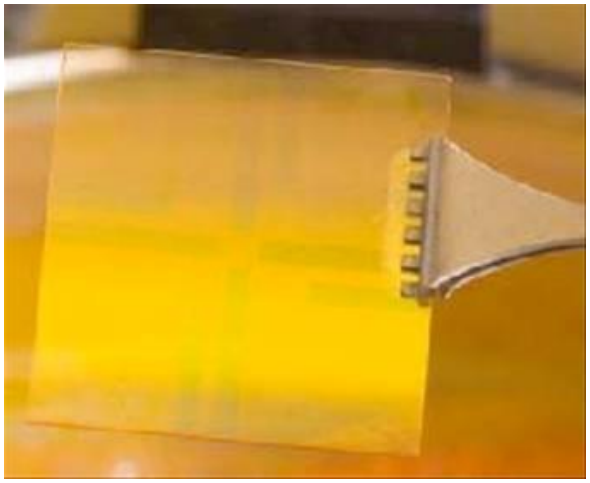
Inkjet Printed Antenna and Phased Array Antenna Systems

Problem Statement

- Manufacturing solutions needed by the military and industry that enhance:
  - quality, affordability, maintainability, and rapid deployment of existing and yet-to-be developed systems
- **Printed Electronics (PE)**
  - can enable low-cost electronic devices with new capabilities/characteristics



Implementation Will Require

new material discoveries and high-rate, affordable processing and manufacturing methods

Baseline Technology

Gaps

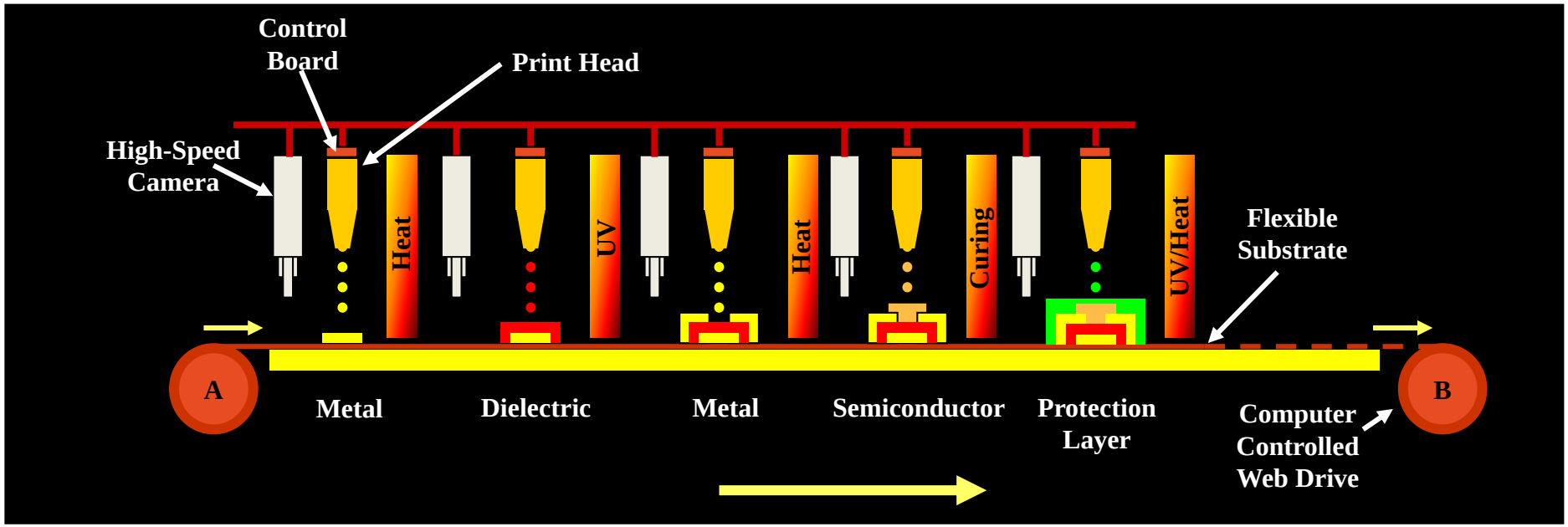
- **Conventional Electronics**
  - Non-conformable substrates
- **Emerging Printed Electronics Methods**
  - Lack of flexibility (materials/features)
  - Cannot integrate organic **and** inorganic printed electronic components on circuits
  - Do not have processes that enable low-cost, high rate integration/production of hybrid systems

Customer Needs

- Validated process
- High volume capable
- Versatile
  - Organic/Inorganic components
  - Compatible with multiple substrates
  - Accommodate multiple devices
  - Multiple print engine process
- Low Cost
  - Affordable processing

High Rate / Multi Stage / Roll-to-Roll Printing Process

- Enables Integration of different materials on different layers
- Excellent alignment between stages
- Large area manufacturing



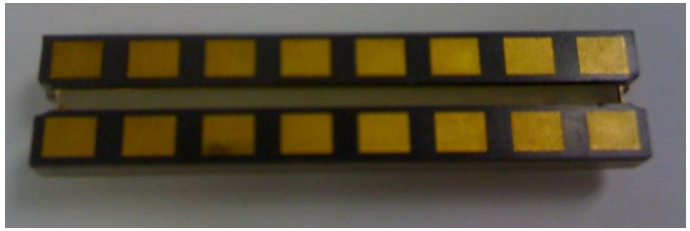
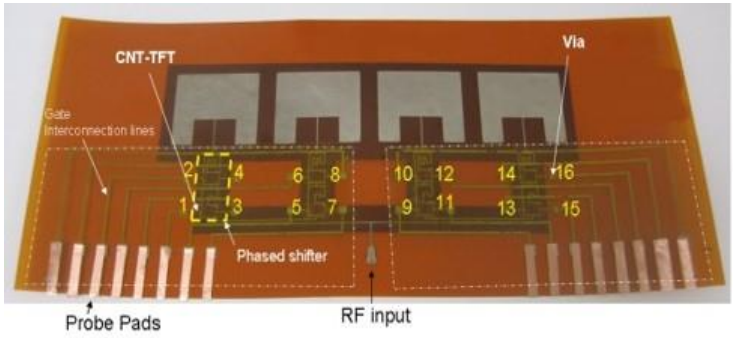
Why Ink-Jet Printing?

Features	Advantages	Benefits
Non-contact printing	Avoids material contact	• Helps prevent contamination • Eliminates risk of defect on a template • Drop on demand printing
Digital image printing	No template required	• Saves time and effort • Tremendous cost savings
Substrate independent process	Manufacturing on any kind of rigid, flexible or curved surface	Integration with any platform is possible such as aircraft wing, car windshield, helmet etc
Smaller machines	Easy to integrate with existing production lines	• Small footprint • Low equipment and setup costs
Customization	Printing of a variety of patterns is possible	• No additional templates are required • Cost savings • Saves time
Low material wastage	Reduces material cost	Overall cost savings
Additive manufacturing process	No etching process involved	Can be performed outside clean room environment
Film layer uniformity	Can achieve better printed layers	Good and uniform device performance

Application to Large Aperture Conformal Phased Array Antennas

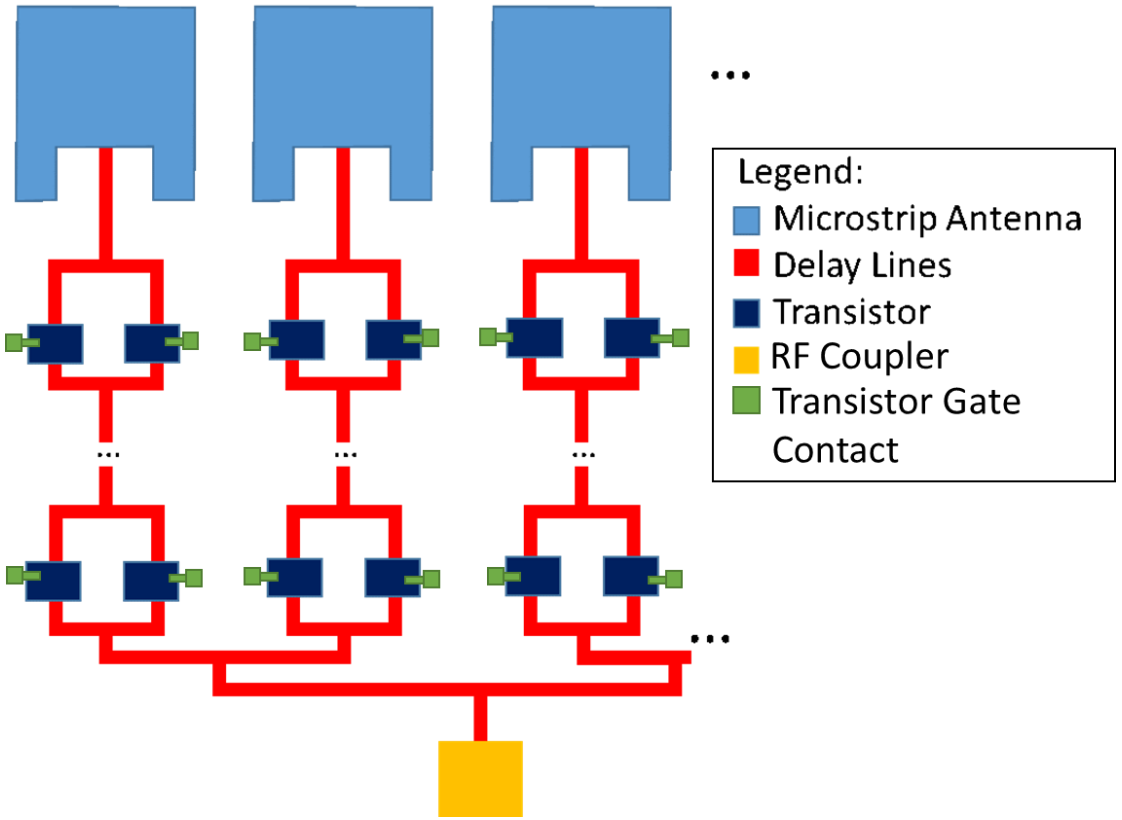
Conformal PAAs

- Comparison between Antenna Array

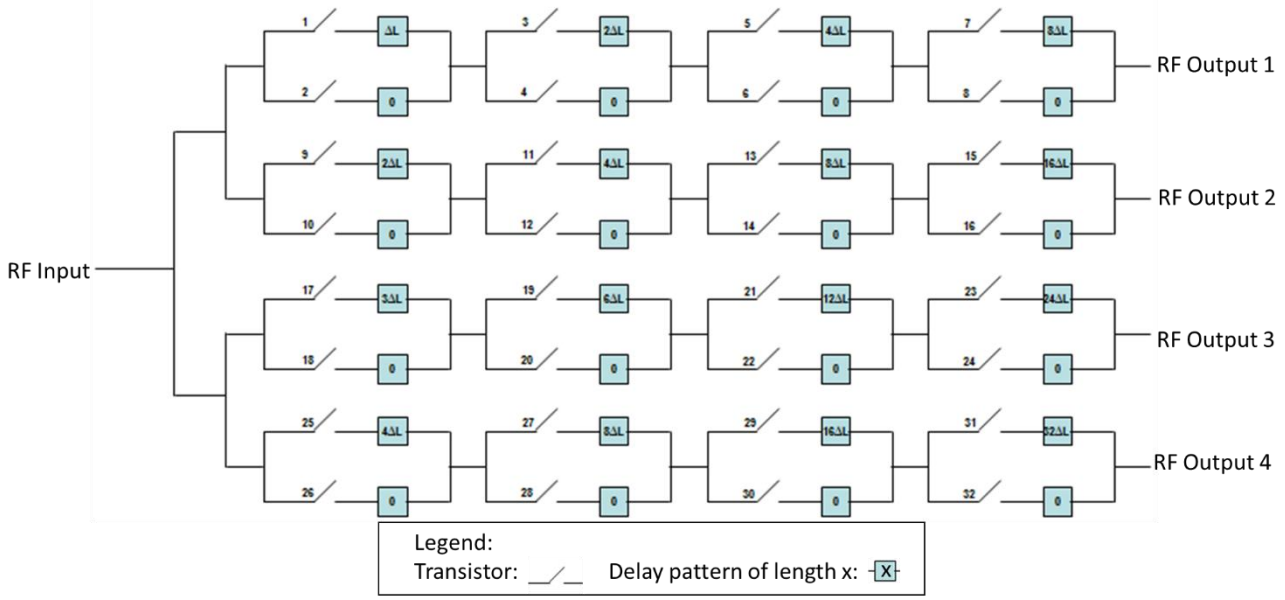
Formation Technique	Advantage	Disadvantage
<u>Rigid Antenna:</u> 	• Mature product / availability	• Rigid and heavy • Thicker profile – cannot integrated on clothing
<u>Flexible Antenna</u> • Printed antenna on flexible substrate 	• Low cost • Flexible and light weight / can be retracted and deployed when needed • Low profile that can be integrated on clothing	• Still in research phase

Phased Array Antenna Design

- Consists of three major modules
  - Phase shifter
  - Transistors
  - Patch Antennas



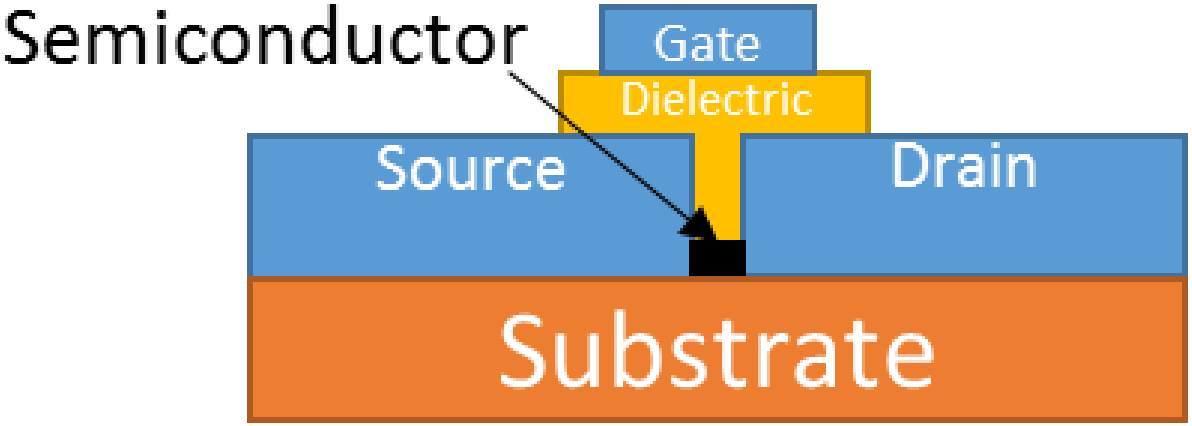
I. Phase Shifter



S.No	Steering Angle	Path Length Difference	Switch Selection Table
1	0	0	(2, 4, 6, 8) (10, 12, 14, 16) (18, 20, 22, 24) (26, 28, 30, 32)
2	2.7	ΔL	(1, 4, 6, 8) (9, 12, 14, 16) (17, 20, 22, 24) (25, 28, 30, 32)
3	5.4	2ΔL	(2, 3, 6, 8) (10, 11, 14, 16) (18, 19, 22, 24) (26, 27, 30, 32)
4	8.13	3ΔL	(1, 3, 6, 8) (9, 11, 14, 16) (17, 19, 22, 24) (25, 27, 30, 32)
5	10.87	4ΔL	(2, 4, 5, 8) (10, 12, 13, 16) (18, 20, 21, 24) (26, 28, 29, 32)
6	13.63	5ΔL	(1, 4, 5, 8) (9, 12, 13, 16) (17, 20, 21, 24) (25, 28, 29, 32)
7	16.43	6ΔL	(2, 3, 5, 8) (10, 11, 13, 16) (18, 19, 21, 24) (26, 27, 29, 32)
8	19.26	7ΔL	(1, 3, 5, 8) (9, 11, 13, 16) (17, 19, 21, 24) (25, 27, 29, 32)
9	22.15	8ΔL	(2, 4, 6, 7) (10, 12, 14, 15) (18, 20, 22, 23) (26, 28, 30, 31)
10	25.1	9ΔL	(1, 4, 6, 7) (9, 12, 14, 15) (17, 20, 22, 23) (25, 28, 30, 31)
11	28.12	10ΔL	(2, 3, 6, 7) (10, 11, 14, 15) (18, 19, 22, 23) (26, 27, 30, 31)
12	31.23	11ΔL	(1, 3, 6, 7) (9, 11, 14, 15) (17, 19, 22, 23) (25, 27, 30, 31)
13	34.45	12ΔL	(2, 4, 5, 7) (10, 12, 13, 15) (18, 20, 21, 23) (26, 28, 29, 31)
14	37.79	13ΔL	(1, 4, 5, 7) (9, 12, 13, 15) (17, 20, 21, 23) (25, 28, 29, 31)
15	41.3	14ΔL	(2, 3, 5, 7) (10, 11, 13, 15) (18, 19, 21, 23) (26, 27, 29, 31)
16	45	15ΔL	(1, 3, 5, 7) (9, 11, 13, 15) (17, 19, 21, 23) (25, 27, 29, 31)

- Using the combination of switches outlined, different beam steering positions are accomplished
- This design is for a 4bit phase shifter, which yields 16 positions between 0 and 45 degrees
- The angle is not limited by the technology, and is scalable to cover larger angular range

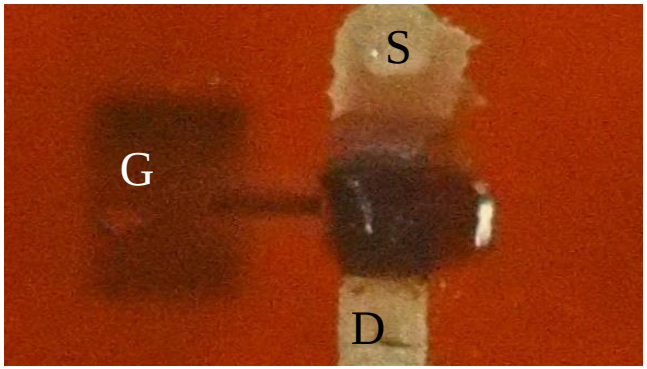
II. Transistors

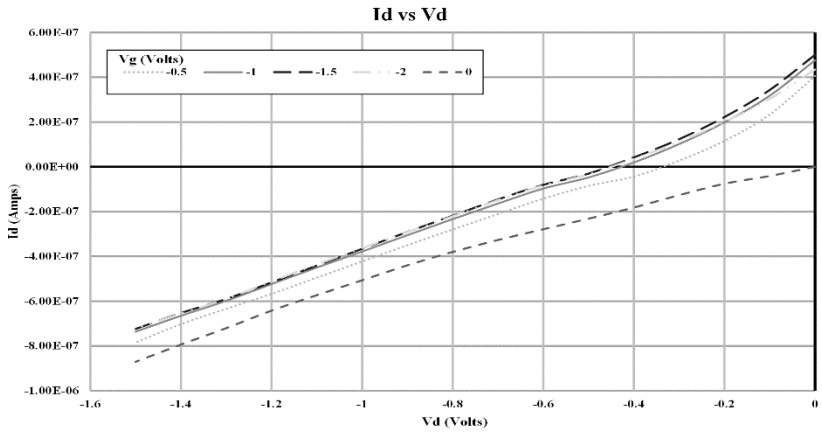


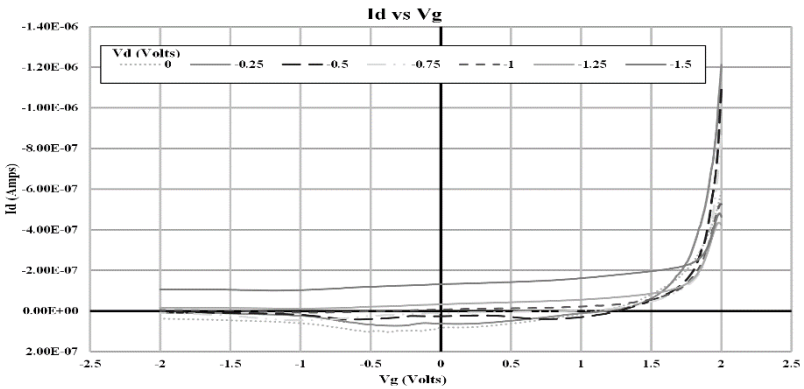
- Uses semiconducting carbon nanotubes as the active layer
- High-k material used to print Dielectric Layer
- Each layer is deposited and cured separately to create fully active device

Transistor Performance

- The devices have exceptional performance due to very high dielectric constant
- On/Off ratios on the order of 10^4 were observed
- Yield rates were around 99%

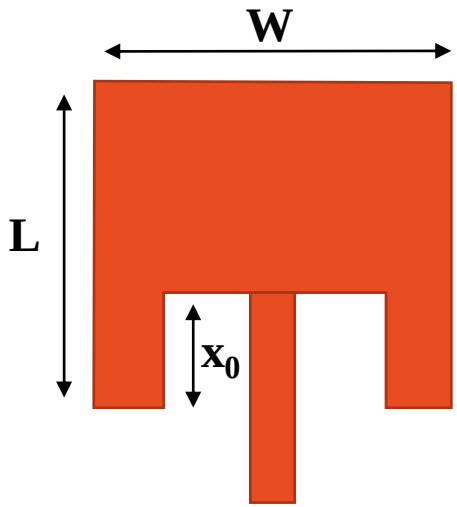






III. Patch Antennas

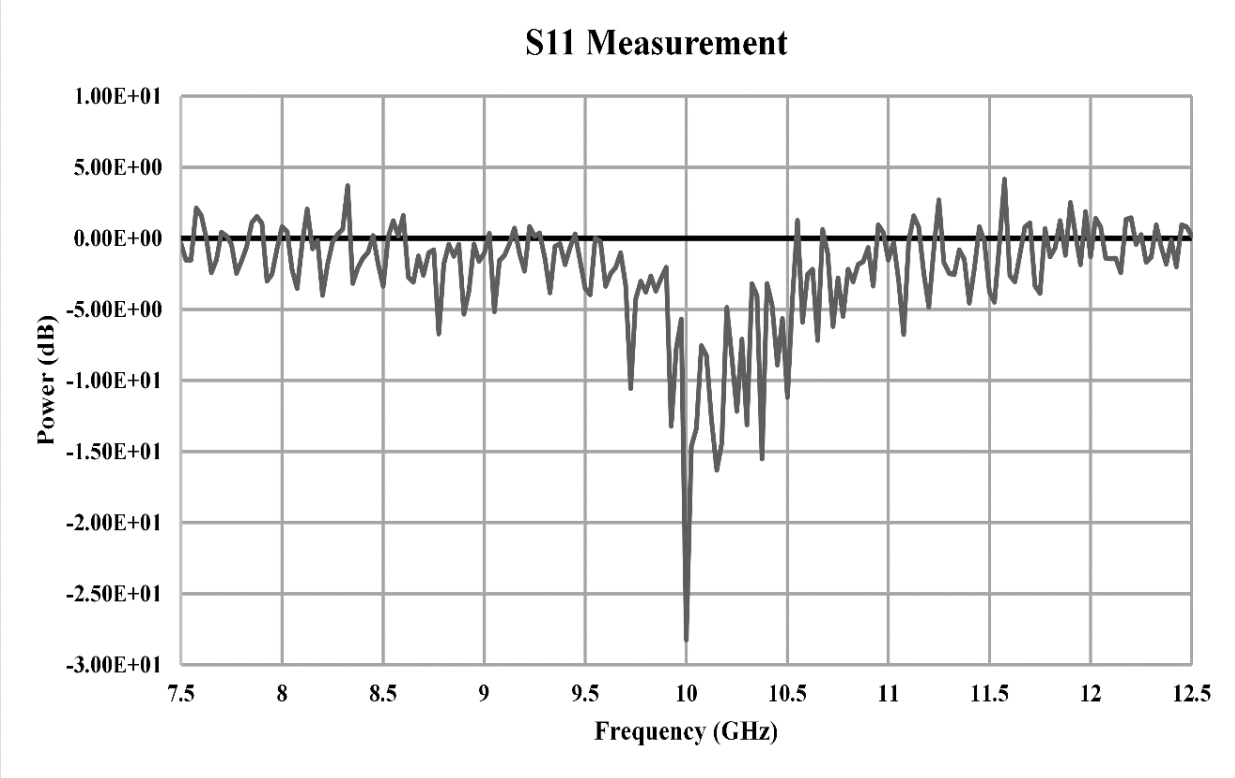
- We can design patch antennas and print them in order to operate at any given frequency
- We also custom design and print other types of broadband antennas
- Example of the design of a 10GHz patch antenna is shown below
- Transmission line design aspects are taken into consideration



10 GHz Dimension	
W	8.4 mm
L	6.4 mm
x_0	2.4 mm

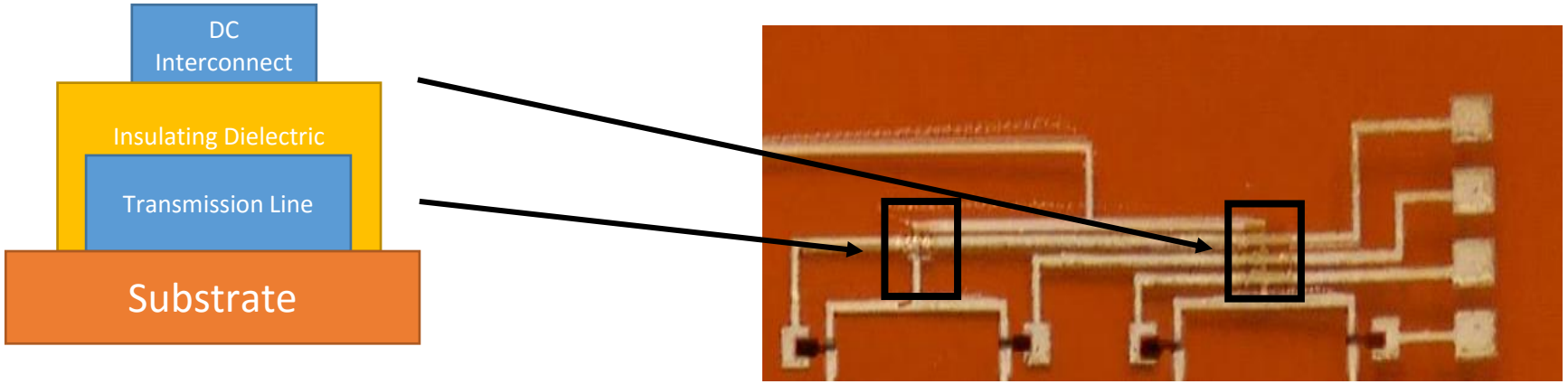
Antenna Testing

- Antennas evaluated in terms of bandwidth and radiation pattern
- Bandwidth was evaluated using S11 measurement
- Found to operate between 9.975 and 10.075 GHz

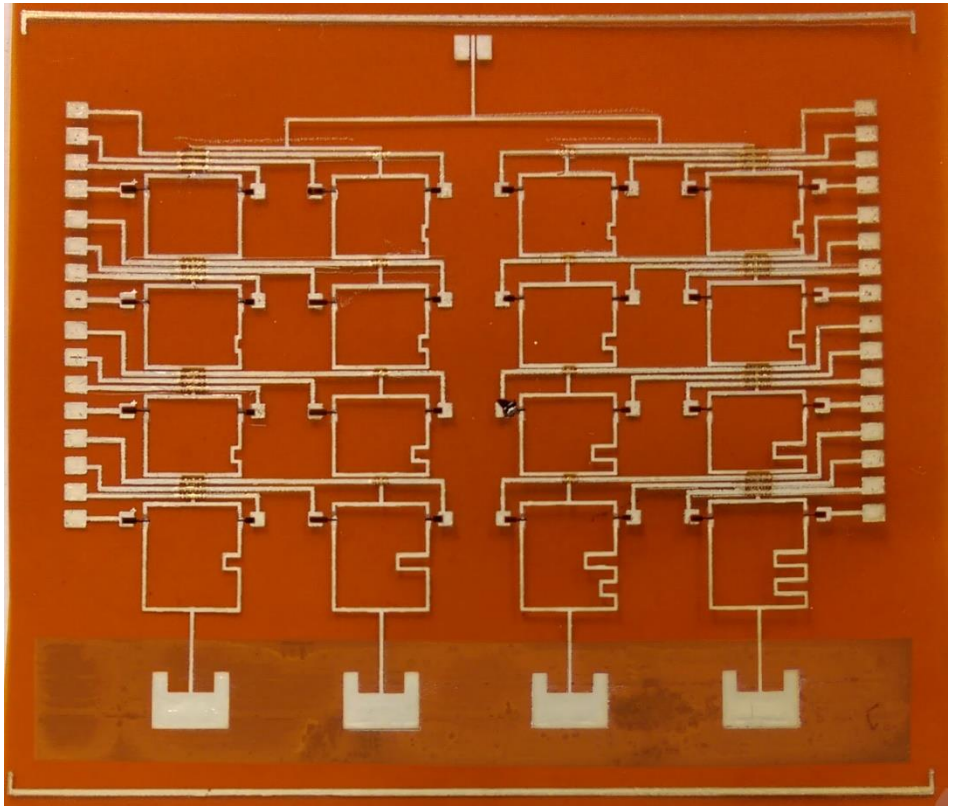


Single Substrate Interconnect

- In order to control phase shifter, a DC interconnect network is needed
- Traditionally, a second substrate is needed, but requires non-printed assembly
- Insulator printed over transmission lines allows for single substrate interconnects



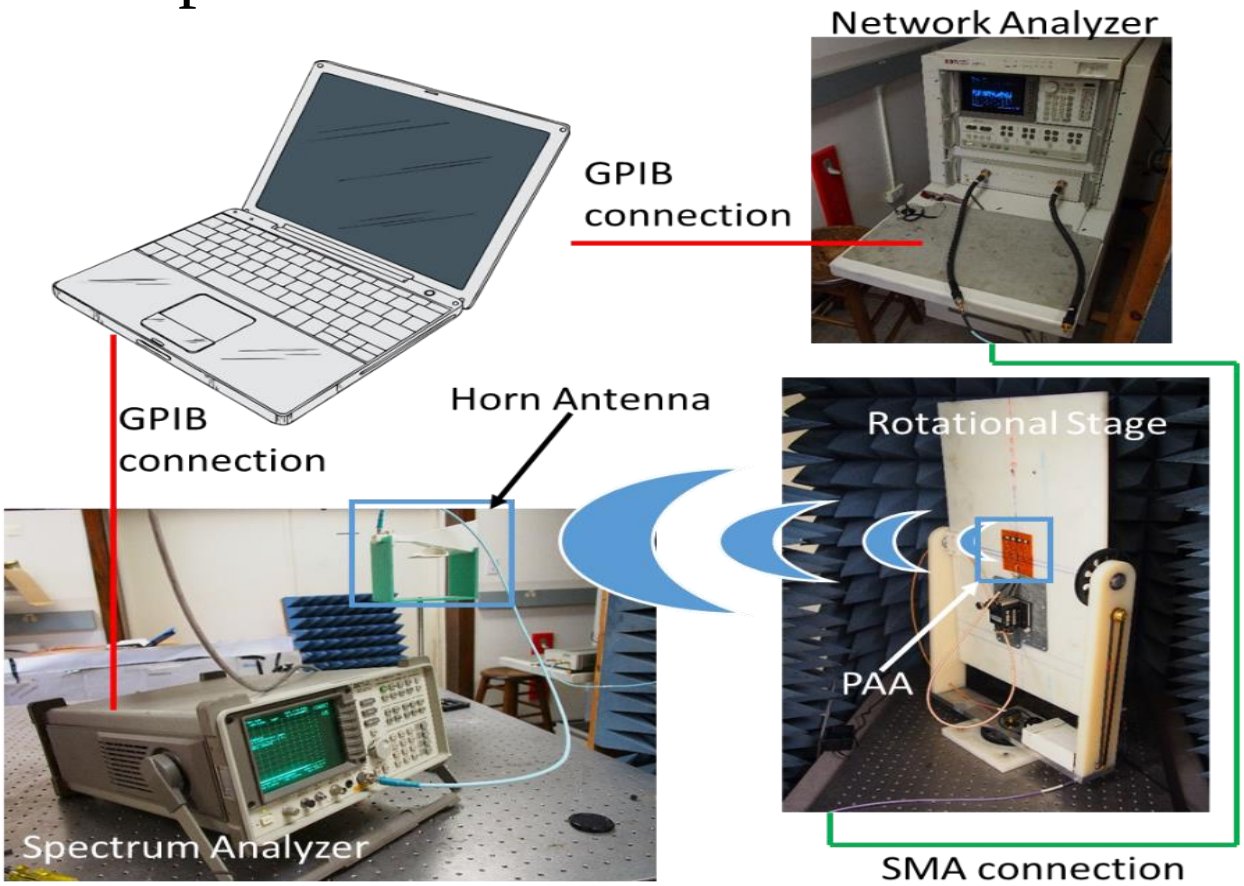
Multilayer Interconnected PAA



- A 4-bit 1x4 PAA operational at 10GHz with single substrate interconnects and CNT Transistors was fabricated
- Transistors exhibited a high yield rate and solid performance
- Multilayer interconnection was performed to package the DC lines
- Beam steering of the PAA was also demonstrated

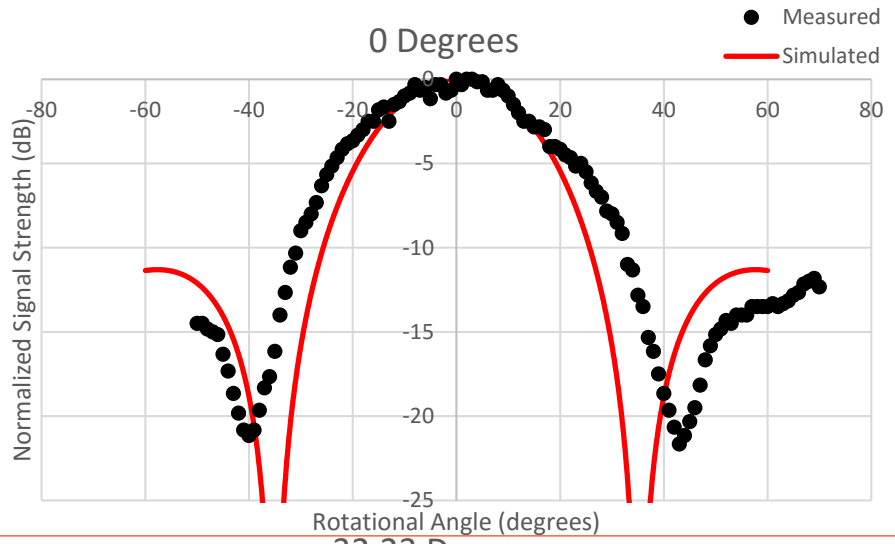
Radiation Pattern Test Setup

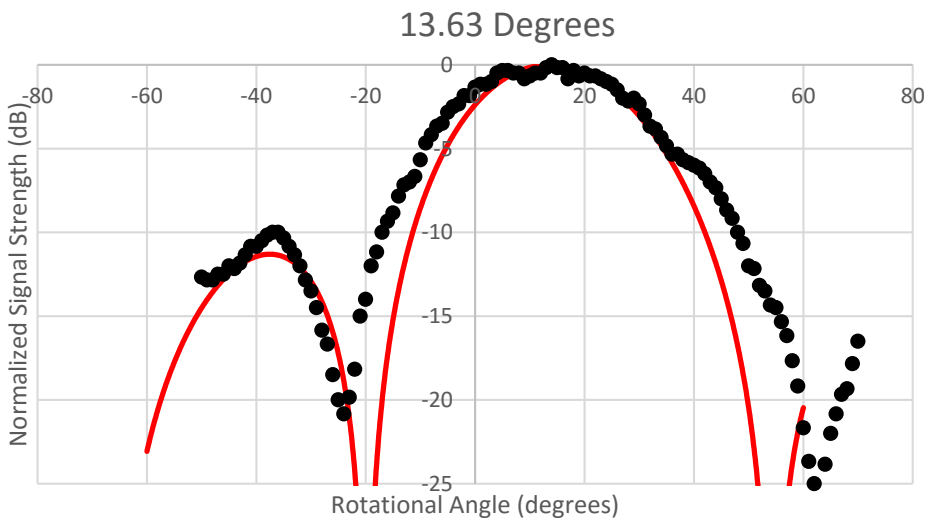
- In order to test the radiation pattern of the PAA, the devices transmission strength is measured at multiple angles
- Automated test system was created to expedite this process and provide precise movement

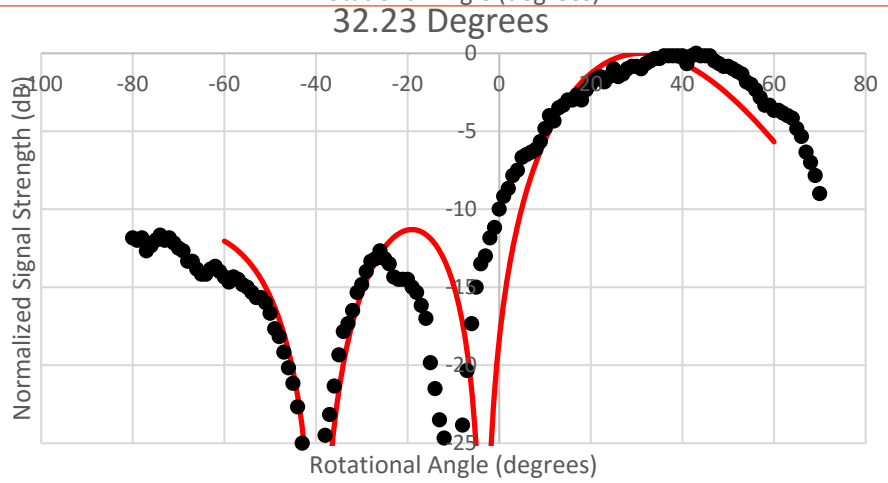


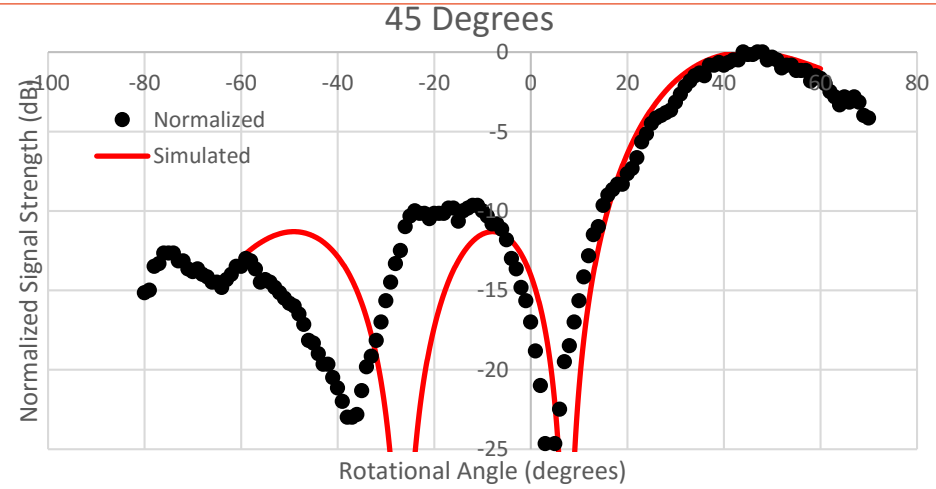
Radiation Pattern @ 10GHz

- PAAs exhibit a high degree of beam steering with a wide variety of angles.



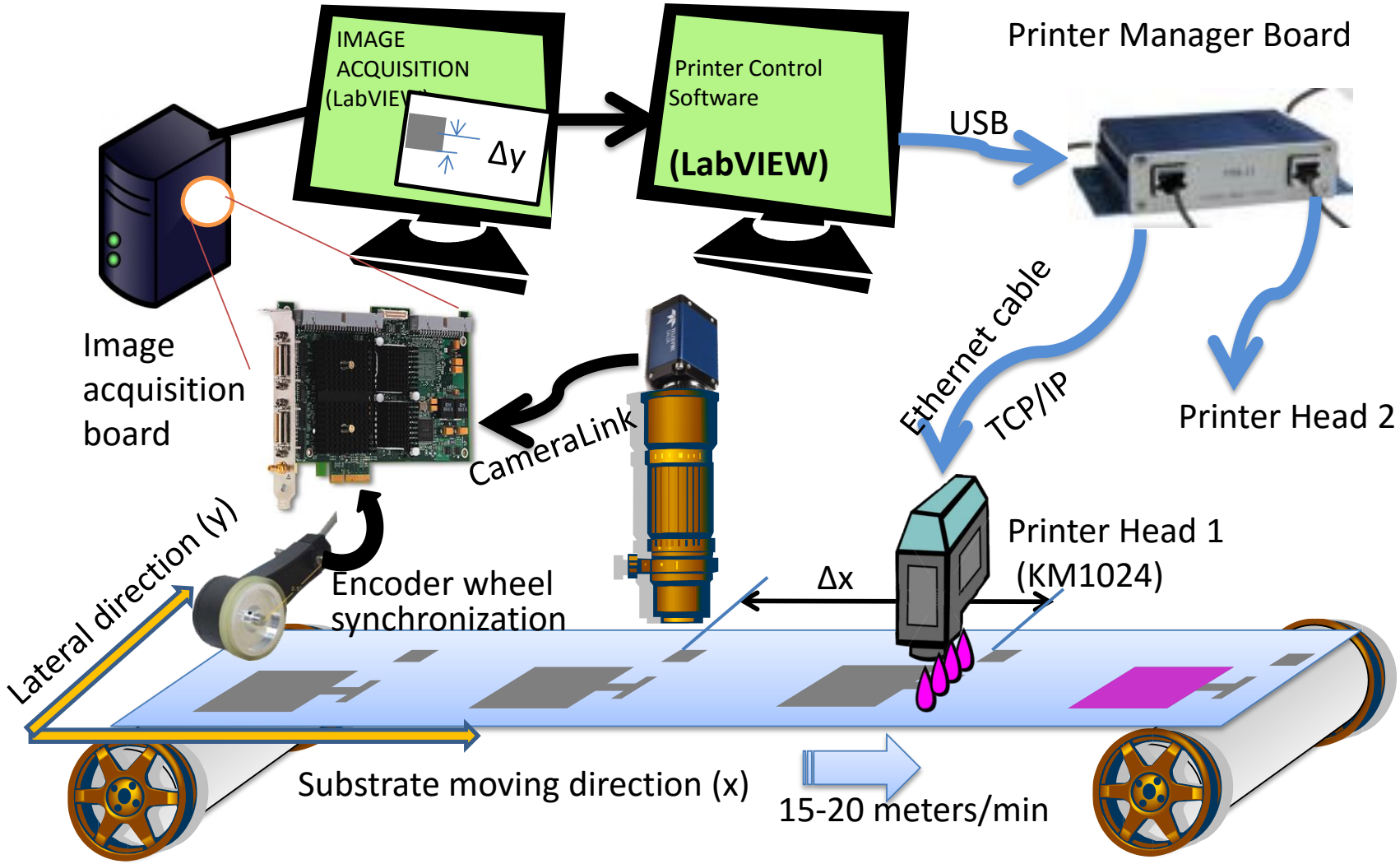






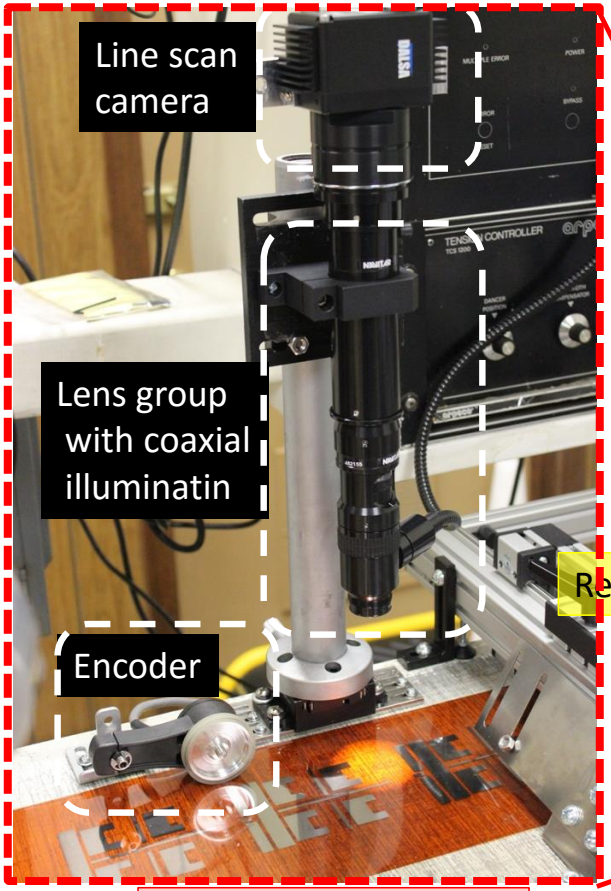
Towards High-Rate Roll-to-Roll (R2R) Ink-Jet Printing

Schematic of a Single Stage Printer

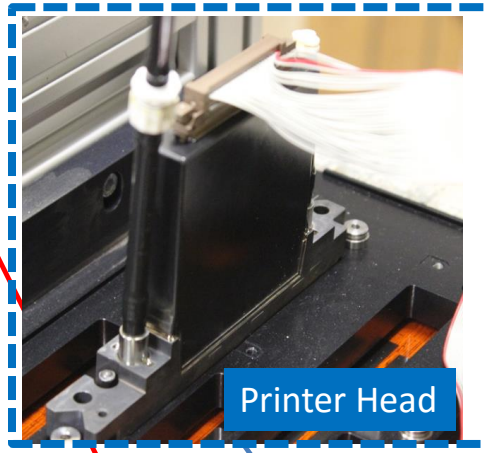


We can assemble and deliver customized R2R solutions to satisfy your needs. Please contact sales for more information

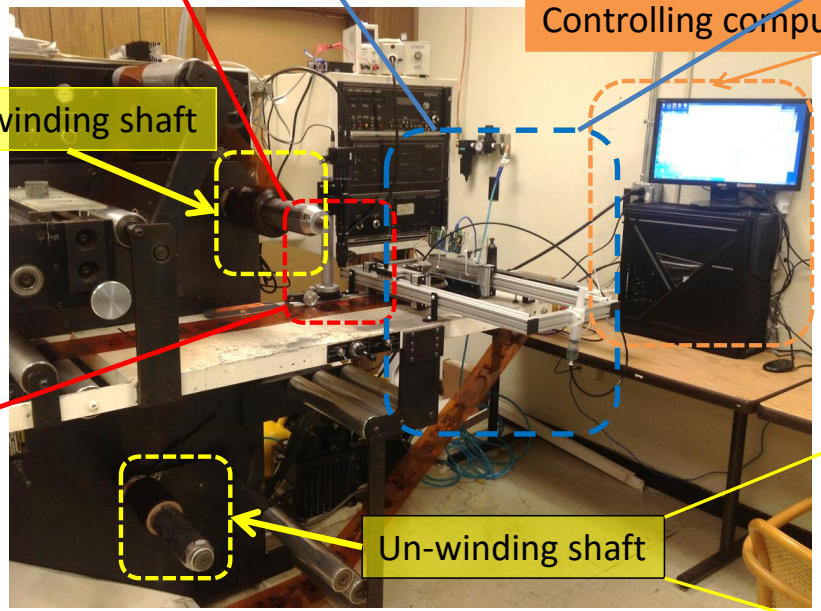
Customized High-Rate Ink-Jet Printer



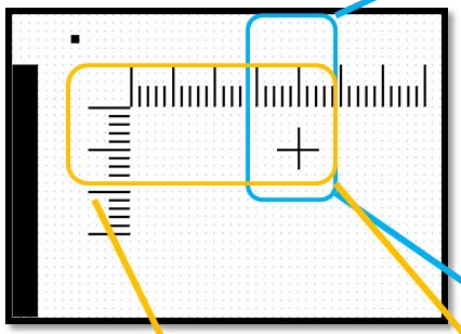
Alignment module
- Line scan camera
- Lens
- Coaxial illumination
- Encoder

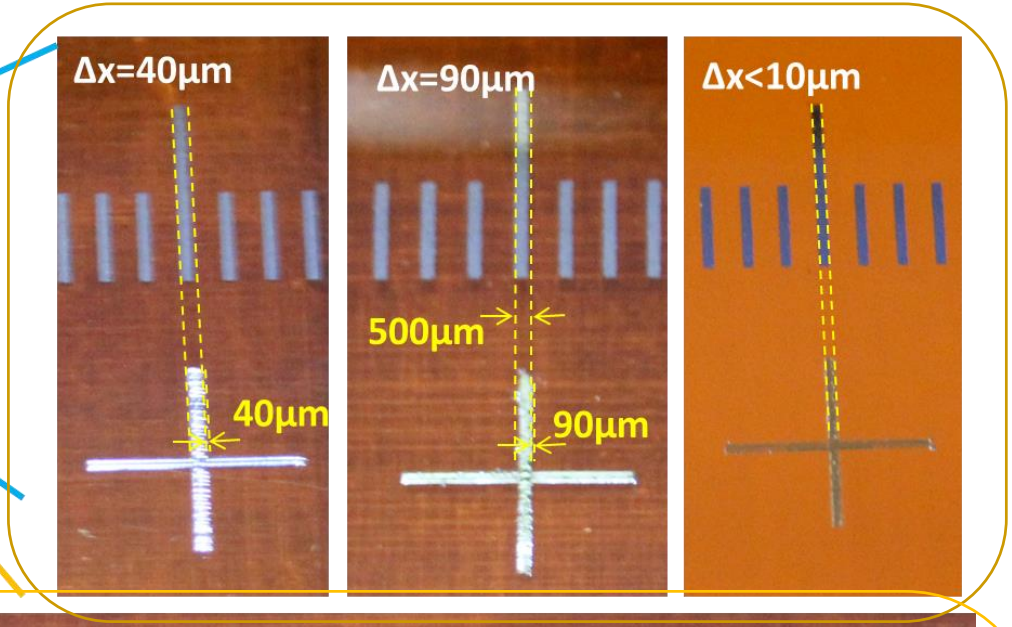


Controlling computer with LabVIEW



Roll-to-roll inkjet printing machine



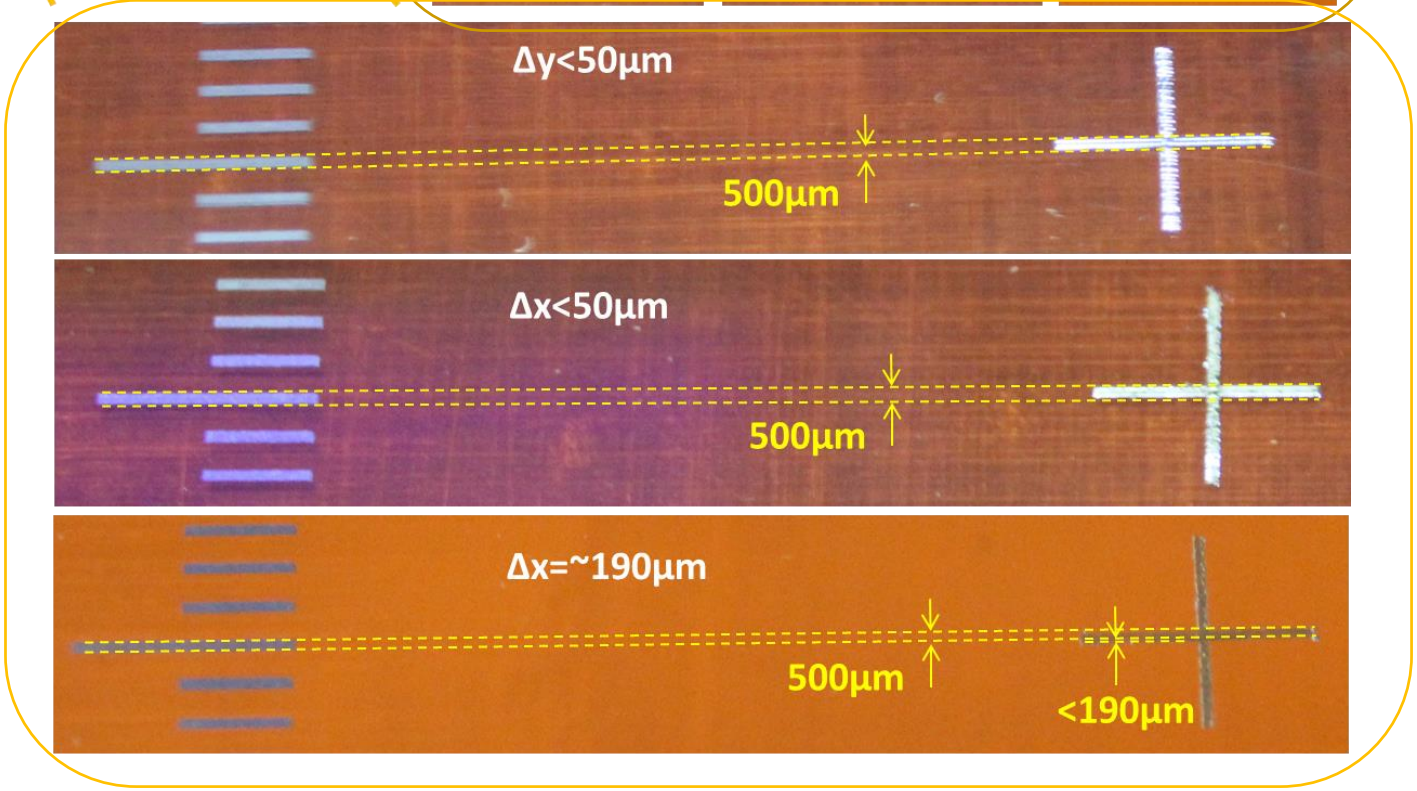


@5m/min

Alignment accuracy:
ΔX<100μm (best case <10um)
Δy<200μm

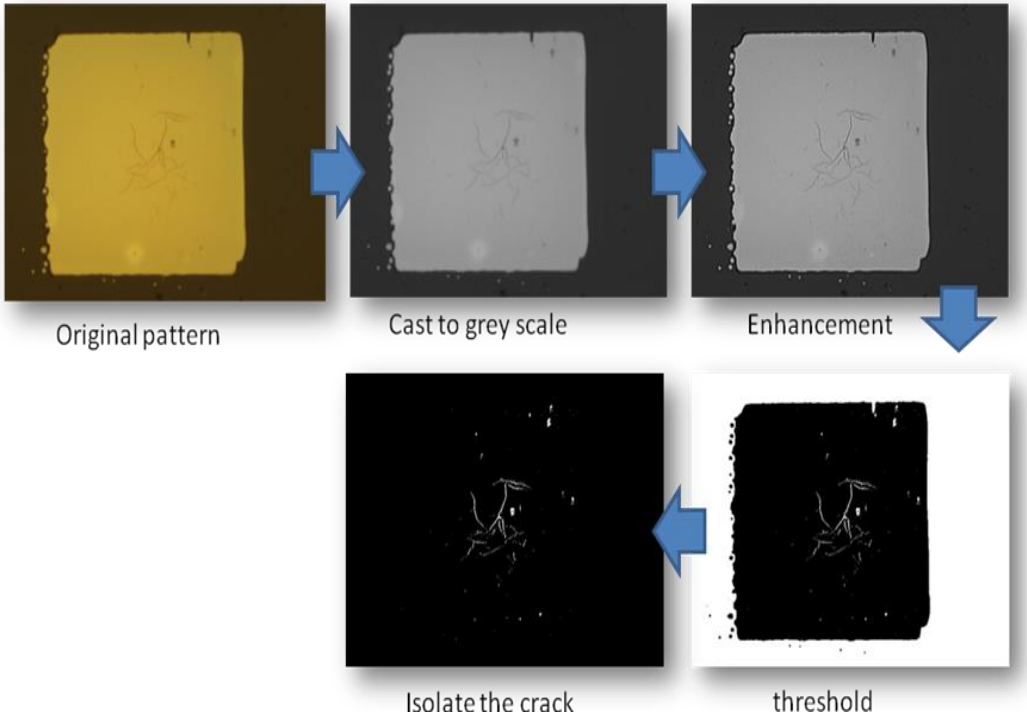
For further improvement:

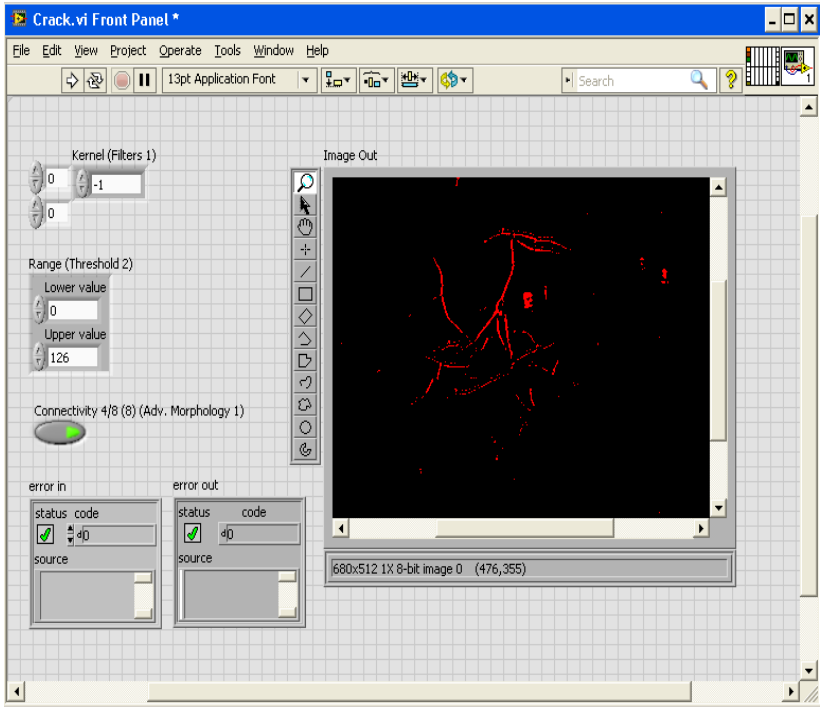
- **Fine tune the Print/Go sensor**
- **Adding tilting**



Quality Control

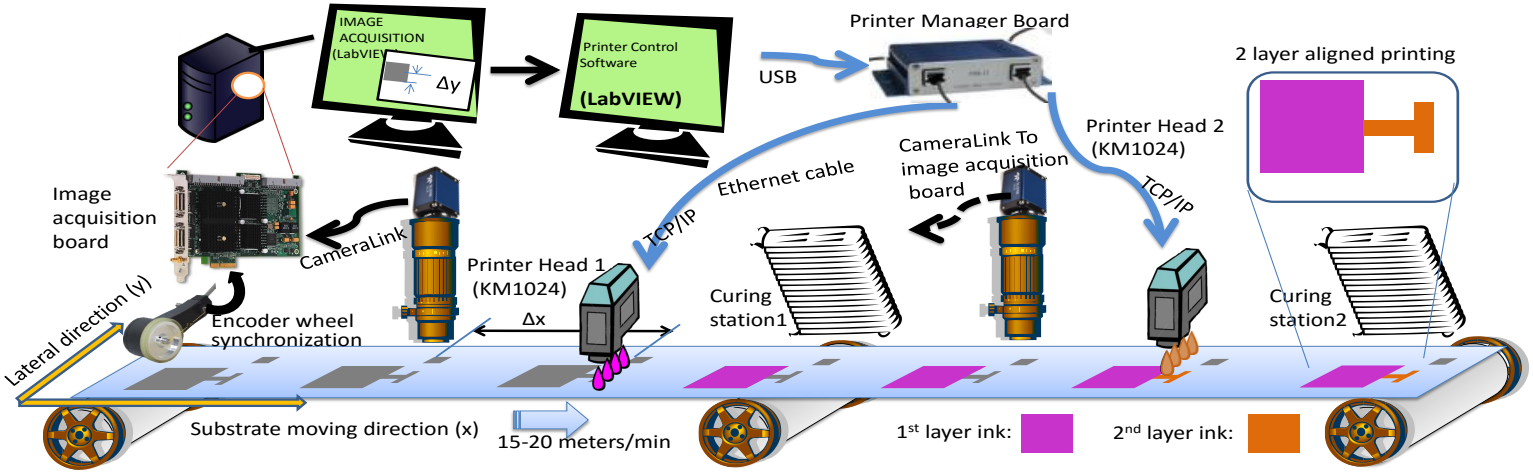
The system should be able to determine the quality of the film.
Software: LabVIEW 2011 with Vision assistant 2011
Hardware: Window XP 64bit
Input: continuous image acquired from camera.
For demonstration purpose, we use an image with a crack pattern.
Output: image showing the crack.

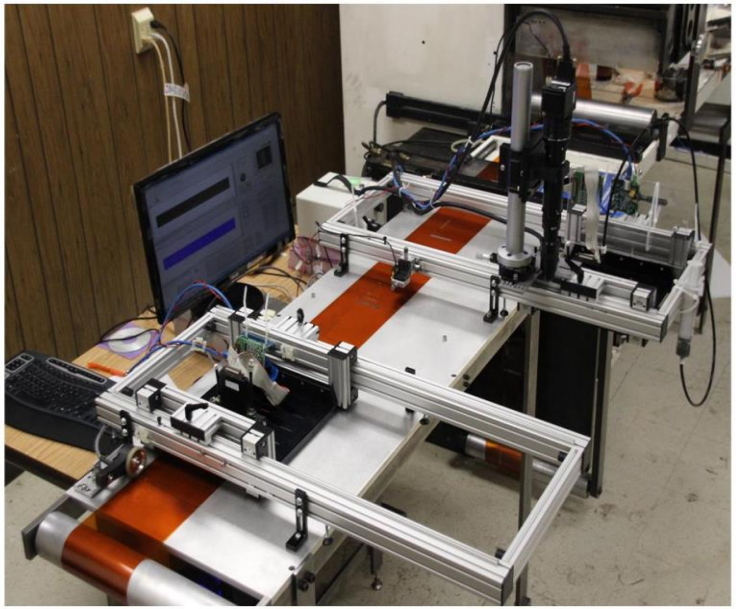


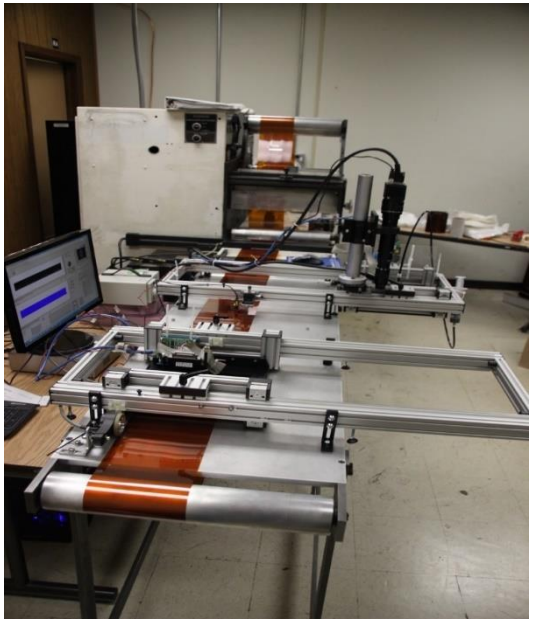


Scalable Printing System

We have the expertise in installing and operating multi-stage R2R printers







For your application needs and services, please contact our sales department at sales@omegaoptics.com. In addition to custom design and printing services, we also offer table-top and R2R ink-jet printers for sale.