Building an integrated end-to-end metal flaw detection system using NDT-KITS phased array probes requires several critical components beyond the transducers themselves. Based on the technical architecture of commercial systems, here are the essential components you'll need:

Signal Generation and Control Electronics

High Voltage Pulse Transmitting Circuit

You'll need a multi-channel pulser capable of generating high-voltage excitation pulses (typically 100-400V) for each probe element[1]. This circuit must provide precise timing control with nanosecond accuracy to enable proper beam steering and focusing. The pulser should support programmable delay patterns for each element to create the desired beam characteristics.

Transmission Delay Control Module

This component manages the precise timing sequences that enable beam steering and focusing[1]. It calculates and applies the appropriate delays to each element based on the desired beam angle and focal point. The delay resolution typically needs to be in the range of 1-10 nanoseconds for effective beam control.

Signal Acquisition and Processing

Multi-Channel ADC Sampling Circuit

A high-speed analog-to-digital converter system capable of simultaneously sampling all active elements at rates of 50-100 MHz or higher[1]. The ADC must have sufficient dynamic range (typically 12-16 bits) to capture both strong surface echoes and weak flaw signals.

Signal Conditioning Circuit

Pre-amplification and filtering circuits that condition the received signals before digitization[1]. This includes low-noise amplifiers, anti-aliasing filters, and gain control circuits to optimize signal quality across the full depth range.

FPGA Signal Processing Module

A field-programmable gate array (FPGA) serves as the core processing engine, implementing real-time algorithms for[1]:

- **Orthogonal demodulation** using CORDIC algorithms to extract signal envelopes
- **Dynamic FIR filtering** with real-time coefficient calculation
- **Time gain control** to compensate for acoustic attenuation
- **Beamforming algorithms** for focusing and steering

Data Processing and Imaging

Feature Information Processing Module

Software algorithms that analyze the processed ultrasonic data to identify and characterize flaws[1]. This includes:

- **Time-of-flight analysis** to determine flaw depth
- **Amplitude analysis** for flaw sizing
- **Pattern recognition** for flaw classification

Total Focusing Method (TFM) Implementation

Advanced imaging algorithms that create high-resolution images by virtually focusing at every point in the inspection volume[2]. This requires significant computational power but provides superior flaw visualization compared to conventional techniques.

Data Storage and Management

High-Speed Memory System

SDRAM or DDR3 memory for buffering large amounts of ultrasonic data during acquisition and processing[1]. Phased array systems generate substantial data volumes that must be managed efficiently.

Data Storage Solutions

Non-volatile storage for saving inspection results, calibration data, and system configurations. This typically includes both local storage and network connectivity for data transfer.

User Interface and Display

Real-Time Visualization Software

Software capable of displaying multiple scan formats[3]:

- **A-Scan**: Traditional amplitude vs. time display
- **B-Scan**: Cross-sectional images showing flaw positions
- **C-Scan**: Plan view images showing flaw extent
- **S-Scan**: Sector scans showing multiple beam angles

Calibration and Setup Software

Tools for probe characterization, system calibration, and inspection parameter setup. This includes wedge delay measurements, sensitivity calibration, and beam profile verification.

Mechanical and Coupling Components

Probe Coupling System

Appropriate coupling methods to ensure efficient ultrasonic transmission into the test material:

- **Contact coupling**: Couplant gels or oils for direct contact
- **Immersion coupling**: Water bath systems for complex geometries
- **Wheel probes**: For automated scanning applications

Scanning Mechanisms

Depending on your application requirements:

- **Manual scanning**: Hand-held probe manipulation
- **Semi-automated**: Guided scanning with position encoding
- **Fully automated**: Robotic or mechanical scanning systems

Power and Connectivity

Power Supply System

Regulated power supplies providing the various voltages required:

- High voltage for pulsers (100-400V)

- Digital logic supplies (3.3V, 5V)
- Analog circuit supplies (±15V typical)

Communication Interfaces

- **USB/Ethernet**: For data transfer and system control
- **PCIe interfaces**: For high-speed data transfer between FPGA and host computer[1]

System Integration Considerations

Timing and Synchronization

Master clock distribution to ensure all system components operate synchronously. This is critical for maintaining phase relationships between elements.

Electromagnetic Compatibility

Proper shielding and grounding to minimize electromagnetic interference, which can significantly impact signal quality in sensitive ultrasonic measurements.

Thermal Management

Cooling systems for high-power components, particularly the FPGA and power amplifiers, which can generate significant heat during operation.

Software Architecture

Real-Time Operating System

A real-time OS or bare-metal firmware capable of meeting the strict timing requirements for phased array operation.

Signal Processing Libraries

Implementation of core algorithms including:

- Fast Fourier Transform (FFT) routines
- Digital filtering algorithms

- Beamforming calculations
- Image reconstruction algorithms

Estimated Component Costs

Based on the system architecture analysis, expect these approximate costs for a basic 16-channel system:

- **FPGA development board**: $500-1,500
- **Multi-channel ADC**: $300-800
- **High-voltage pulsers**: $1,000-3,000
- **Signal conditioning**: $500-1,000
- **Software development**: $2,000-10,000 (depending on complexity)

The total system cost, excluding the NDT-KITS probes, would likely range from $5,000-20,000 for a functional prototype, with costs decreasing significantly for production volumes.

This comprehensive system architecture provides the foundation for building a capable metal flaw detection system that can effectively utilize the affordable NDT-KITS phased array probes while delivering professional-grade inspection capabilities.

⁂

1. https://sci-hub.se/downloads/2021-06-14/c5/tian2020.pdf
2. https://acs-international.com/product/a1550-introvisor/
3. https://www.linkedin.com/pulse/ultrasonic-flaw-detectors-explained-detecting-hidden-ylc8c