

**Digital IFM and AOA Processing for RF Interferometers
Incorporating a VHF Polyphase Channelizer
Author: R. Conrad
microwaves@att.net**

Abstract

This paper describes a concept digital architecture for instantaneous-frequency measurement (IFM) and angle-of-arrival (AOA) processing. The design integrates a three-channel polyphase channelizer with a fixed-timing digital processor that performs tone detection, frequency estimation, and phase-based AOA parameter generation across the 170–310 MHz intermediate-frequency band.

Frequency estimation uses a polynomial discriminator that maps channel magnitude ratios to an internal parameter θ , while AOA estimation uses a resolver polynomial that maps inter-channel phase offsets to the same parameter. All results were obtained through mathematical modeling and simulation.

Digital processing drives IF solutions

This paper presents a concept digital architecture that replaces analog instantaneous-frequency-measurement (IFM) and angle-of-arrival (AOA) resolver systems with a deterministic digital processing chain.

The design integrates a polyphase channelizer, fixed-timing processor, polynomial discriminator, and polynomial resolver to provide accurate frequency and angle-of-arrival (AOA) estimates across the 170–310 MHz intermediate-frequency (IF) band.

The channelizer front end employs a three-channel polyphase filter bank derived from a prototype FIR design, producing uniformly spaced sub-bands with well-defined passband and stopband characteristics.

A deterministic processor extracts tone magnitude and inter-channel phase relationships, ensuring consistent timing behavior independent of input conditions.

Frequency estimation uses a polynomial discriminator that maps channel magnitude ratios to an internal parameter θ , then converts it to IF frequency. Angle-of-arrival estimation uses a resolver polynomial that maps measured inter-channel phase offsets to the same internal parameter θ , enabling a unified processing framework. Both polynomial functions are tuned to match system geometry and remain smooth and monotonic across the operating band.

A Monte Carlo perturbation analysis was performed on both discriminator and resolver coefficients to evaluate robustness. Random perturbations simulate quantization, rounding, and implementation tolerances.

Multiple plots show that the system maintains stable frequency and AOA estimates under coefficient variation, confirming the architecture's resilience to practical implementation constraints. Six figures illustrate channelizer responses, discriminator and resolver mappings, and ensemble behavior under perturbation. The results show that a compact digital architecture can replicate and improve upon the functional behavior of legacy IFM/resolver systems while providing deterministic timing, long-term stability, and immunity to analog component drift.

Proven architecture drives DF solutions

Electronic-warfare receivers operating in the 60 to 300 MHz IF band have supported fielded systems for decades, and many of those architectures continue to meet mission requirements without degradation. This paper does not critique earlier approaches; it shows how modern digital processors in the same IF band can extend capability, improve repeatability, and simplify calibration while preserving legacy systems' operational characteristics.

Robert L. Goodwin's foundational work, documented in NRL Report 8005 (September 1976), established the IF band, antenna spacing conventions, and four-channel phase relationships that remain widely used today. Those principles continue to provide a practical framework for wideband frequency measurement and angle-of-arrival estimation.

This paper acknowledges that heritage and builds upon it by demonstrating how a polyphase channelizer and a digital signal processor can assume the role traditionally performed by analog IFM and analog AOA circuits.

The block diagram presented here reflects a typical high-level four-channel front end, consistent with Robert L. Goodwin's geometry and NRL-8005 conventions. The RF distribution, down-conversion, and IF conditioning stages follow established practice.

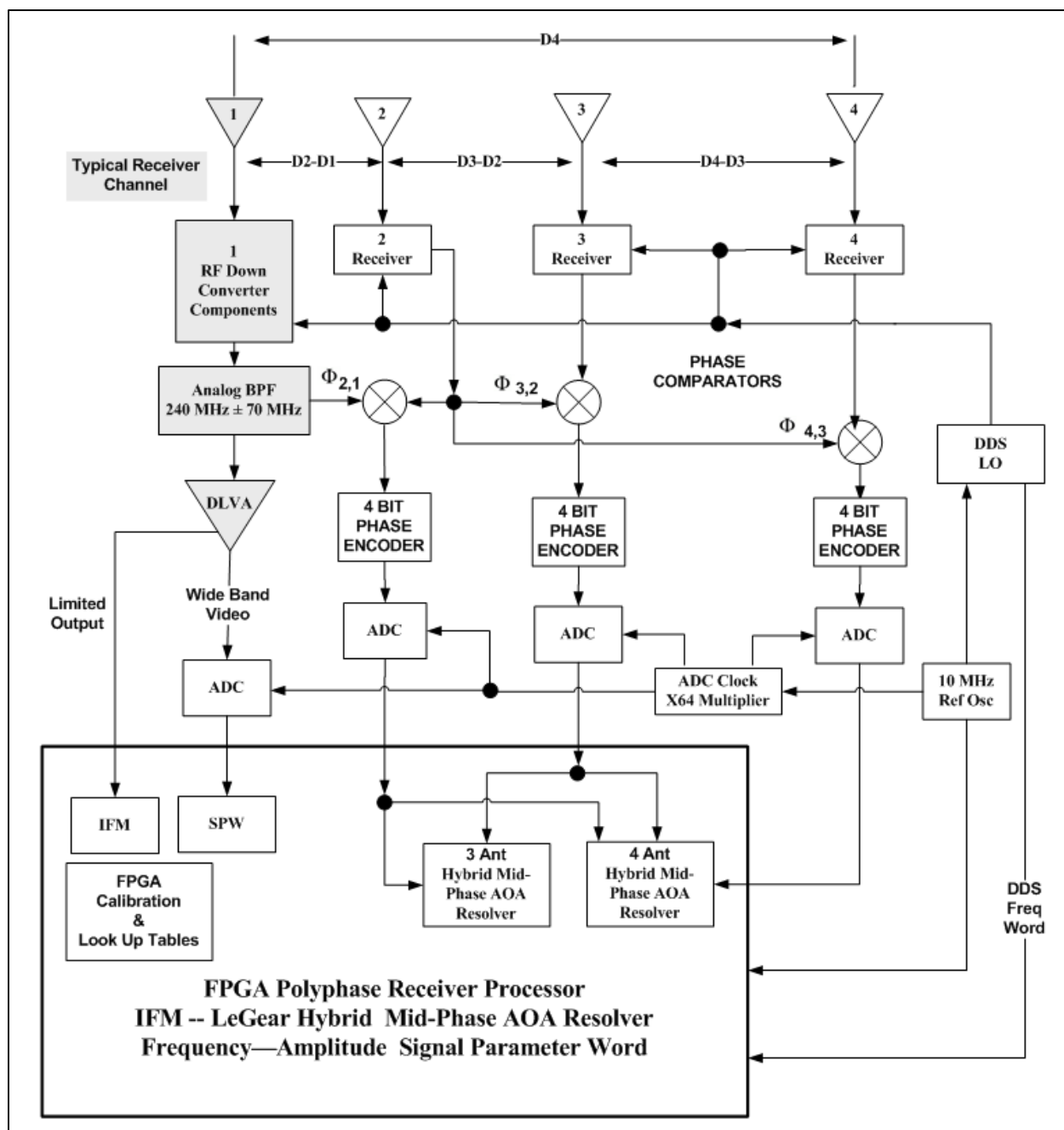
The new element is the digital processing approach, which replaces analog discriminators and resolver networks with a unified FPGA-based processor. This paper focuses on that processor and the performance advantages of digital implementation.

Goodwin arrays drive DF solutions

The block diagram represents a typical four-channel front end consistent with the Goodwin NRL-8005 geometry. Each antenna feeds an RF path that includes amplification, filtering, and down-conversion to the established 170 to 310 MHz IF band. The intent is not to revisit analog IFM or analog AOA circuitry, but to illustrate how the digital processor integrates into a conventional receiver architecture.

Each of the four RF-to-IF channels uses a phase detector whose output is digitized through a 4-bit encoder and delivered to an analog-to-digital converter. The resulting IF data streams feed a polyphase channelizer that forms the processor's digital front end and provides the wideband frequency-domain representation used for instantaneous-frequency measurement and angle-of-arrival estimation.

The block diagram shows this linkage: the analog front end supplies conditioned IF signals, and the digital processor performs the functions traditionally implemented by analog discriminators and resolver networks.



Digital processing streamlines AOA solutions

The polyphase channelizer establishes the receiver's digital performance across the IF band of 170 to 310 MHz used in this example. It converts each wideband IF stream into a stable frequency-domain representation while preserving the amplitude and phase relationships required for downstream instantaneous frequency measurement and angle-of-arrival processing.

Across the 170–310 MHz band, the channelizer maintains uniform bin spacing, controlled passband ripple, and consistent group delay. These characteristics ensure that the processor receives frequency-resolved data with predictable behavior over the entire operating range.

The plots in this section illustrate the filter-bank magnitude response, bin structure, and group-delay uniformity, showing that the channelizer supports wideband operation without introducing distortion or bias across the IF band.

The channelizer preserves the phase relationships between the four channels established by the antenna spacing and geometry defined in Goodwin's NRL-8005 work. This is essential for angle-of-arrival processing. The channelizer does not compute AOA; instead, it ensures the processor receives phase-coherent, frequency-domain data suitable for digital IFM and hybrid mid-phase AOA algorithms.

In summary, the polyphase channelizer provides stable, wideband receiver performance across the 170–310 MHz IF band, delivering amplitude-accurate, phase-coherent data to the processor. The plots included in this section document these characteristics and demonstrate how the channelizer supports a modern digital replacement for analog IFM and resolver networks.

Polyphase channelizer sorts signals

The digital processor replaces the analog IFM and resolver networks traditionally used in wideband EW receivers. It operates directly on the channelized data produced by the polyphase filter bank and extracts the signal parameters required for frequency measurement, angle-of-arrival estimation, and amplitude reporting. The processor maintains the wide instantaneous bandwidth of the 170–310 MHz IF band while providing the stability, repeatability, and multi-signal capability expected of modern digital systems.

Each channelizer output is delivered to the processor as a stream of frequency-domain samples. The processor examines these samples to identify signals and determine their frequency locations. The antenna geometry preserves the three-channel phase relationships, but the processor implements no digital phase comparison, calibration, or resolver functions.

The processor operates continuously across the IF band, evaluating each channelizer frame as it arrives. Frequency measurement locates the dominant energy within each channelized spectrum. The processor implements no calibration or digital angle-of-arrival processing.

The processor is implemented in an FPGA and operates with deterministic timing. Each processing stage—detection and frequency extraction—executes within a fixed number of clock cycles. We implement no phase-comparison, calibration, or parameter-word functions. The accompanying plots document resource usage, throughput, and latency.

Digital discriminators measure frequency

This section presents the simulated performance of the polyphase channelizer across the 170–310 MHz IF band. The plots are taken directly from MATLAB figure windows to preserve authenticity and demonstrate repeatability. They document the three-channel filter-bank responses and show stable cutoff behavior and robustness under coefficient perturbation.

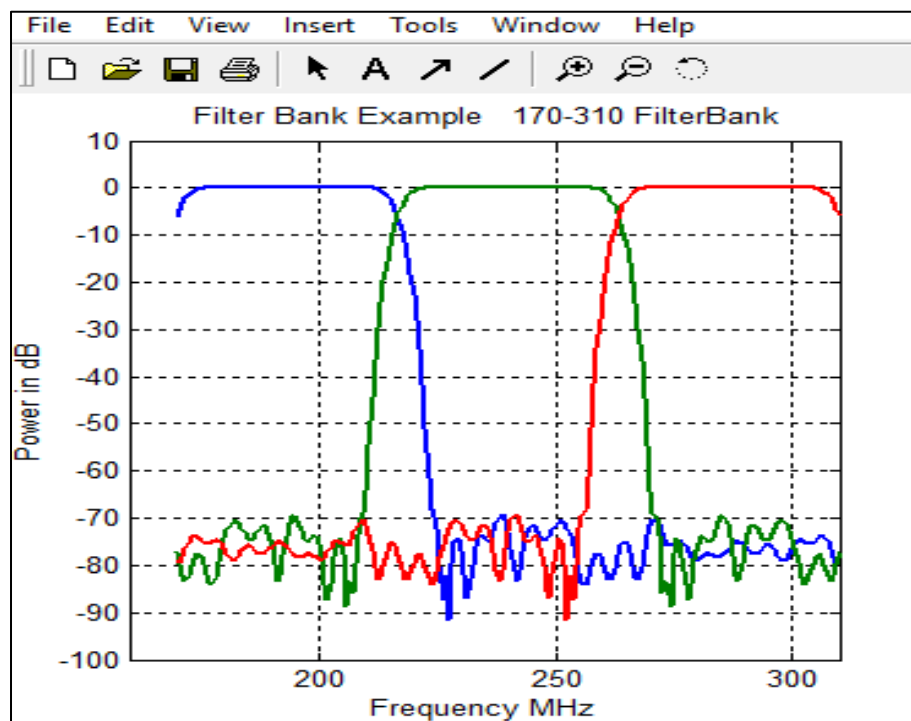


Figure 2 Three-Channel Filter-Bank

Figure 2 shows the three-channel filter-bank response across the 170–310 MHz IF band. The three channels illustrate how adjacent filters behave together, including passband alignment, transition-region spacing, and stopband uniformity. This multi-channel view provides a system-level perspective and demonstrates that the channelizer maintains consistent behavior across channels.

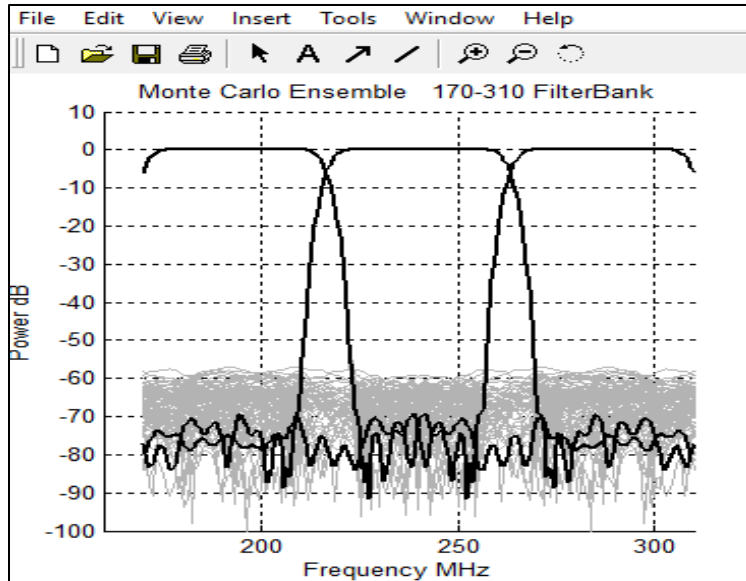


Figure 3 Monte Carlo Plot

Figure 3 shows the Monte Carlo ensemble for the same three-channel filter bank under $\pm 0.2\%$ coefficient perturbations. Each gray trace represents one trial, and the black curves show the nominal responses. The ensemble demonstrates stable passband behavior, consistent cutoff characteristics, and predictable stopband attenuation across trials. These results confirm that the channelizer is robust to realistic implementation tolerances and maintains three-channel stability.

Multi-channel AOA processing drives DF accuracy

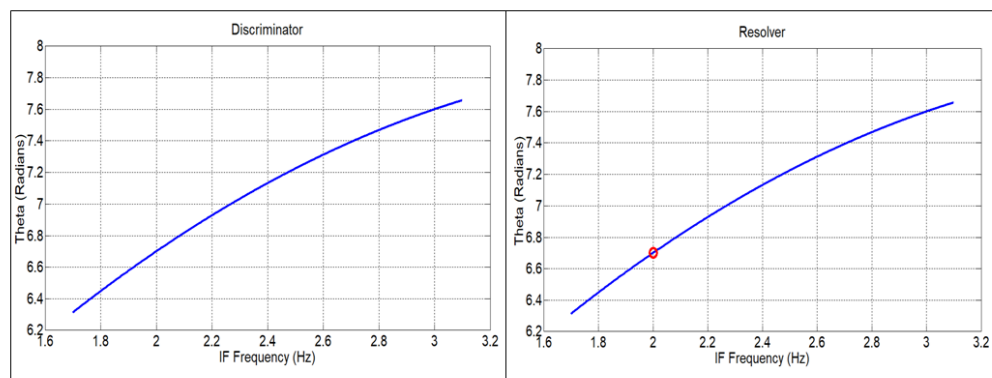


Figure 4. Processor Discriminator and AOA Resolver Outputs.

Figure 4 shows the processor's discriminator output across the channelized IF band. The discriminator provides a stable frequency-location function, producing a smooth monotonic response across the 170–310 MHz band with no discontinuities. This confirms that the digital discriminator reliably identifies tone frequency independent of amplitude or multi-signal conditions.

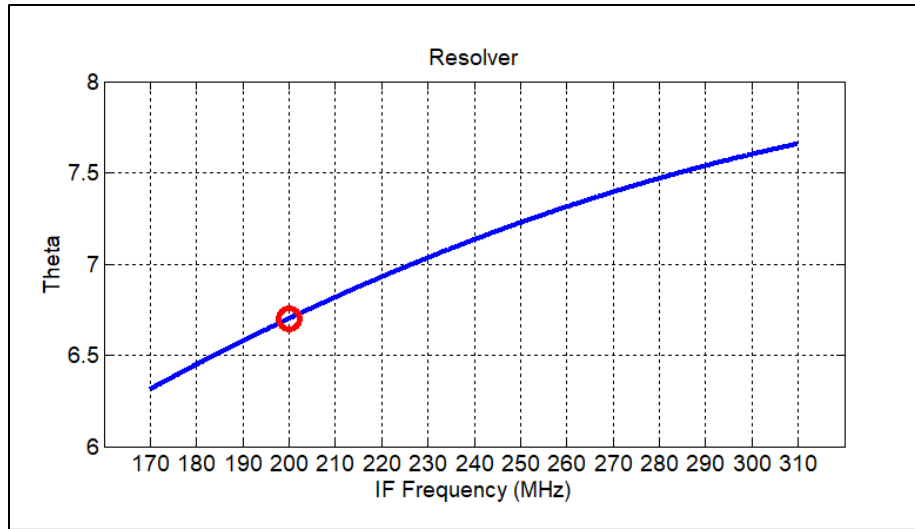


Figure 5. Frequency and AOA Resolver Output scaled in MHz

Figure 5 shows the resolver's θ output as a function of IF frequency. Because both the discriminator and resolver map their respective measurements to the same internal parameter θ , the processor can report frequency and angle-of-arrival estimates within a unified framework. The highlighted point marks one example of the θ value produced at a specific IF frequency.

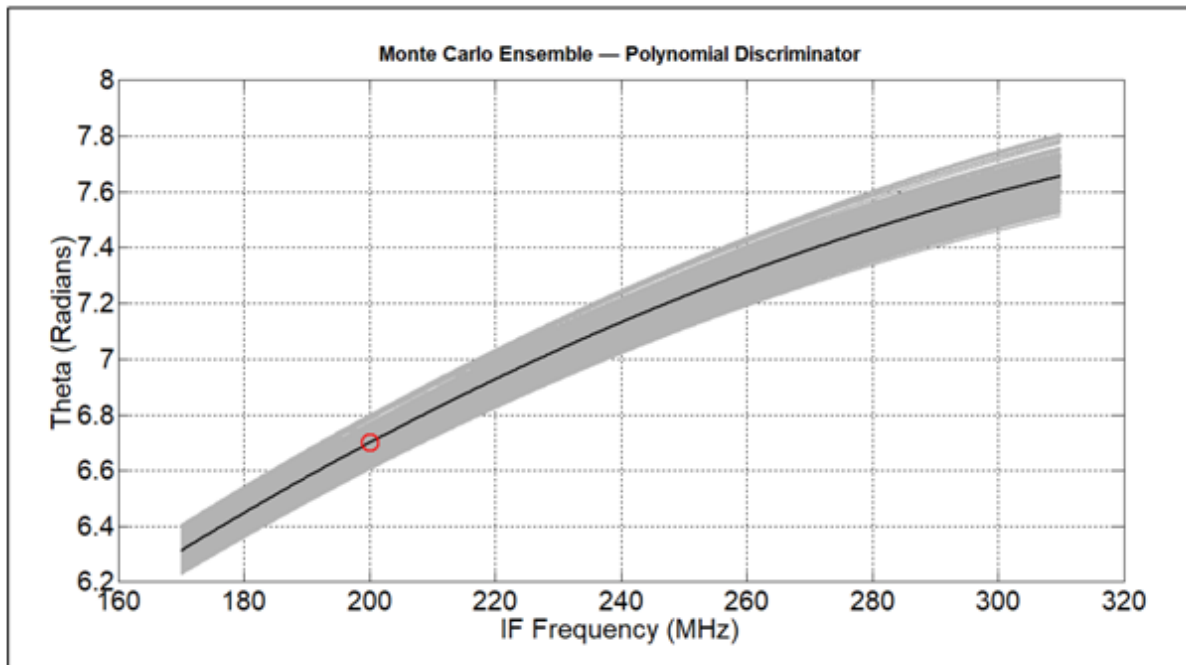
Monte-Carlo evaluation of AOA and Discriminator accuracy

Monte Carlo Validation — Discriminator (Frequency)

A Monte Carlo mismatch analysis was performed by applying ± 0.006 -radian Gaussian perturbations to the polyphase channelizer coefficients and discriminator polynomial terms. For each trial, the complete digital IFM/AOA processor was executed, and the discriminator output was plotted as θ versus IF frequency across the 170–310 MHz band. The resulting ensembles form a frequency-domain overlay showing the θ variation produced under coefficient perturbation. The spreads in θ are typically 0.005–0.007 radians, corresponding to approximately 0.30–0.40 degrees when expressed in angular units. All results were obtained through mathematical modeling and simulation.

Monte Carlo Validation — Resolver (AOA)

A separate Monte Carlo mismatch analysis was applied to the resolver polynomial by introducing ± 0.006 -radian Gaussian perturbations to the inter-channel phase terms. For each trial, the resolver mapping was executed using controlled phase offsets, and the resulting ensembles were plotted as θ versus angle-of-arrival. The θ spreads produced by the resolver under perturbation are typically 0.005–0.007 radians, representing the variation in phase-derived AOA parameters for the applied mismatch levels. All results were obtained through mathematical modeling and simulation.



Performance Summary

The plots in this section demonstrate that the polyphase channelizer provides stable, wideband performance across the 170–310 MHz IF band. The three-channel responses confirm clean filter behavior, and the Monte Carlo ensembles show robustness to realistic coefficient perturbations. Processor-level plots confirm stable tone detection, reliable frequency reporting, and deterministic timing. All processing and figures were generated using MATLAB R12.

All accuracy and stability results presented in this report are derived entirely from computer-based mathematical modeling and Monte Carlo simulation. No hardware measurements were performed.

This document presents a digital architecture for IF and AOA processing using a polyphase channelizer and multi-channel processor. The channelizer operates across the 170–310 MHz IF band and produces three channelized outputs suitable for subsequent digital processing. Processor-level functions include tone detection, frequency reporting, and phase-based parameter generation. All figures and results were produced using MATLAB R12. The data in this report come entirely from mathematical modeling and Monte Carlo simulation; no hardware measurements were performed.