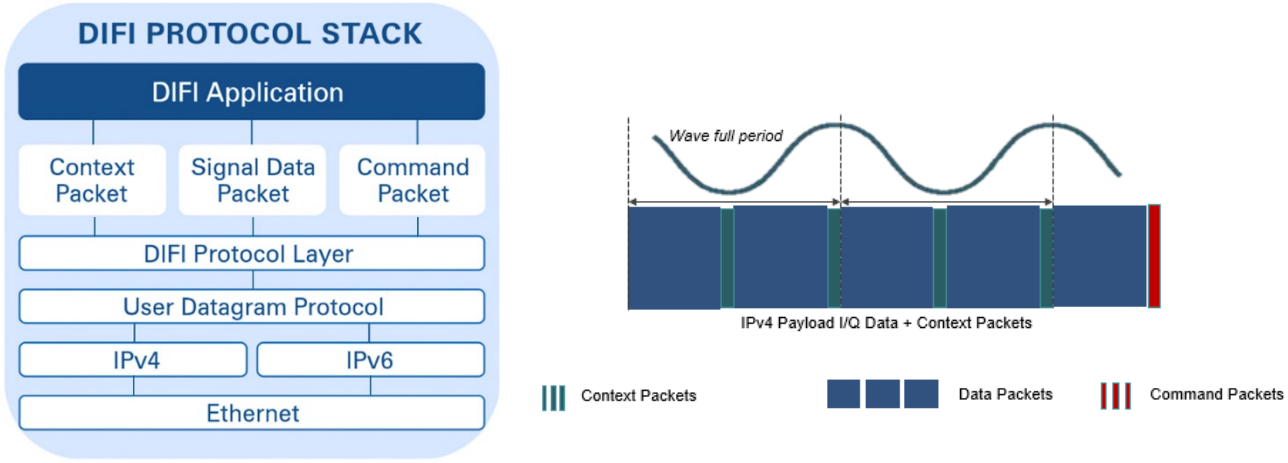


Figure 4. DIFI protocol stack overview and visual diagram of context, data, and command packet flow.

Packetized RF creation flow

The DIFI packet flow supports cyclical payload structures, allowing RF waveform cycles to terminate and restart cleanly at the final packet of a given cycle. This enables users to define arbitrary packet sizes and export configurations to generate DIFI-compliant flows. The process begins with RF simulation tools such as Keysight's PathWave Signal Generation or SystemVue software, which serialize IQ data and export it to binary files. These files are then processed and uploaded to Keysight BreakingPoint software (BPS), running on a traffic generator and protocol emulator capable of producing DIFI packet flows. BPS supports a wide range of port speeds to match the DIFI ecosystem, including 1/10 Gigabit Ethernet (GE) via SFP/SFP+ for modems, and 40 GE / 100 GE interfaces for QSFP+/QSFP28 narrowband and wideband digitizers, respectively. While the DIFI specification (as of version 1.3) does not mandate packet sizes, current IFC vendors typically use fixed 1500-byte packets for flows under 10 Gbps and 9000-byte packets, or jumbo frames, for higher-throughput services. DIFI modem uplinks are generally flexible, supporting packet sizes from 64-bytes to 9000-bytes. BPS accommodates for this variability, making it a versatile tool for emulating realistic DIFI traffic across diverse interface types.

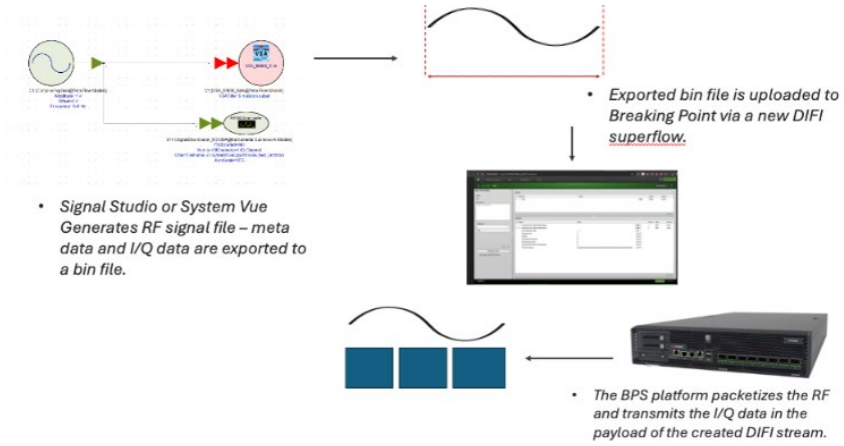


Figure 5. DIFI packetized RF signal creation and traffic generation scenario.

Packet rates in terms of network traffic bandwidth will depend on the digitized RF signal characteristics. Here's a table showing estimated Layer 3 packet stream bandwidths for digitized RF signals, based on varying sample rates, bandwidths, and bit depths. As you reach 2 GHz of bandwidth with larger bit depth and higher sample rates, much higher throughput can be expected on the ethernet digitized stream. These estimates assume IQ data (hence the factor of 2 in the calculation):

Bandwidth (MHz)	Sample rate (Gsps)	Bit depth	BW / Sample rate	Overhead	Estimated L3 bandwidth (Gbps)
100	0.14	16	70 %	20%	5
500	0.71	16	70 %	20%	27
1000	1.4	12	70 %	20%	41
1500	2.1	12	70 %	20%	62
2000	2.9	8	70 %	20%	55

Ethernet Traffic Test Scenarios for Integrators

The following scenarios illustrate potential DIFI-based solutions and their surrounding ecosystems. Each scenario highlights components for which we've provided test examples in the subsequent sections. These three examples represent real-world, planned implementations of DIFI in SATCOMsignal services.

Scenario 1: RF conversion to DIFI Ethernet transport to legacy RF modems

In this scenario, the DIFI flows from the ground station to modem are bookended by digitizers on each end such that the RF can be first digitized, the resulting DIFI flows transported over distance via an ethernet fabric, to then be converted back to RF to legacy RF modems on the far end which can only handle analog RF signals. In scenario 1, the IFC is emulated by Keysight's BreakingPoint Software (BPS) that runs on a DIFI packet generator. Notice the inclusion of DIFI combiners and dividers which provide a means of combining antenna feeds into a single DIFI stream while the use of a divider at the other end enables disaggregation and distribution of the DIFI flows to specific target modems.

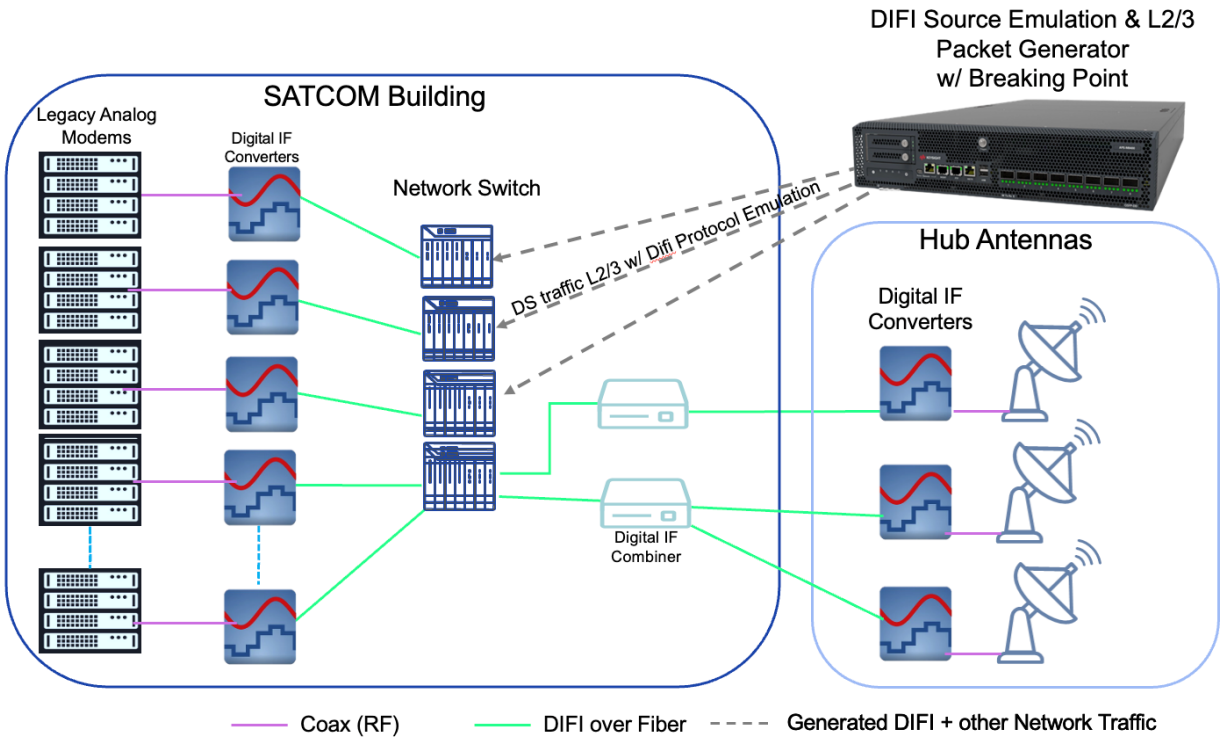


Figure 6. DIFI real-world traffic scenario shows DIFI distribution to legacy modems.

Scenario 2: RF conversion to DIFI Ethernet transport to DIFI modems

In this scenario, the DIFI flows from the ground station emulated by a DIFI packet generator to go directly to DIFI modems at the far end transported over distance via an Ethernet fabric. In scenario 2, the IFC is emulated by Keysight's BPS and sent through the network fabric with DIFI modems on the other end. BPS can create upstream DIFI traffic by sending L3 traffic via the modem upstream back to a receive port on the BPS chassis. Both downstream and upstream traffic can be received on the BPS ports for determination of packet loss and data integrity to determine pass fail. Additional flows of background traffic can be generated through the routing and switching.

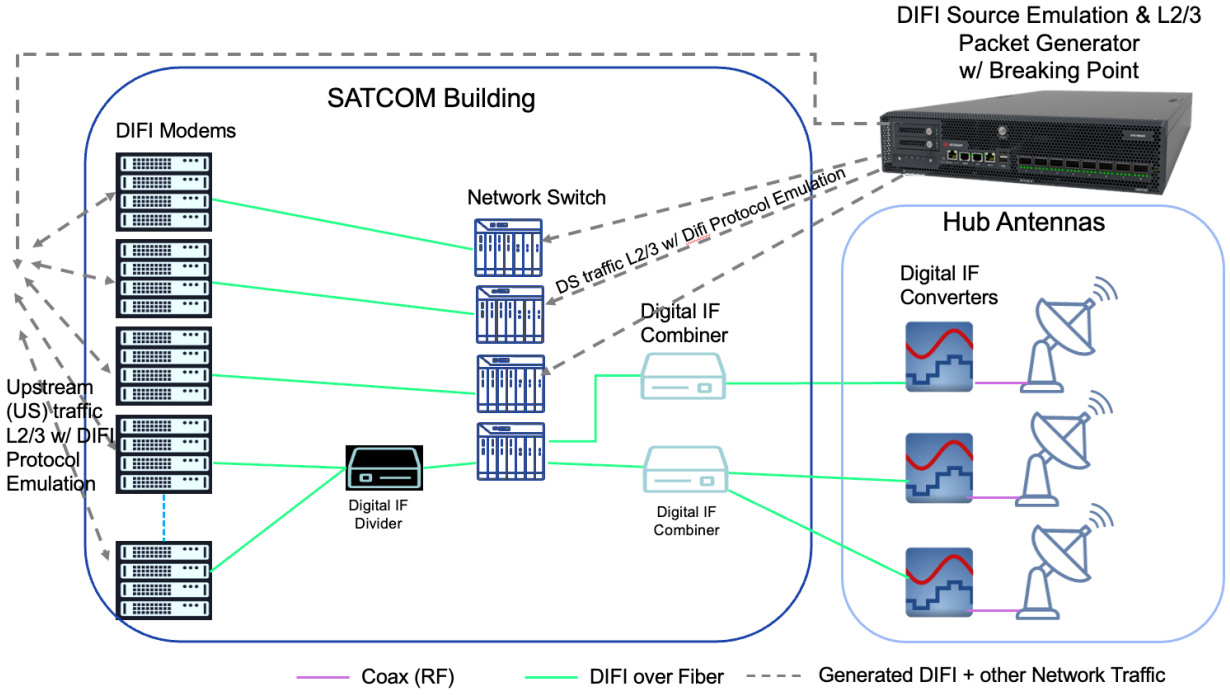


Figure 7. DIFI real-world traffic scenario showing DIFI distribution to DIFI modems.

Scenario 3: Testing network transport fabric in isolation

The network infrastructure can be tested in isolation to determine if QoS policies function properly as well as the performance and scalability of the network design. IxNetwork and its accompanying family of hardware and software interfaces can be used to test the connectivity and functional integrity of the network transport the SATCOM system relies on.

In addition to network traffic and protocol validation, Keysight has tools to emulate impairments such as latency and packet loss due to network factors related to distance and microbursts.

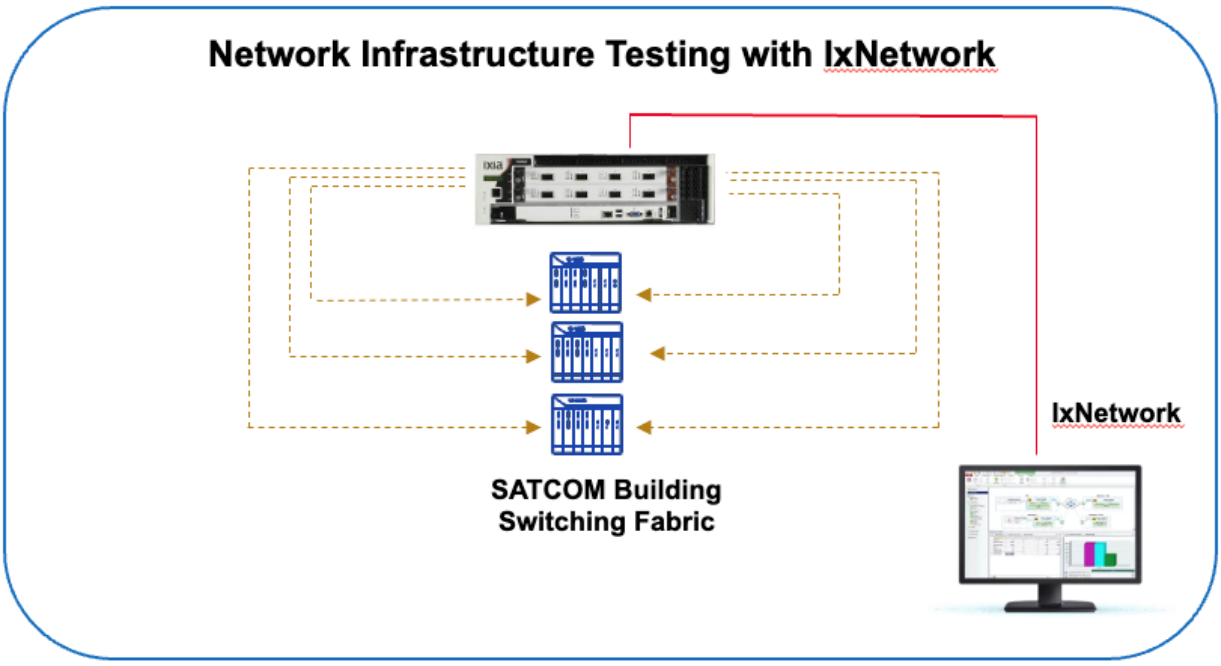


Figure 8. DIFI real-world scenario showing network infrastructure testing with IxNetwork. https://www.keysight.com/gb/en/products/network-test.html

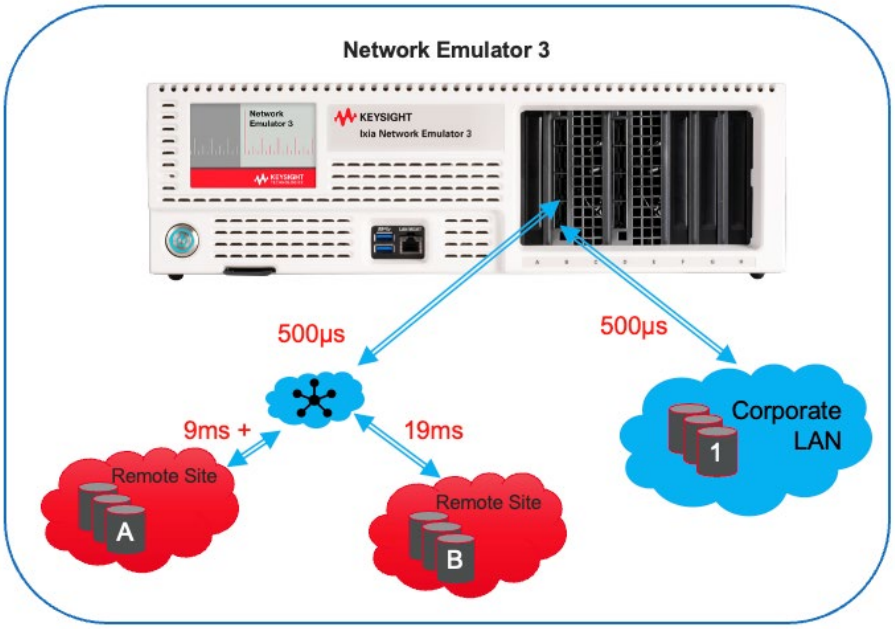


Figure 8.1. Keysight's Network Emulator 3 can be put in-line to emulate delay factors caused by distance or packet loss due to network disturbances which can potentially cause issues when decoding contiguous packet streams of RF data. https://www.keysight.com/gb/en/products/network-test/network-test-hardware/network-emulator-3.html

DIFI Device Specific Test Cases

The DIFI ecosystem comprises several key components, including IFCs, modems, combiners, and dividers, which can be evaluated either individually or as part of an integrated system. Functional and performance testing of these components is essential to ensure compliance with DIFI standards and interoperability across the ecosystem. The following are representative test case examples designed to validate the behavior, throughput, and protocol adherence of each DIFI component under various operational scenarios.

Test case 1: IFC analog-to-digital RF digitization quality

Downstream from base station

To evaluate the RF quality of a generated DIFI flow, the analog-to-digital conversion process within the IFC must be stimulated with a known RF signal. This is typically achieved by connecting an L-band signal generator, such as the Keysight VXG or MXG, to the IFC under test. The IFC, acting as the Device Under Test (DUT), digitizes the incoming RF signal and produces a DIFI-compliant data stream. This stream can then be captured and analyzed using Keysight's PathWave Vector Signal Analysis (VSA) software. The VSA tool enables detailed inspection of the digitized waveform, allowing engineers to assess signal fidelity and identify any degradation, distortion, or anomalies introduced during the digitization process.

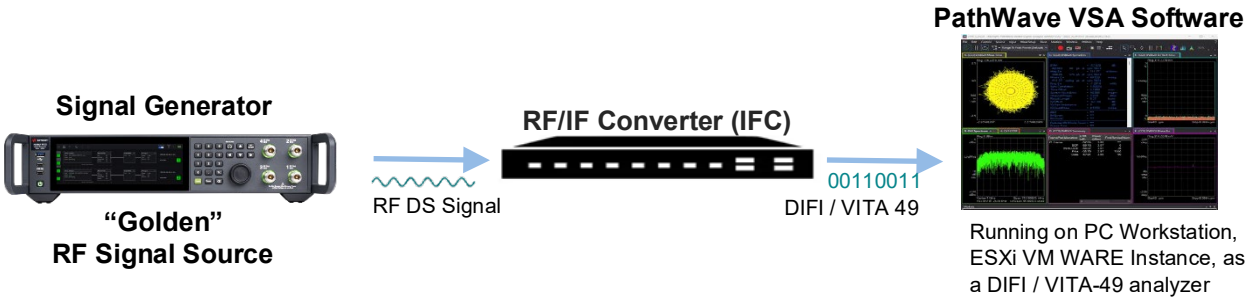


Figure 9. How to test analog-to-digital conversion through an IFC with a signal generator and VSA software.

	Test	L-band stimulus	L-band measurement	Digital IF measurement
1	Frequency translation accuracy	Continuous Wave (CW), off-center [1]	Frequency	Frequency
2	Phase noise		Phase noise	Phase noise
3	Power translation accuracy	1, 2, & 5 CWs	CW power levels	CW power levels
4	Noise floor, Spurious, Harmonics		Sample noise level	Noise floor, spurious, harmonics
5	Error Vector Magnitude (EVM)	7 Modulated waveforms	EVM per carrier	EVM per Carrier
6	Power change profile	Power change profile [2]	Power chang profile	Time domain integrity

1. Detects IQ out of order (spectral inversion)
2. Up & down by 9 dB @ 3 dB/s every 10 s

Test case 2: IFC digital-to-analog RF digitization quality

Upstream to base station emulation

To evaluate the digital-to-analog conversion performance of an IFC within the DIFI ecosystem, a DIFI packet stream must be delivered to the IFC. This can be accomplished using a packet generator running with Keysight's BreakingPoint software (BPS), which emulates upstream DIFI traffic. The IFC, acting as the DUT, converts the incoming digital stream into an RF signal. This output RF signal is then captured and analyzed using a Keysight RF signal analyzer, such as the PXA, in combination with the VSA software. This setup enables precise measurement of the generated RF signal's quality, allowing engineers to detect any degradation, distortion, or deviation from the original DIFI test stimulus.

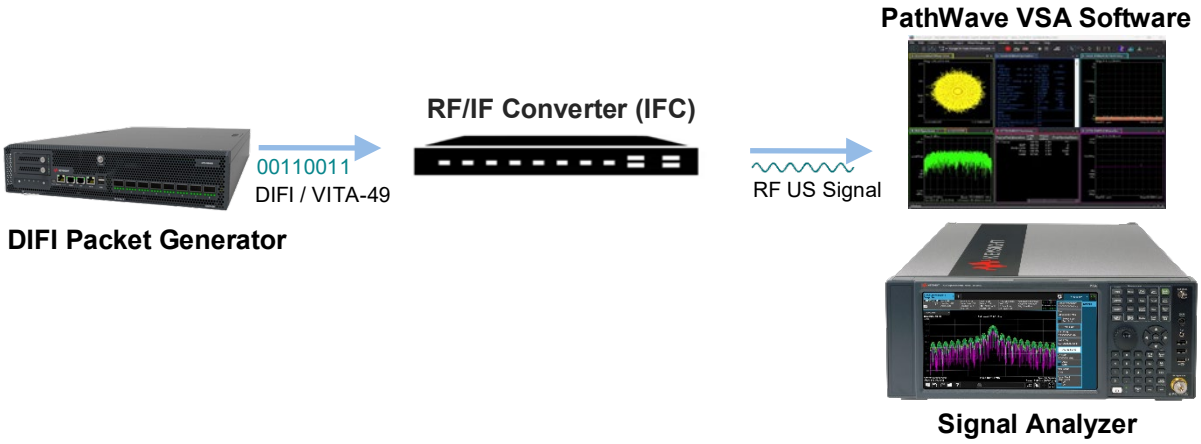


Figure 10. How to test digital-to-analog conversion through an IFC with a DIFI packet generator and a signal analyzer running PathWave VSA software.

	Test	Digital IF Stimulus	Digital IF Measurement	L-Band Measurement
1	Zero Signal Performance	Zero signal	Sampling noise level	Noise floor & spurs on spectrum analyzer
2	Frequency Translation Accuracy	1 Continuous Wave (CW), off-center [1]	Frequency	Frequency
3	Phase Noise		Phase noise	Phase noise
4	Power Translation Accuracy	1, 2, & 5 CWs	CW power levels	CW power levels
5	Noise Floor, Spurious, Harmonics		Sampling noise level	Noise floor, spurious, harmonics
6	Error Vector Magnitude (EVM)	7 modulated waveforms	EVM per carrier	EVM per carrier
7	Packet Loss	Dropped packet	Time domain packet loss	Time domain blanking

1. detects IQ out of order (spectral inversion)

Test case 3: Adjacent channel performance

Analog-to-digital & digital-to-analog quality simultaneously

To assess both the digital-to-analog and analog-to-digital conversion performance of an IFC within the DIFI ecosystem, a dual-path test setup can be employed. For digital-to-analog evaluation, a DIFI packet stream is transmitted to the IFC using a packet generator such as Keysight's APS-100 with BreakingPoint software. The IFC, acting as the Device Under Test (DUT), converts the incoming digital stream into an RF signal. This RF signal is then captured using a Keysight PXA signal analyzer in conjunction with the PathWave VSA software to evaluate signal fidelity and detect any degradation or deviation from the original DIFI stimulus.

Simultaneously, the analog-to-digital conversion capability of the IFC can be tested by injecting a known RF signal — typically from a Keysight VXG-C or MXG L-band signal generator — into the IFC's RF input. The IFC digitizes this signal and generates a DIFI stream, which is again captured and analyzed using the PathWave VSA software to assess the quality of the digitized waveform.

Performing both conversions concurrently introduces a realistic stress scenario, allowing engineers to evaluate how well the IFC maintains signal integrity under simultaneous load conditions. This dual-path test is particularly valuable for identifying performance bottlenecks, synchronization issues, or signal degradation that may not be apparent when testing each path in isolation.

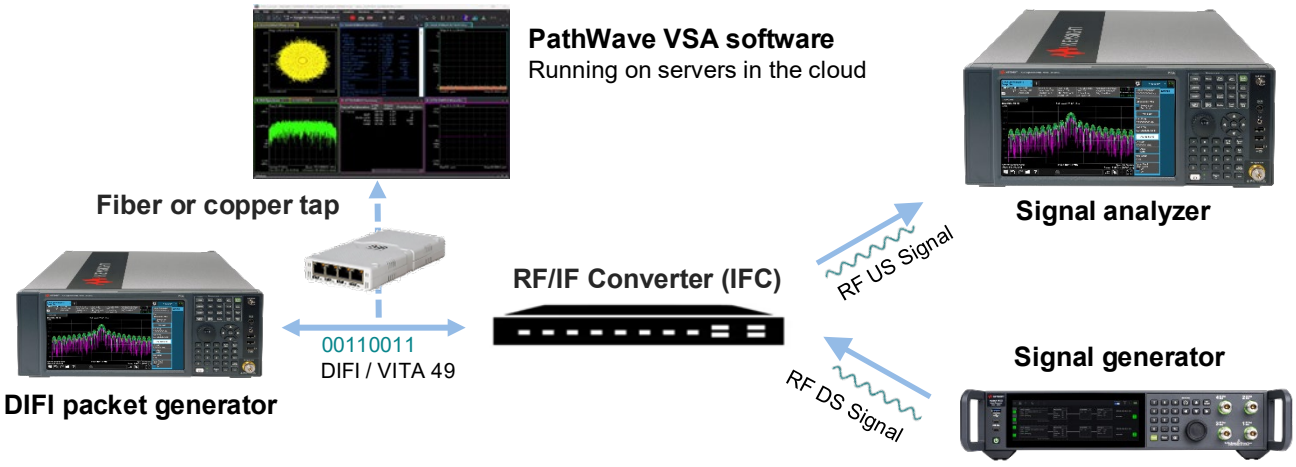


Figure 11. How to test analog-to-digital and digital-to-analog conversion simultaneously through an IFC.

	Test	IF Stimulus	L-band measurement	Digital IF measurement
1	Voltage Standing Wave Ratio (VSWR), Transmit (Tx) & Receive (Rx) ports [1]	VSWR stimulus, Tx & Rx	VSWR	N/A
2	Uplink to Downlink Isolation [2]	Digital IF max power CW	Verify max power out	CW crosstalk power
3	Downlink to Uplink Isolation [3]	L-Band max power CW	CW crosstalk power	Verify max power out

1. VSWR is measured on both L-Band IF ports, Tx & Rx
2. Cross-port measurement, Tx to Rx
3. Cross-port measurement, Rx to Tx

Test case 4: DIFI digital combiner performance

A DIFI Combiner (CD) aggregates multiple DIFI-compliant IQ data streams into a single Ethernet output stream, enabling streamlined integration and analysis. A DIFI packet generator running with BreakingPoint software simplifies the generation of multiple DIFI streams, allowing precise control over parameters such as packet rate, packet loss, and latency. The impact of these network conditions on IQ data quality can be thoroughly evaluated using PathWave VSA software.

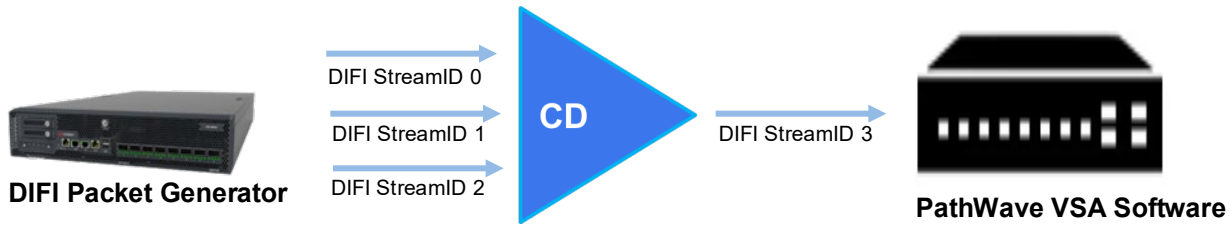


Figure 12. How to test DIFI digital combiner performance.

	Test	Digital IF stimulus	Digital IF measurement
1	Zero signal performance	Zero signal	Noise Power Spectral Density (PSD)
2	Frequency translation accuracy	1 Continuous Wave (CW), off-center 1	Frequency
3	Power translation accuracy		Power
4	Noise floor & spurious		Noise PSD & sample center frequency spurs
6	Error Vector Magnitude (EVM)	Modulated waveform	EVM
7	Packet loss	Dropped packets	Time domain
8	Input power changes	Power change profile	Sampling, power, & spur integrity

1. detects IQ out of order (spectral inversion)

Test case 5: DIFI digital divider performance

As with the combiner, a divider (CD) can be tested using the exact same method.

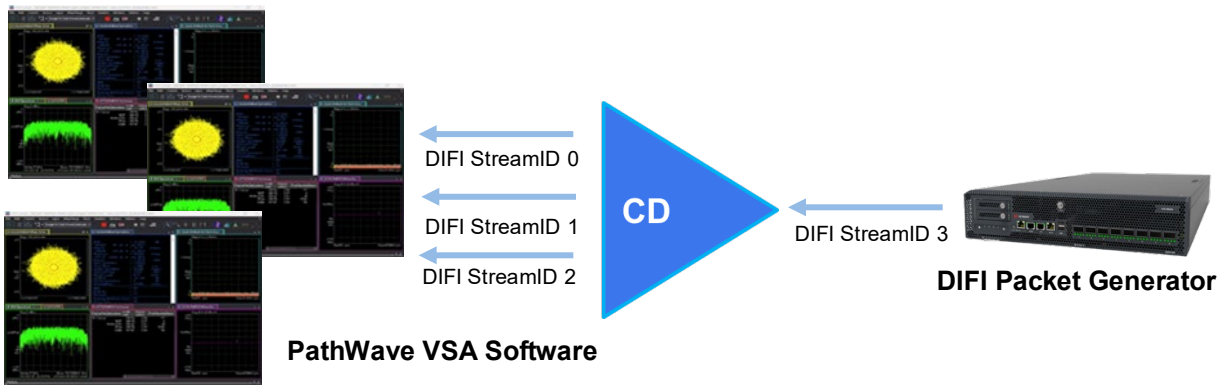


Figure 13. How to test DIFI digital divider performance.

	Test	Digital IF stimulus	Digital IF measurement
1	Zero signal performance	Zero signal	Noise Power Spectral Density (PSD)
2	Frequency translation accuracy	1 Continuous Wave (CW), off-center 1	Frequency
3	Power translation accuracy		Power
4	Noise floor & spurious		Noise PSD & sample center frequency spurs
6	Error Vector Magnitude (EVM)	Modulated waveform	EVM
7	Packet loss	Dropped packets	Time domain
8	Input power changes	Power change profile	Sampling, power, & spur integrity

1. detects IQ out of order (spectral inversion)

Test case 6: Modem to modem performance

End-to-end modem resiliency under load is a critical factor in evaluating the operational robustness of a modem's design. By applying network load to the DIFI interface of a modem and directing the digitized DIFI traffic to a second modem, you can assess the system's ability to maintain synchronization, accurately perform RF conversion, and reliably acquire or re-acquire connections with other DIFI-capable devices under stress. Keysight's visibility infrastructure enables selective filtering of DIFI streams, which can then be analyzed using tools like PathWave VSA for in-depth RF performance evaluation.

Test objectives

- Frequency measurement accuracy
- Power measurement accuracy
- Acquisition and re-acquisition
- Bit Error Rate (BER) performance
- Synchronization retention
- Input power response

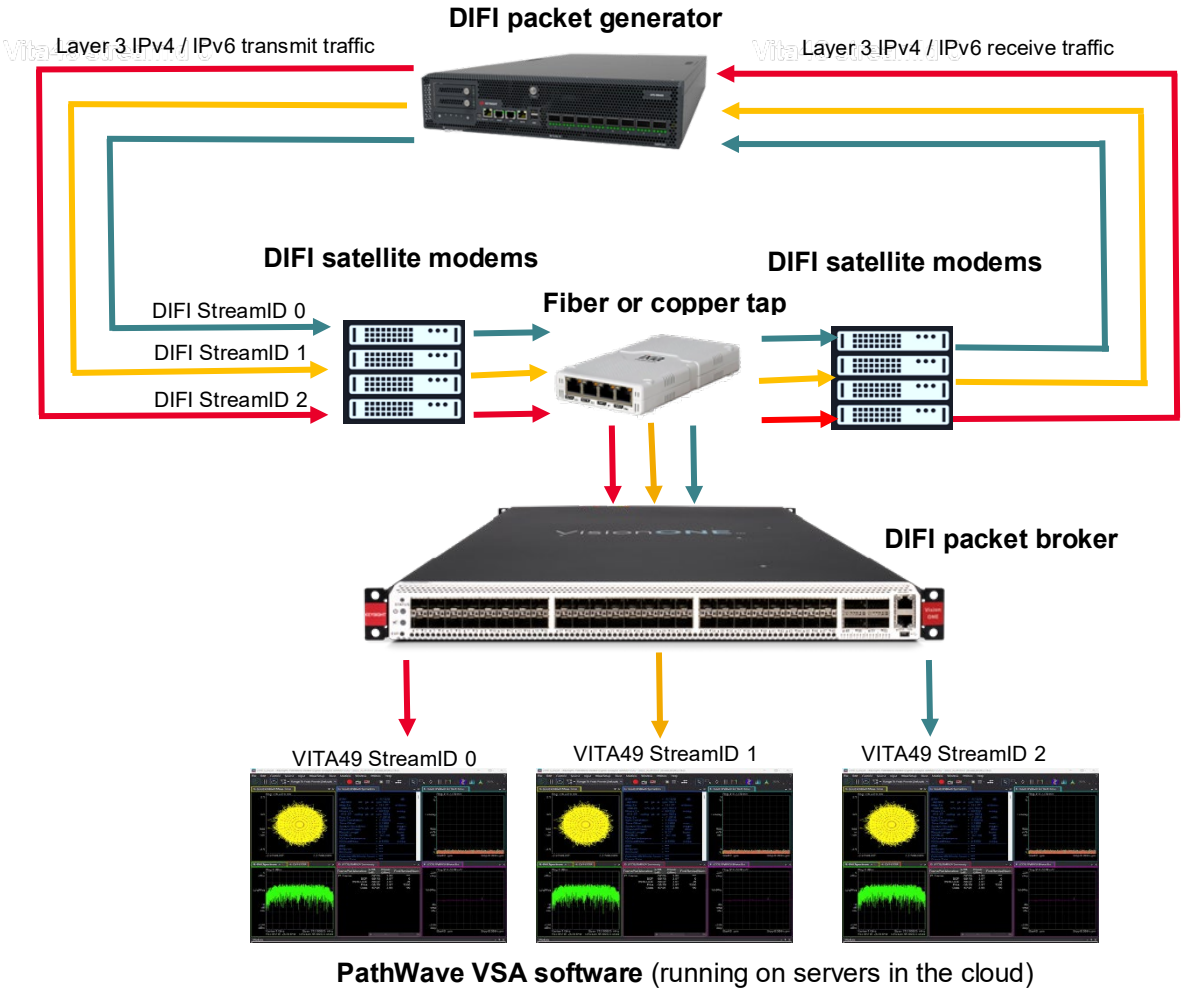


Figure 14. How to test DIFI modem to modem performance.

Network Visibility for DIFI

Keysight offers a comprehensive suite of visibility tools for monitoring Ethernet traffic, empowering operators to assess the health of RF signals as they traverse transport network designs. These visibility solutions are highly scalable, enabling real-time monitoring of multiple DIFI feeds and sources to detect signal degradation early and prevent potential communication loss.

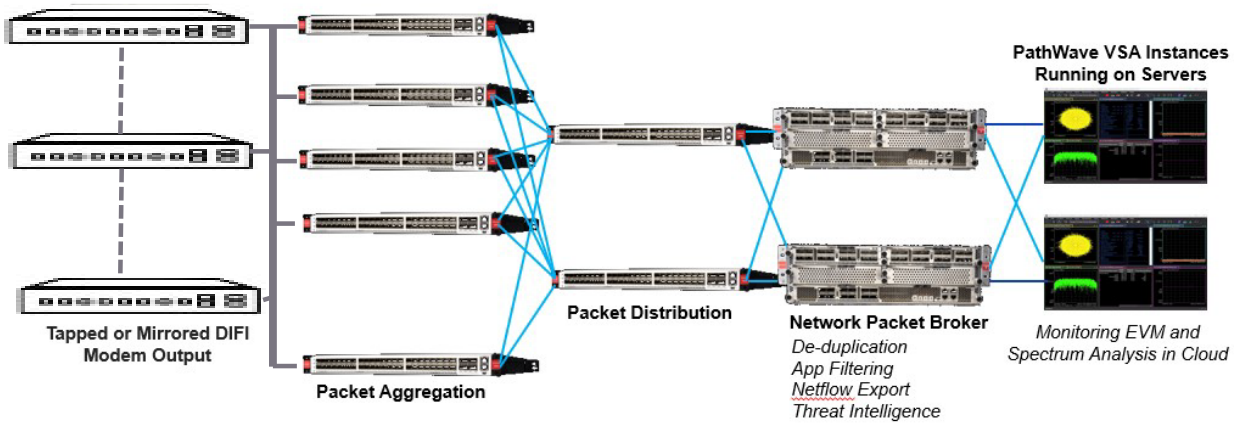


Figure 15. Visibility architecture for data centers and multi-site bay stations using Network Visibility Solutions **(**NVS) cluster.

Conclusion

Whether you're a network operator, DIFI equipment manufacturer, or end user, Keysight provides the tools and infrastructure needed to accelerate the development, validation, and deployment of DIFI-based systems — bringing robust, high-performance designs to market faster and more efficiently. For more insights on how to accelerate your digital ground station innovation, please visit: Home - DIFI Consortium

References

Test cases 1-5: from “SI2025 02 06 R 1400 AJV Digital IF Domain Performance Testing - High Level Recommendations”. Author: A.J. Vigil, Ph.D., P.E. Senior Scientist, Systek Digital IF Technical Lead, PdM WESS

Figure 3: “Ground Segment Market Prospects 5th Edition”. November 2024, Novaspace 2024, nova.space

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