

Toward Virtualized Flight Test Telemetry Architectures in the Era of Digital IF

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Abstract:

Flight test telemetry infrastructures are geographically distributed and support multi-station tracking of airborne platforms. However, baseband processing functions remain physically deployed at each site. The number of parallel telemetry channels and supported modulation schemes is therefore constrained by locally installed hardware. This paper argues that virtualization is the natural evolution of such architectures. Virtualization abstracts these processing functions into software-defined chains running on shared compute platforms. This abstraction relies on digitizing the received signal after RF downconversion to intermediate frequency. Once converted to digital IF and transported over a network, signal acquisition is decoupled from signal processing, which no longer needs to reside at the antenna site.

Standardized digital IF transport protocols such as VITA-49 (VRT), the Digital IF Interoperability (DIFI) profile, and IRIG 106 Chapter 10 over UDP already enable network-native streaming of digitized signals. In parallel, the growing adoption of electronically steered antennas that provide early digital outputs further accelerates this architectural transition by bringing digitization closer to the RF front-end. With digital IF transport, processing chains can be instantiated, replicated, or reconfigured dynamically across shared compute resources. Channel count, supported bandwidth, and aggregate decoding throughput can scale with available processing capacity rather than fixed hardware deployments. As flight test instrumentation becomes increasingly digital, virtualization provides a coherent and scalable framework for telemetry signal processing.

Key words: Flight Test, Telemetry, Digital IF, Virtualization, Software-Defined Receiver, Multi-Station

Introduction

Flight test telemetry systems rely on geographically distributed ground infrastructures to receive, track, demodulate, decode, and record data transmitted by airborne platforms. Although acquisition sites are distributed, receiver and baseband processing functions are still often tied to physical hardware deployed locally at each site. As a result, channel count, modulation support, and aggregate processing throughput remain constrained by installed receiver equipment.

This hardware-centric model becomes limiting when mission configurations require additional channels, higher bit rates, new receiver algorithms, or parallel algorithm validation. At the same time, telemetry acquisition is becoming increasingly digital: received signals can be digitized after RF downconversion, transported as digital intermediate-frequency (IF) streams, or produced directly by electronically steered and digitally beamformed antenna systems [10].

The main argument of this paper is shown in Fig. 1: digital IF transport enables a transition from fixed site-local receiver hardware toward virtualized receiver processing. In the conventional deployment, both signal acquisition and decoding remain at the

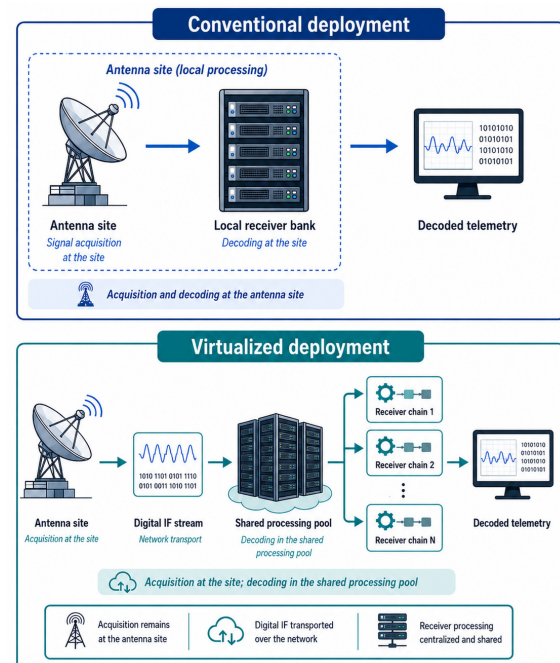


Fig. 1. Architectural shift from site-local acquisition and decoding to digital-IF-based virtualized receiver processing.

antenna site. In the virtualized deployment, acquisition remains close to the antenna, while the transported digital IF stream feeds receiver-chain instances hosted on shared compute resources.

The objective is not to replace the RF acquisition layer, prescribe a specific Digitizer architecture, or assume that best-effort cloud processing is sufficient for telemetry. The focus is the architectural consequence of making telemetry signals available as digital IF streams: receiver processing becomes a deployable, schedulable, and scalable function.

The contribution of this paper is threefold. First, it presents a compact architecture for virtualized telemetry processing based on digital IF streams. Second, it frames telemetry receiver chains as instantiable software-defined processing units. Third, it illustrates horizontal and vertical receiver scaling using a PCM/FM trellis receiver chain deployed on both a COTS PC and a mid-range server-class platform.

From Signal Acquisition to Digital IF Streams

The key architectural transition described above depends on the availability of network-native digital IF streams. In this paper, a digital IF stream denotes a packetized stream of complex IQ telemetry samples accompanied by timing and signal-context metadata. This definition is consistent with digital IF transport profiles in which digitized IF/RF sample data and metadata are carried over standard packet networks [1], [2].

Figure 2 shows two representative acquisition paths. In the classical acquisition path, a conventional antenna and RF front-end feed a COTS SAFRAN Digitizer, which may also perform channelization close to the antenna site. Rather than transporting the full acquisition bandwidth, this stage can extract the telemetry channels of interest and emit per-channel digital IF streams sampled at rates matched to their occupied bandwidth.

In the direct digital antenna path, an electronically steerable or digitally beamformed antenna provides digital IF outputs closer to the RF aperture. In this case, the digital IF stream is produced natively by the antenna subsystem or by tightly integrated digital front-end electronics. Both paths lead to the same architectural boundary: timestamped, metadata-rich digital IF streams that can be transported, replicated,

Representative Digital IF Acquisition Paths

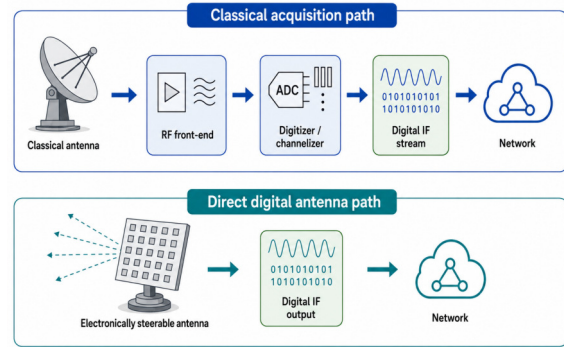


Fig. 2. Representative acquisition paths producing digital IF streams for networked telemetry processing.

recorded, and processed over a network.

Table 1 summarizes the resulting functional split.

Relevant transport formats and standards include VITA-49, the Digital IF Interoperability profile, and IRIG 106 Chapter 10 network transports [1]–[3]. These standards are important because telemetry processing requires not only samples, but also the timing and signal context required to interpret them correctly. IRIG 106 also provides the broader aeronautical telemetry standardization context, including telemetry waveform and frequency considerations [4].

Instantiable Software-Defined Receiver Chains

Once the acquired signal is available as a digital IF stream, the receiver can be represented as a software-defined processing chain. Each receiver-chain instance consumes one input stream and its associated signal context, applies a configured receiver algorithm, and produces decoded bits, frames, and quality metrics. This framing is consistent with the broader software-defined radio principle of moving receiver functionality from fixed hardware into programmable processing chains [5].

Figure 3 summarizes the functional structure of a typical receiver chain. Its configuration may include waveform type, bit rate, sampling rate, input stream identity, and processing mode.

In the proposed model, the receiver chain is not a fixed hardware appliance but an instantiable processing unit. Several instances can be created for several telemetry channels. A single stream can also be replicated toward multiple processing functions, such as an operational receiver, an experimental receiver, a recorder, a monitor, or a replay chain, as shown in Fig. 4.

Key architectural shift. The unit of telemetry processing changes from a fixed hardware receiver channel to a schedulable receiver-chain instance.

Containerization can support this model by packaging each receiver chain with its dependencies, configuration interface, and monitoring endpoints.

Tab. 1: Functional split enabled by digital IF transport.

Remains near acquisition	Moves to processing pool
Antenna, tracking, RF front-end, timing, digitization, optional channelization	Filtering, recording, synchronization, demodulation, decoding, monitoring, replay, and algorithm validation.

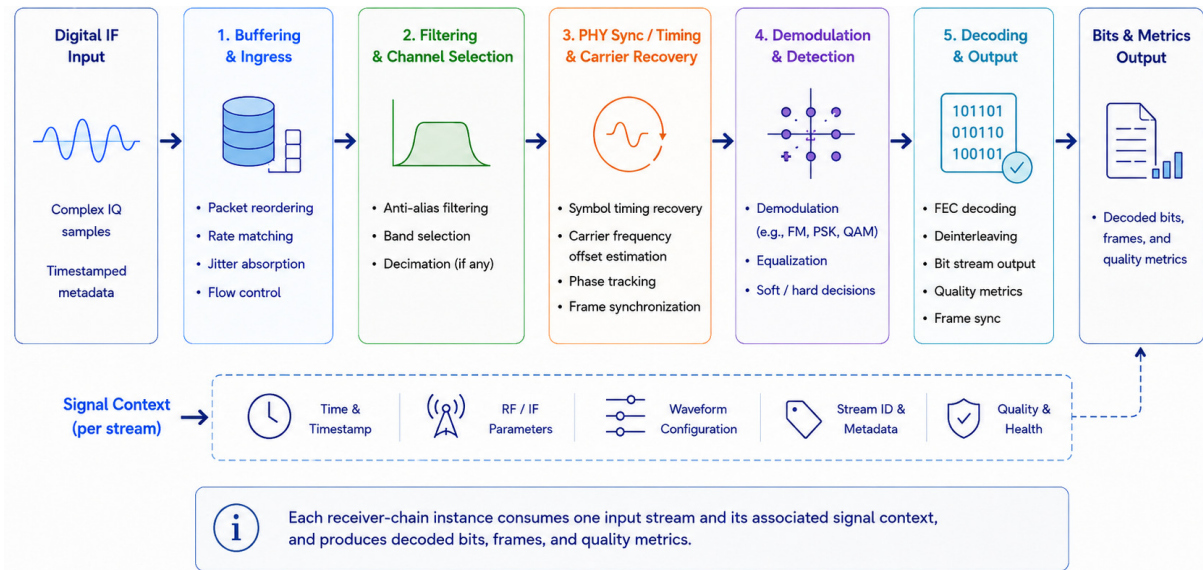


Fig. 3. Generic software-defined telemetry receiver-chain pipeline from digital IF input to decoded bits, frames, and quality metrics.

However, containerization is a deployment and replication mechanism, not a substitute for real-time engineering. Similar ideas are used in virtualized radio access architectures, where centralized or containerized processing is useful only when resource allocation and timing constraints are explicitly controlled [6], [7]. Deterministic telemetry processing still requires explicit control of buffering, CPU affinity, scheduling policy, memory allocation, memory

bandwidth, and network behavior.

Horizontal and Vertical Receiver Scaling: More Channels or Higher Bit Rates

Virtualized telemetry processing turns receiver capacity into a resource allocation problem, as illustrated in Fig. 5. A processing node can host a receiver-chain instance only if it has enough compute capacity, input network bandwidth, memory bandwidth, buffering margin, and latency margin for that chain. Horizontal scaling uses these resources to instantiate more receiver chains for more telemetry channels. Vertical scaling assigns more resources to each chain in order to support a higher bit rate.

To illustrate this tradeoff, this section considers a software PCM/FM receiver chain based on trellis demodulation. Trellis and sequence-estimation approaches are relevant to telemetry CPM/PCM-FM receivers because they provide a demanding receiver workload compared with simple hard-decision demodulation [8], [9]. This makes the PCM/FM trellis chain a useful feasibility example for virtualized telemetry processing.

The use case is based on two representative compute platforms. The first is a COTS PC equipped with an i7-class processor providing 8 physical cores and 16 logical threads. The second is a mid-range server-class platform with 64 logical threads. The considered server platform supports AVX2 but not AVX-512, which is important when interpreting the reported scaling figures.

Figure 6 summarizes the observed allocation trade-off. On the COTS PC, a single PCM/FM trellis receiver chain easily sustains 60 Mbit/s. On the mid-range server, horizontal scaling allows eight independent 60 Mbit/s receiver-chain instances to run

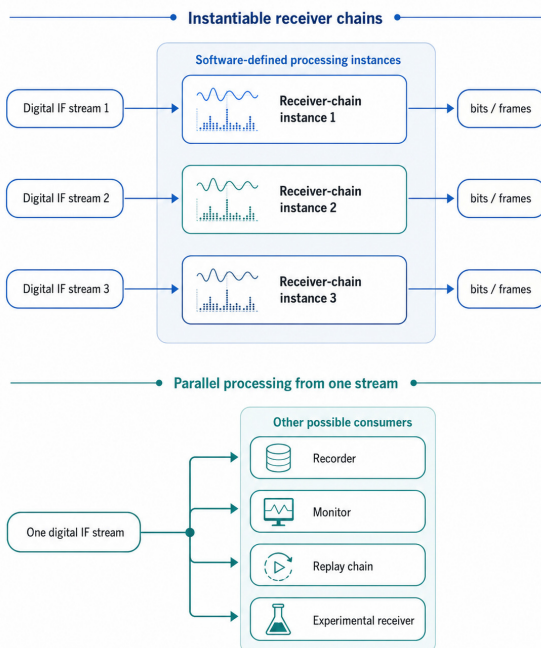


Fig. 4. Digital IF streams can be connected to independent receiver-chain instances or replicated toward parallel processing functions.

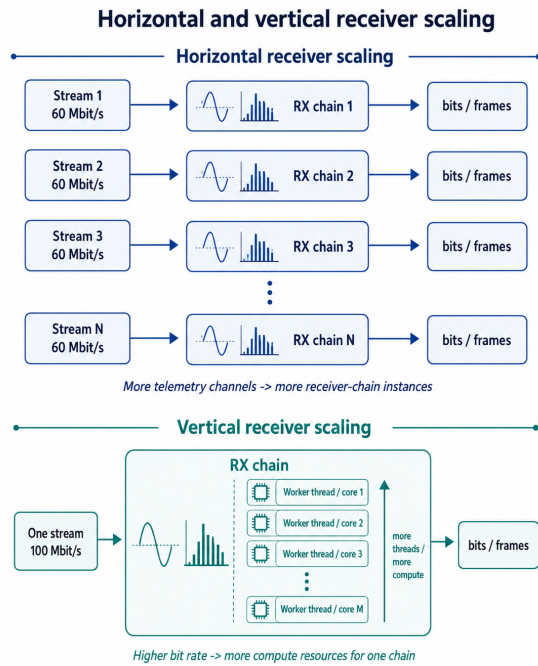


Fig. 5. Horizontal scaling increases the number of receiver-chain instances, whereas vertical scaling assigns more compute resources to each chain.

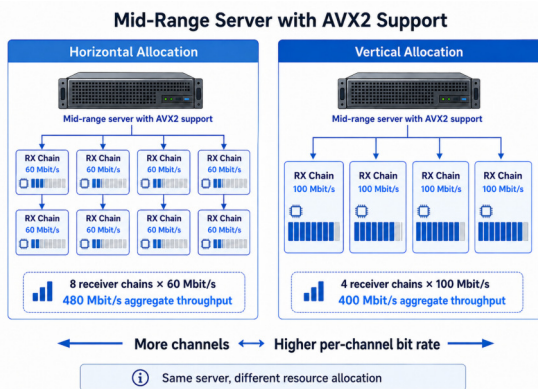


Fig. 6. Example of allocation tradeoff: horizontal scaling favors more 60 Mbit/s receiver chains, while vertical scaling assigns more compute to fewer 100 Mbit/s chains.

concurrently, corresponding to 480 Mbit/s of aggregate processed telemetry throughput.

The same server also illustrates vertical scaling. When the target bit rate per receiver chain is increased to 100 Mbit/s, more compute resources must be allocated to each chain. Under this allocation, the number of simultaneous receiver-chain instances is reduced from eight 60 Mbit/s chains to four 100 Mbit/s chains. The example shows that higher bit rate per channel consumes more of the node capacity and therefore reduces the number of parallel channels that can be hosted on the same server.

The values in Fig. 6 are platform-dependent. Ta-

ble 2 summarizes the main hardware factors that move the scaling frontier. The considered mid-range server supports AVX2 but not AVX-512, so the reported capacities should be read as representative of that platform class rather than as architectural limits. The key point is not the absolute throughput of a single processor, but the change in capacity model: receiver capacity becomes a platform-dependent compute-resource allocation and scheduling problem rather than a fixed hardware-deployment constraint.

Real-Time Operation and Multi-Station Processing

The scalability tradeoff discussed above is necessary but not sufficient for operational telemetry. The proof-of-concept receiver deployment considered here is representative of practical flight-test use cases, since it must sustain continuous streams under real-time constraints. In a virtualized architecture, these constraints are enforced through orchestration, scheduling, buffering, and admission-control policies.

A receiver-chain instance should only be admitted on a compute node with sufficient network, compute, memory, buffering, and latency margins. Packet loss, jitter, timestamp continuity, and stream ordering must be controlled before virtualized receiver processing can be considered equivalent to conventional site-local processing.

Digital IF transport also opens new opportunities for multi-station telemetry processing, as illustrated in Fig. 7. In conventional architectures, each ground station often performs local demodulation and then contributes decoded data or quality metrics to a downstream selection process. Best Source Selection and data-quality-driven source selection are already relevant operational concepts in flight-test telemetry [11], [12]. With timestamped digital IF streams, several stations can provide signal-level

Tab. 2: Compute factors affecting virtualized receiver capacity.

Resource	Effect on receiver scaling
Core count / logical threads	Increases the number of parallel receiver-chain instances.
Clock frequency	Improves per-chain throughput and real-time processing margin.
SIMD support	Wider instruction sets, such as AVX-512, can accelerate receiver kernels.
Memory bandwidth	Limits simultaneous high-rate chains and buffering throughput.

Tab. 3: Operational controls required for virtualized telemetry processing.

Constraint	Required control
Packet loss	Sequence counters, timestamp checks, and gap handling.
Jitter and latency	Bounded buffering and real-time scheduling.
CPU scheduling	Affinity, reserved cores, and controlled thread placement.
Memory bandwidth / NUMA	Node-aware placement and admission control.
Multi-station timing	Timestamp continuity and stream synchronization.

information to a common processing pool.

Compared with conventional post-demodulation source selection, access to timestamped digital IF streams preserves more information for receiver-level comparison, replay, or diversity processing. In future work, the same framework may support soft combining or reconstructed reliability information across several stations. The proposed architecture does not require a specific multi-station combining algorithm; it provides the transport and processing framework in which such algorithms can be instantiated, compared, validated, and operationalized.

Conclusion

This paper presented a virtualized flight test telemetry processing architecture enabled by digital IF transport. By making acquired signals available as timestamped digital IF streams, receiver processing can be decoupled from antenna sites and deployed

as instantiable software-defined chains on shared compute resources.

A PCM/FM trellis receiver chain illustrated the scalability tradeoff. A COTS i7-class platform can sustain one 60 Mbit/s chain, while the considered mid-range AVX2 server can host eight 60 Mbit/s chains or four 100 Mbit/s chains. This shows how telemetry capacity becomes a platform-dependent resource allocation problem rather than a fixed receiver-hardware count.

Real-time constraints remain central, including packet loss, jitter, latency, timestamp continuity, scheduling, memory bandwidth, and admission control. In this model, telemetry capacity is defined by the availability of digital IF streams and the compute resources allocated to receiver-chain instances.

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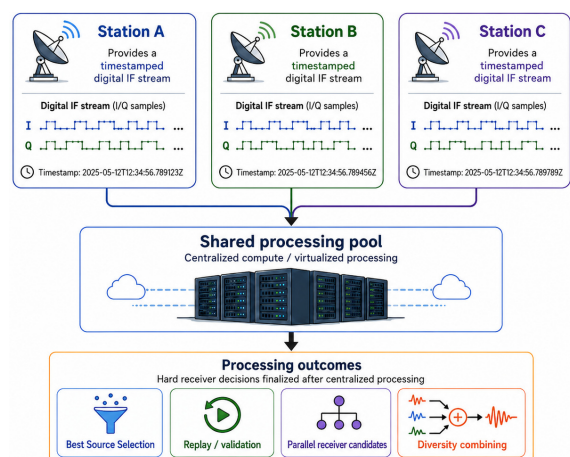


Fig. 7. Timestamped digital IF streams enable centralized multi-station receiver processing before hard decisions are finalized.