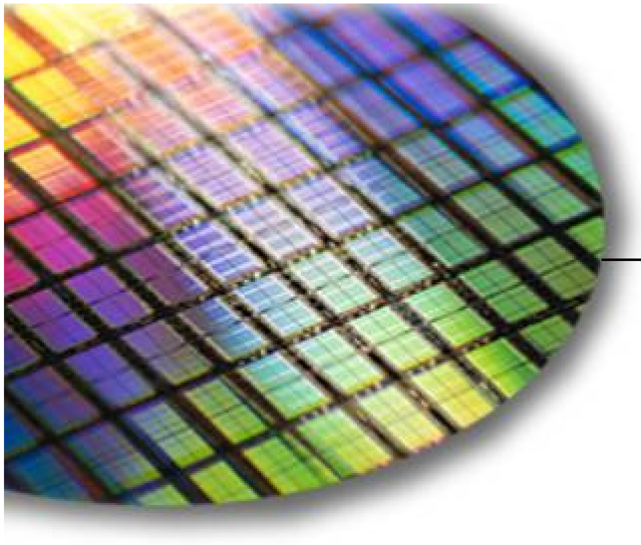


The World Leader in High Performance Signal Processing Solutions

RADAR
DEFENSE vs. AUTOMOTIVE

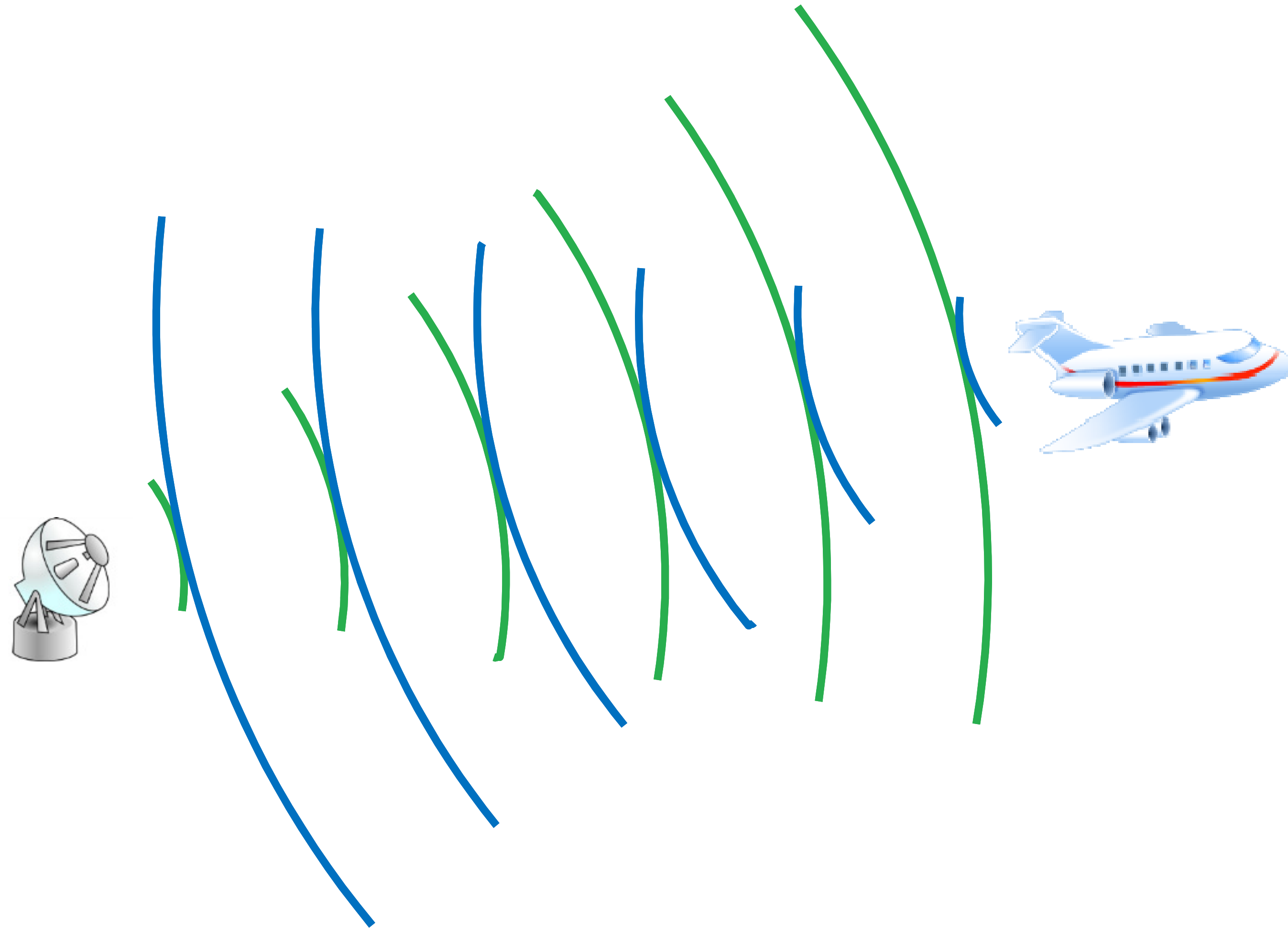
Larry Hawkins, Patrick Walsh, Jarrett Liner, Mike Curtin, Mike Mullins

ANALOG DEVICES

FUNDAMENTAL GOALS OF RADAR

- **We want to**
  - **Detect and track targets in the presence of noise, clutter, and other interference; and/or**
  - **Image terrain and targets**
- **The quality of the results of these operations is determined by**
  - **Detect:** P_D/P_{FA} → **Signal and interference statistics, Signal-to-Interference Ratio (SIR)**
  - **Track: precision and accuracy → SIR and algorithm**
  - **Image: "Sharpness" and contrast → Resolution, SIR, sidelobes**
- ***The most basic purposes of radar signal processing are to improve SIR and resolution***

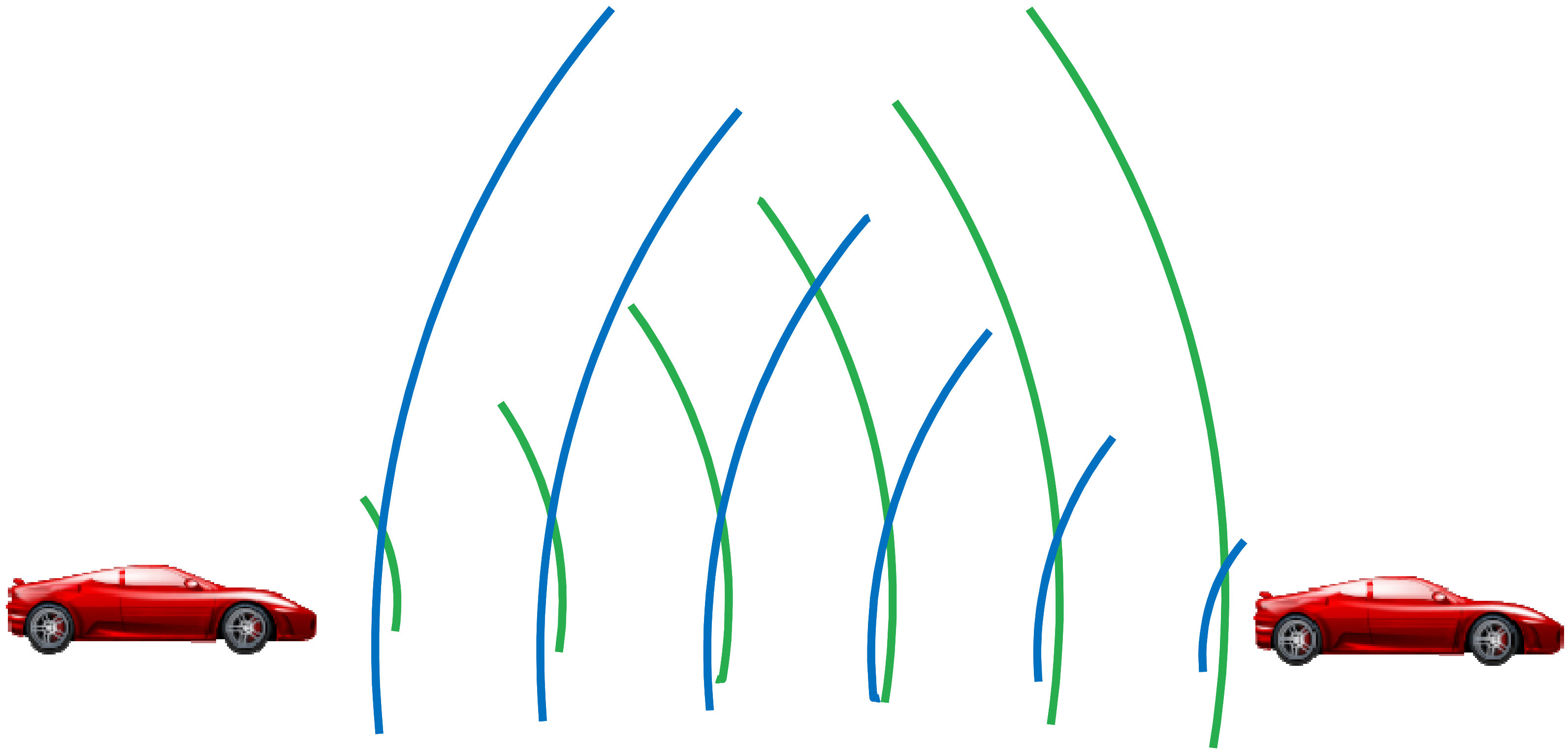
DEFENSE RADAR



$$D = \frac{c * t_D}{2}$$

$D = Distance\ (m)$
$c = Speed\ of\ Light\ (m/s)$
$t_D = Time\ of\ Flight\ (s)$

AUTOMOTIVE RADAR



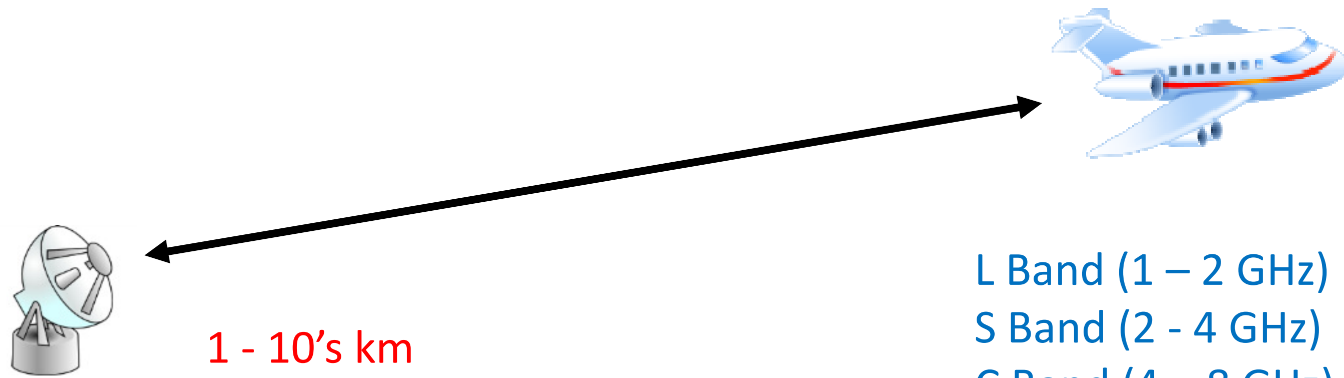
$$D = \frac{c * t_D}{2}$$

$D = Distance\ (m)$

$c = Speed\ of\ Light\ (m/s)$

$t_D = Time\ of\ Flight\ (s)$

RADAR DIFFERENCES



1 - 10’s km

L Band (1 – 2 GHz)
S Band (2 - 4 GHz)
C Band (4 – 8 GHz)
X Band (8 – 12 GHz)

RANGE

1- 200m

K Band (24GHz)
E Band (77GHz)

FREQUENCY MODULATION

Defense

- **FMCW**
  - **PLL**
  - **DAC**
  - **DDS**
- **Pulse Doppler**
- **Doppler**

Automotive

- **FMCW**
  - **PLL**
  - **DAC**
  - **DDS**
- **UWB**
- **Pulse Doppler**

WAVEFORM GENERATION FOR RADAR

- **Digital to Analog Converter (DAC)**
  - **Complex and wide bandwidth waveform, non-linear frequency modulated waveforms**
    - e.g. AD9129 5.6Gsample/s DAC is capable of generating signals across 1.4GHz of bandwidth

- **Direct Digital Synthesis (DDS)**
  - **Linear frequency modulated sweep, frequency agile pulse generation**
  - **Vary Frequency, Phase or Amplitude**
    - e.g. AD9914/15 with 1.4GHz Bandwidth

- **In the L and S bands, both options can be used directly**
  - **Reduce system complexity, saving power, size, and weight**

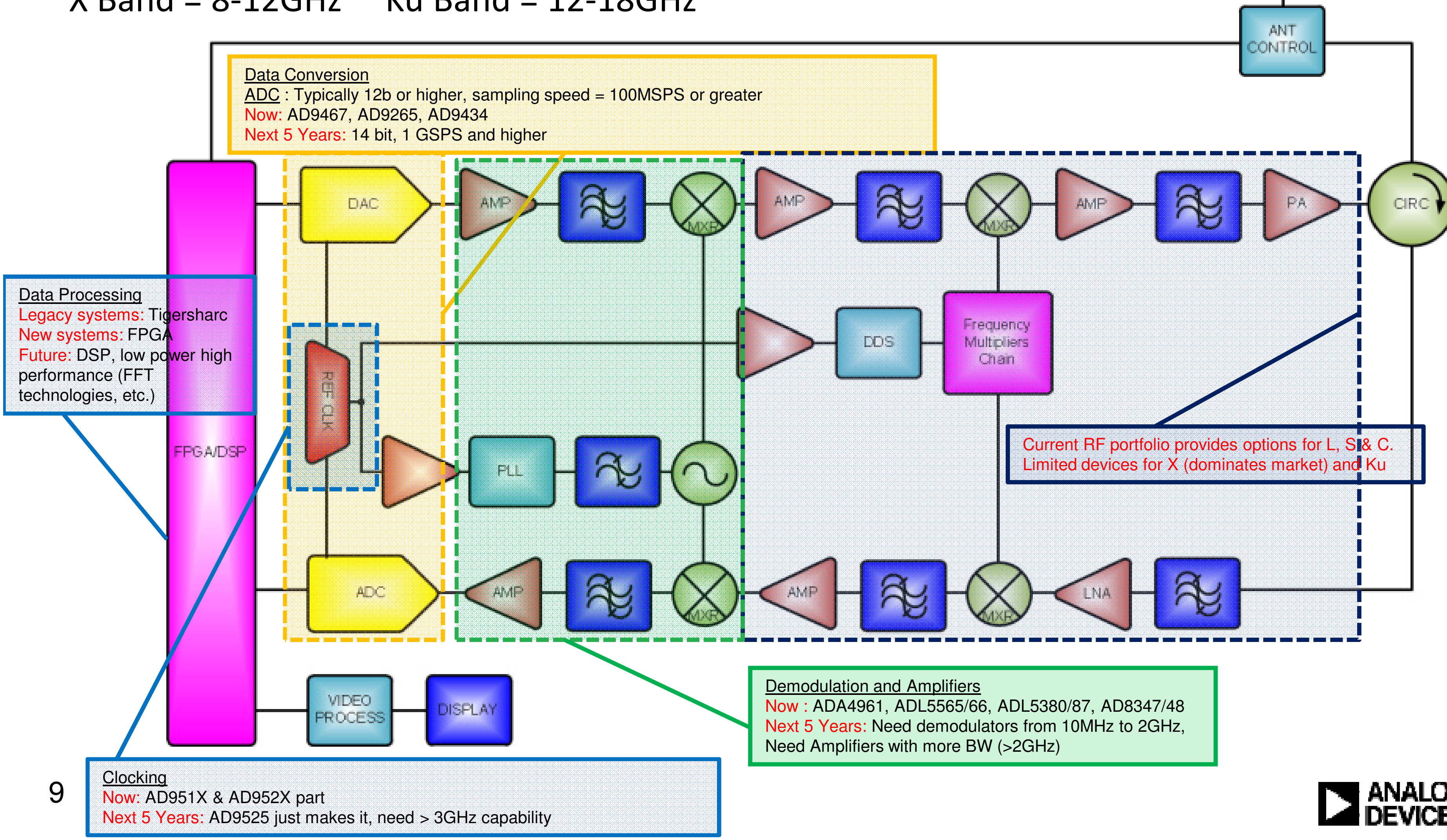
WAVEFORM GENERATION FOR RADAR - CONTINUED

- **Fractional-N Phase Locked Loop (PLL)**
  - **Linear frequency modulated sweep, frequency agile pulse generation similar to DDS**
  - **Can operate in L to X band directly**
  - **e.g. ADF4159 Direct Modulation/Fast Waveform Generating, 13GHz, Fractional-N Frequency Synthesizer**

ARCHITECTURES: CLASSIC DEFENSE RADAR SIGNAL CHAIN COVERS ALL FREQUENCY BANDS OF INTEREST (L, S, C, X & KU)

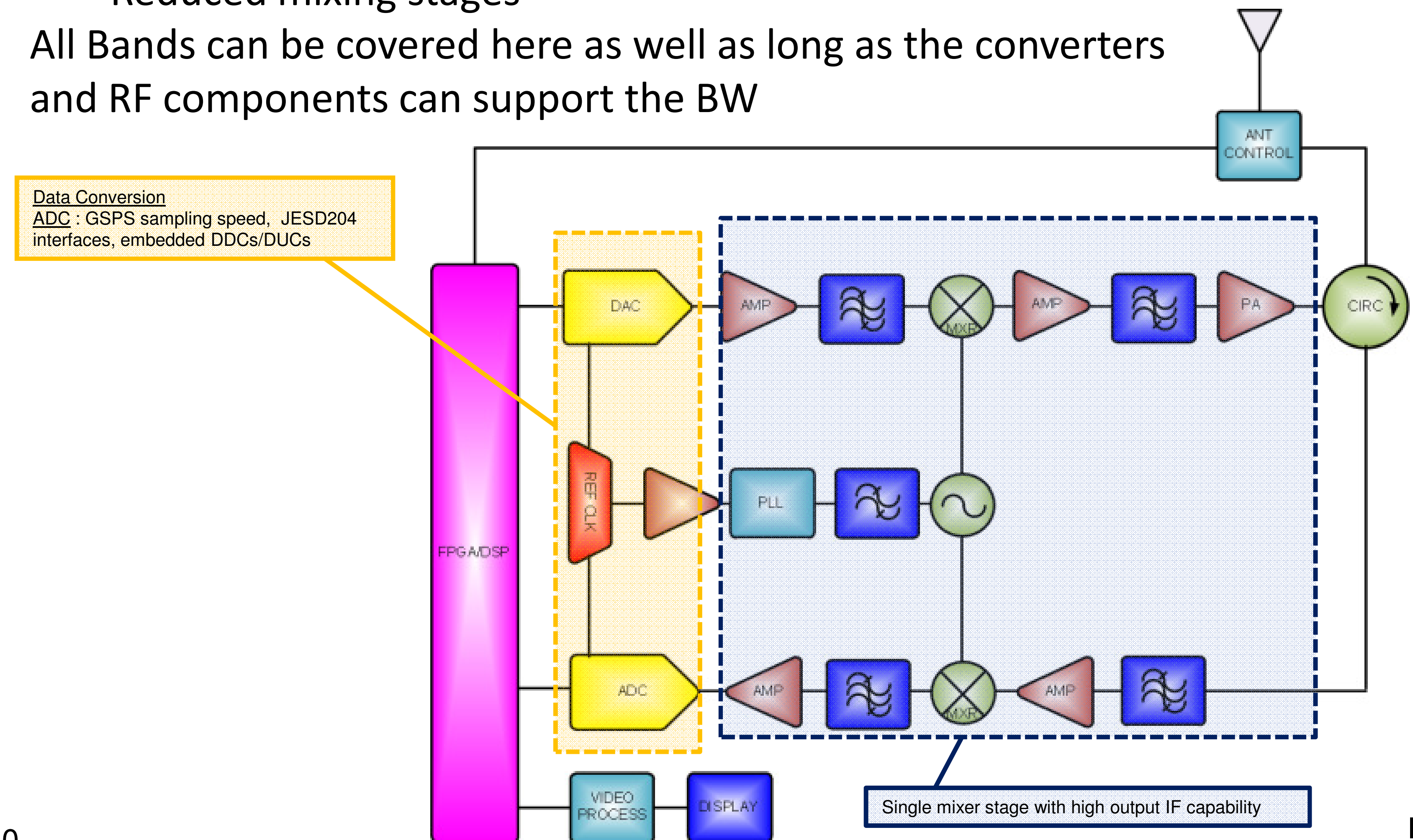
L Band = 1-2GHz S Band = 2-4GHz C Band = 4-8GHz

X Band = 8-12GHz Ku Band = 12-18GHz



FUTURE DEFENSE RADAR SIGNAL CHAIN

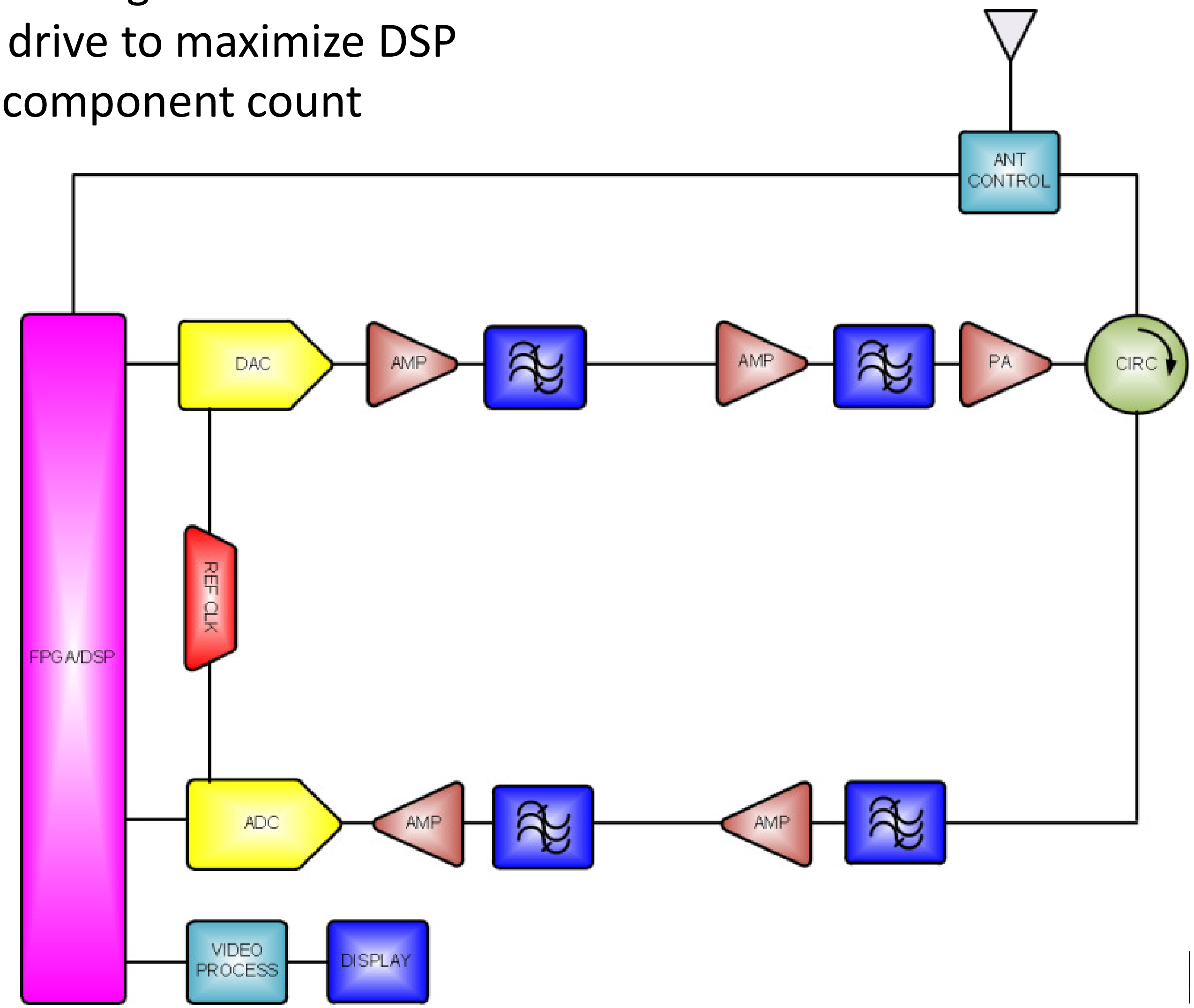
- Reduced component count with increased focus on the DSP
  - Trends to higher converter sampling rates
  - Reduced mixing stages
- All Bands can be covered here as well as long as the converters and RF components can support the BW



ANALOG DEVICES

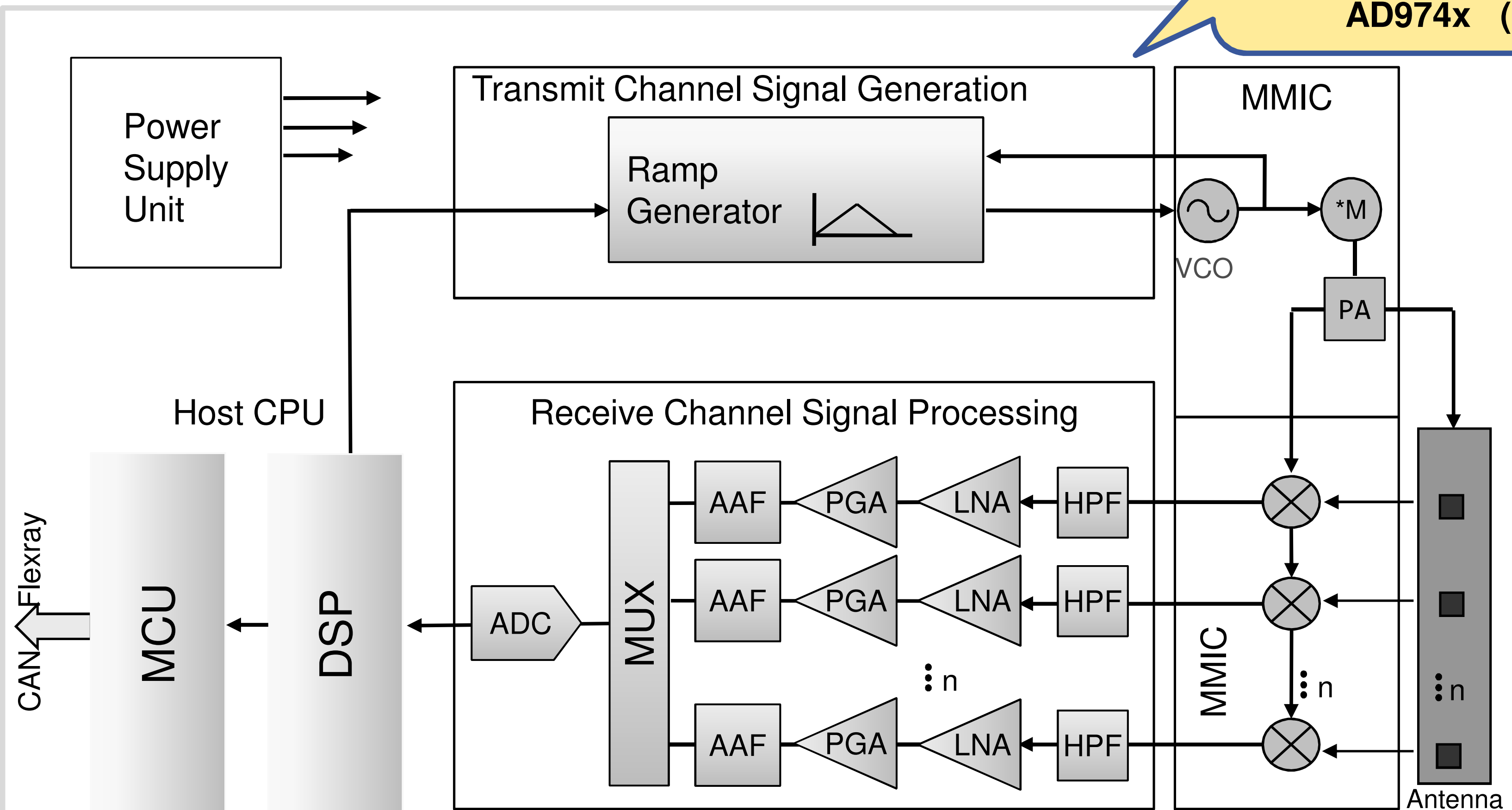
DIRECT RF CONVERSION DEFENSE RADAR SIGNAL CHAIN

- Ideal solution is Direct RF conversion for all bands
  - Limited by analog BW of converters
  - Continues drive to maximize DSP
  - Minimum component count



ANALOG DEVICES

FMCW AUTOMOTIVE RADAR FUNCTION BLOCKS, SAME FOR LSR AND HSR RADAR



PLL: ADF4158 (LSR)
ADF4159 (LSR+HS
DAC: AD56xx (LSR)
AD974x (HSR)

Blackfin or Sharc DSP

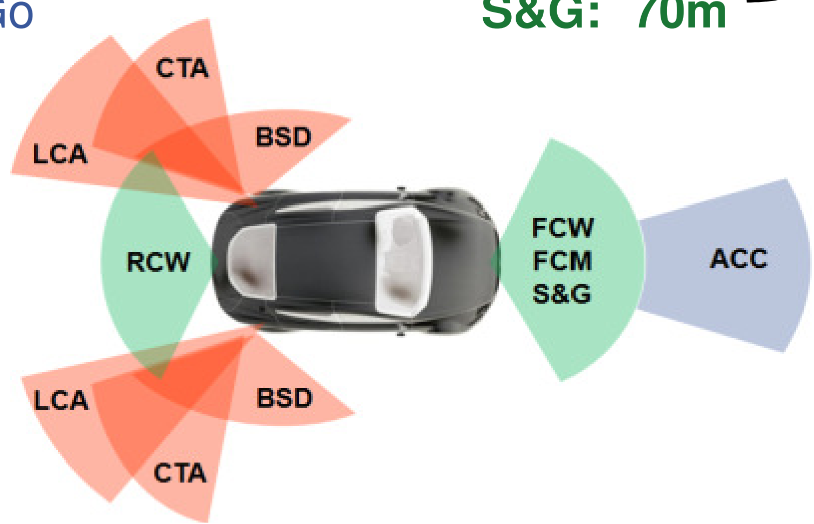
AD828x (HSR) 1MHz-15MHz
AD725x (LSR) 500KHz

ADF590x 24GHz TX/RX

ADAS (ADVANCED DRIVER ASSISTANCE SYSTEMS) RADAR

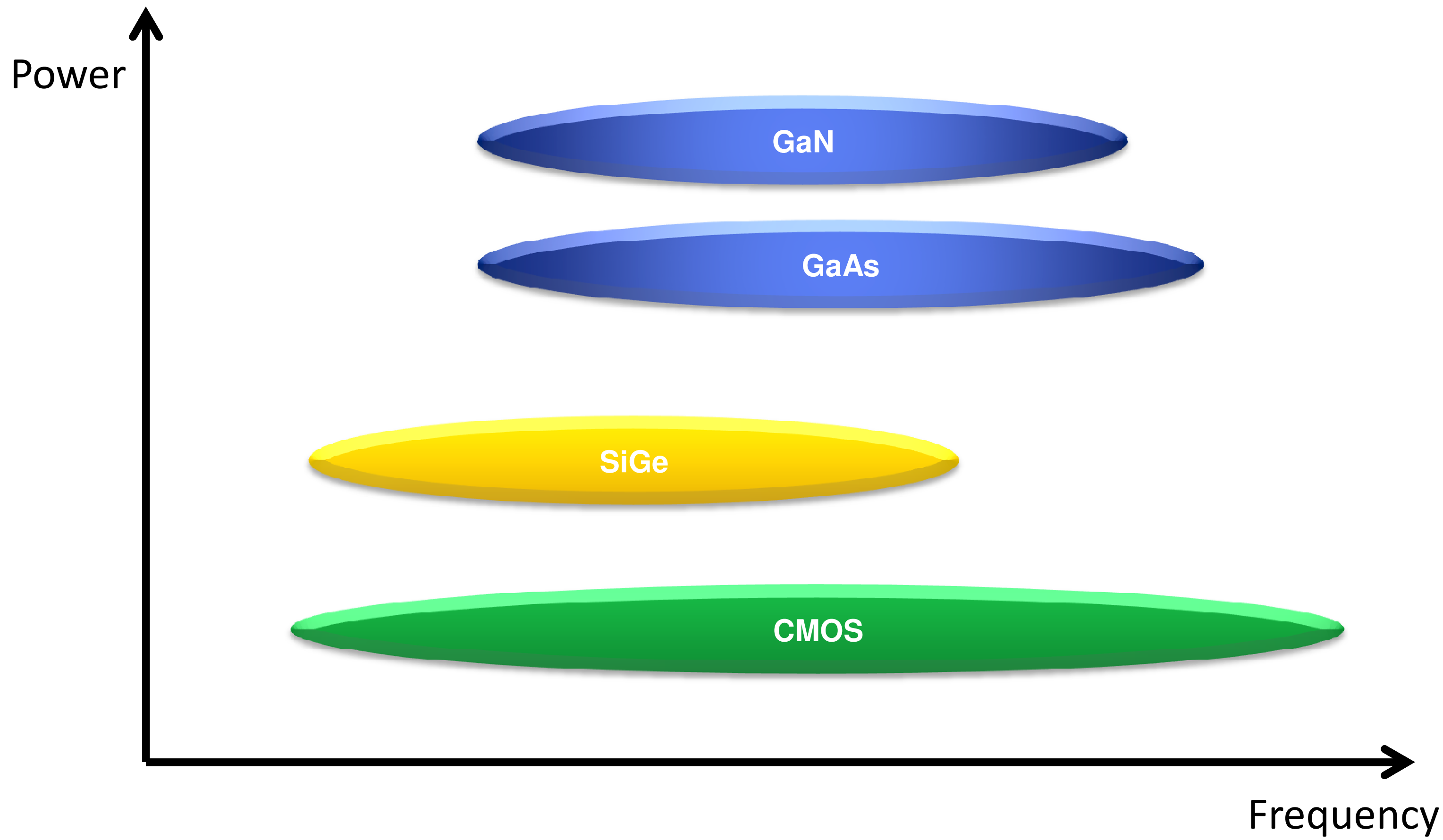
Different Ranges, FOV Fields-of-View, and Purposes

Long Range			
Adaptive Cruise Control	**ACC:**	**150 to 200m**	**FOV: +/-8°**
Short/Medium Range			
Blind Spot Detection	**BSD:**	**10m**	**FOV: +/-75°**
Lane Change Assist	**LCA:**	**70m**	
Cross Traffic Alert	**CTA:**	**30m**	
Forward Collision Warning	**FCW:**	**70m**	**FOV: +/-65°**
Forward Collision Mitigation	**FCM:**	**70m**	
Rear Collision Warning	**RCW:**	**70m**	
Stop & Go	**S&G:**	**70m**	



ANALOG DEVICES

TECHNOLOGY



OUTPUT POWER

Defense

- **+10dBm to +50dBm**

Automotive

- **+10dBm**

POWER MANAGEMENT REQUIREMENTS

Defense

- Low Power Consumption
- Power Consumption High
- Phased Array Solutions Similar to Automotive Solutions

Automotive

- Low Power Consumption Required
  - Operates in Enclosed Module

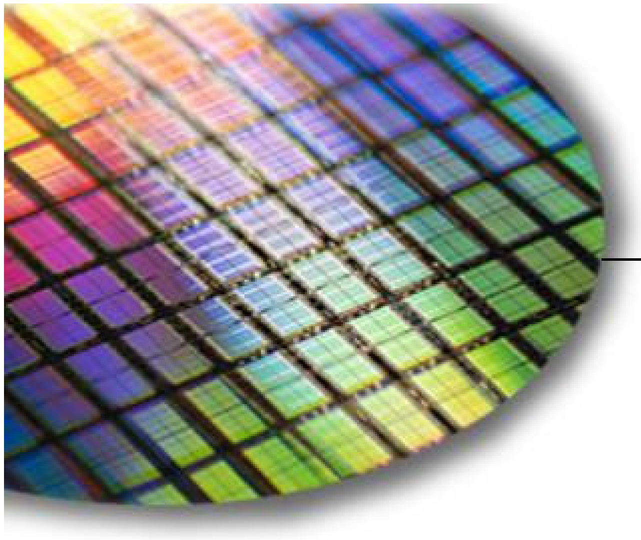
PHASE NOISE REQUIREMENT

Defence

- Range from Medium to High Performance

Automotive

- Medium



The World Leader in High Performance Signal Processing Solutions

APPENDIX

ANALOG DEVICES

DEFENSE RADAR EXAMPLES

Airborne Multi-Mode Fire Control

Airborne Air and Ground Surveillance

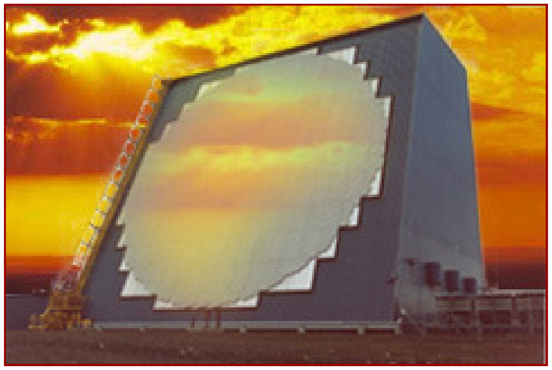
Air Surveillance Radar Sets (ASR)

Surface Movement Radar (SMR)

Radars Range from the Very Large …

AN/FPS-85

AN/FPS 108 Cobra Dane



Ballistic Missile Defense Radars

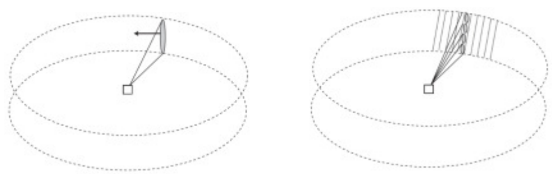
PAVE PAWS

Arecibo (Puerto Rico) 305 m radio astronomy dish

AUTOMOTIVE RADAR EXAMPLES

Military Applications: Search & Track

2D and 3D Search



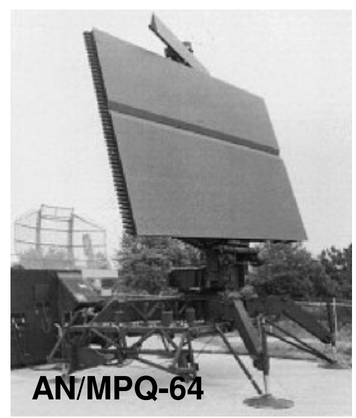
- **2D: AN/SPS-49 Shipboard**
  - Frigates, AEGIS cruisers

- **3D: AN/SPS-48 Shipboard**
  - AEGIS predecessor
  - Aircraft carriers, amphibious assault ships

3D Air Defense

- **AN/TPS-75 Air Defense**

- **AN/MPQ-64 Sentinel Air Defense**

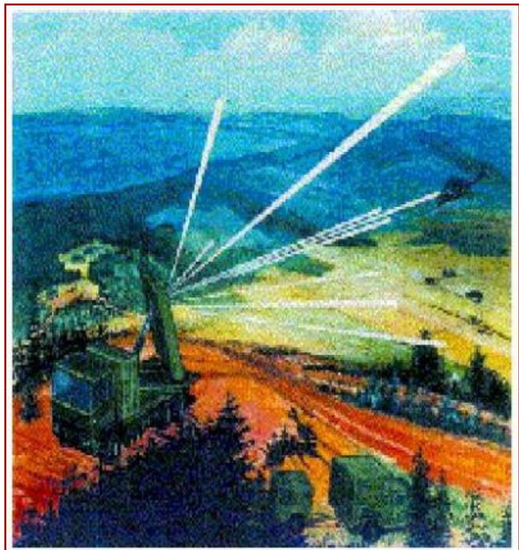


Images from *Principles of Modern Radar: Basic Principles*, SciTech Publishing, 2010

Military Applications: Search & Track

Weapons Locating Radar

- AN/TPQ-36, -37



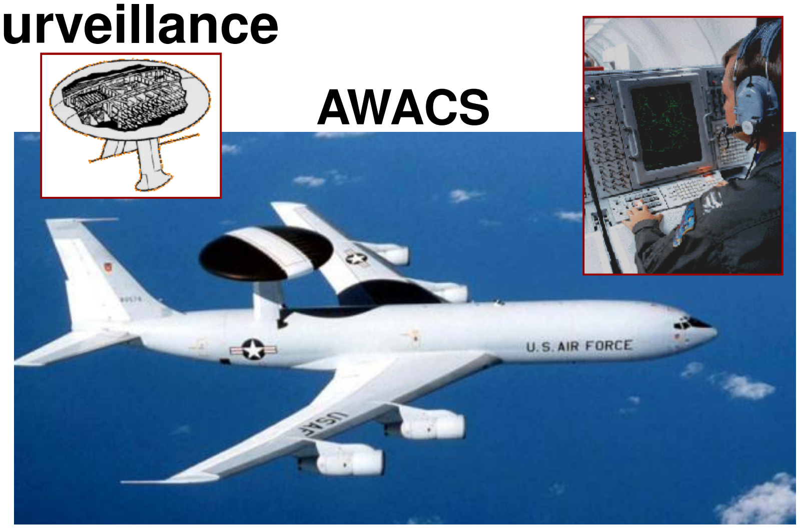
Shipborne Air and Missile Defense

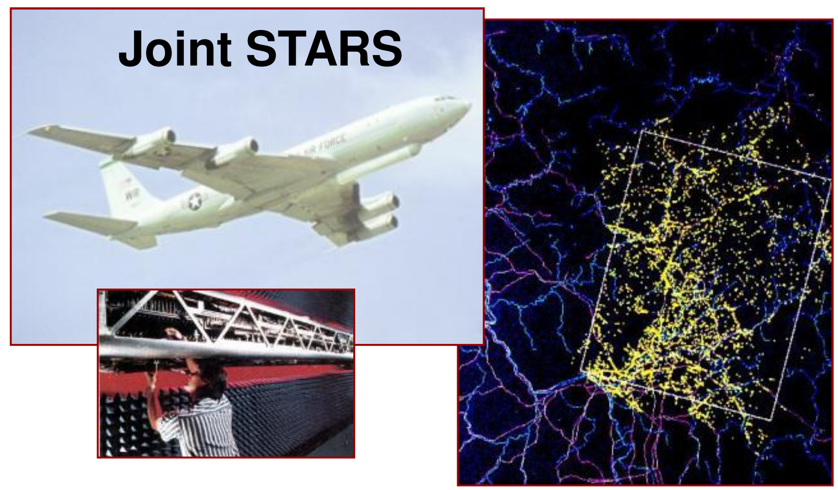
- AN/SPY-1

Military Applications: Search & Track

- Airborne Multi-Mode Fire Control

- Airborne air and ground surveillance



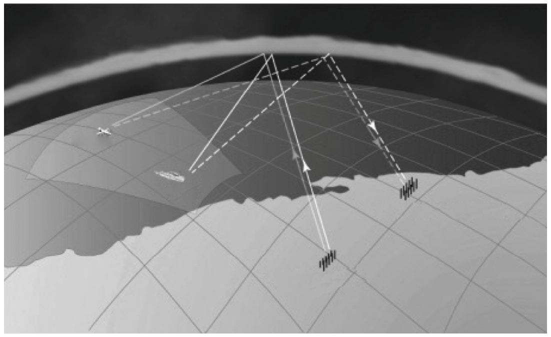


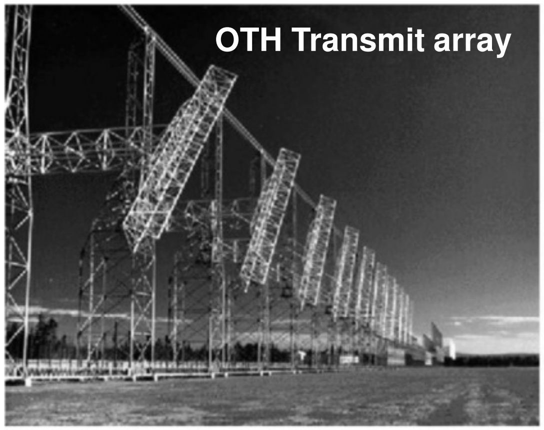
ANALOG DEVICES

Military Applications: Search & Track

Over-the-Horizon Radar

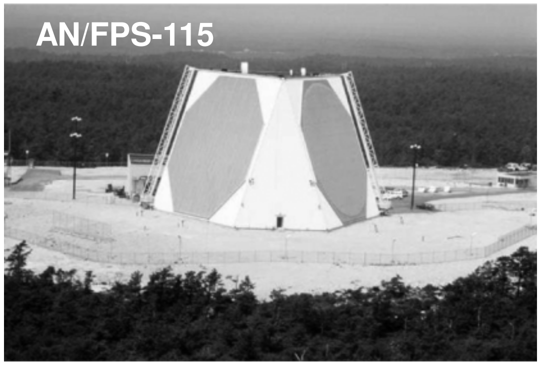
- HF (3 – 30 MHz)
- Utilizes ionospheric reflection





Ballistic Missile Defense

- AN/FPS-115 ("PAVE PAWS")



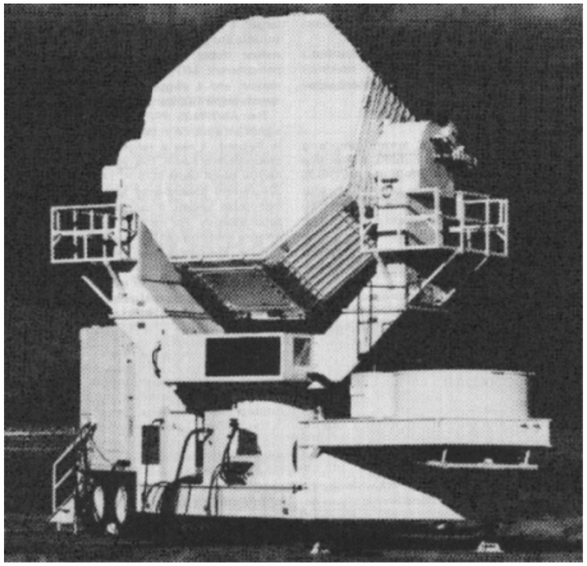
- AN/TPY-2 Theater High Altitude Air Defense Radar

Some images from *Principles of Modern Radar: Basic Principles*, SciTech Publishing, 2010

Other Military Applications

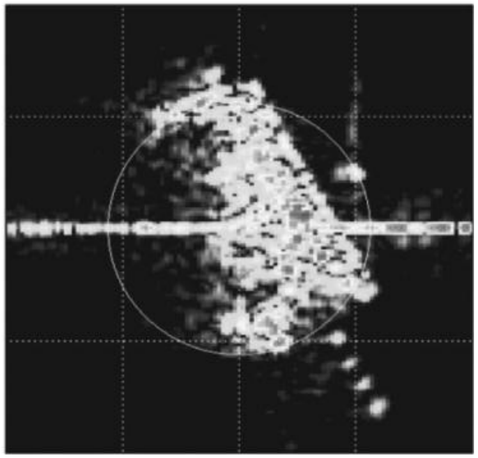
Instrumentation and Range Radars

- AN/MPQ-39 (MOTR)



Turntable Inverse SAR Imaging

- GTRI ISAR range



- *And, of course, imaging ….*

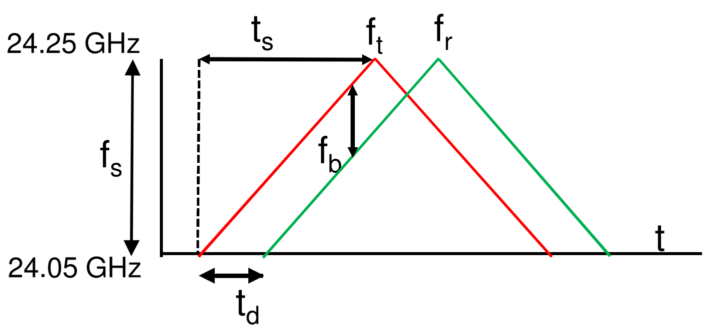
ANALOG DEVICES

Automotive Radar Frequencies

24GHz NB	24GHz UWB	26GHz UWB	77GHz	79GHz UWB
Worldwide	US/Canada Japan EU until 2013/ will be extended to 2022 but with reduced bandwidth	US/Canada Japan	"Worldwide"	Singapore EU
different bandwidth EU: 200MHz (75cm) [450MHz] (33cm) US: 200MHz (75cm) JP: 200MHz (75cm)	US: 7GHz (2.2cm) JP+EU: 5GHz (3cm)	US: 1 GHz (15cm) JP: July 2010 5 GHz (3cm)	1 GHz (15cm) JP: 500MHz (30cm)	4 GHz (4cm)
20dBm	**-41dBm**	**-41dBm**	**23.5dBm**	**-9dBm**

ANALOG DEVICES

FMCW - Frequency Modulated Continuous Wave Radar Principle (simplified, static condition)



(1) $t_d = 2*D/c$ → 1us at 150m

(2) $D = c*t_s*f_b/(f_s*2)$

(3) $BW = f_s*t_{dmax}/t_s$

(4) $BW = f_s*2*D_{max}/(c*t_s)$

f_t:	Transmit Frequency
f_r:	Receive Frequency
D:	Distance
t_d:	Time of flight for D
f_b:	Beat Frequency
f_s:	Sweep Frequency
t_s:	Sweep Time
C:	Light Speed Constant
BW:	Max AFE Bandwidth

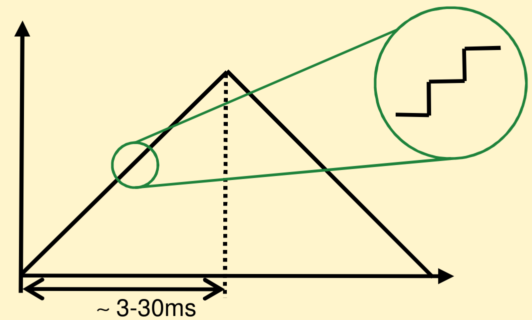
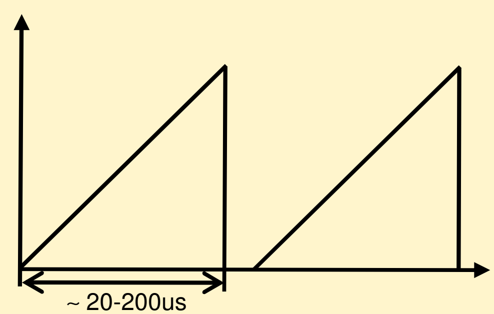
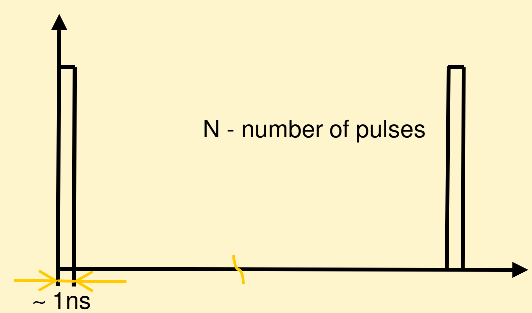
Example:

f_s = 200MHz

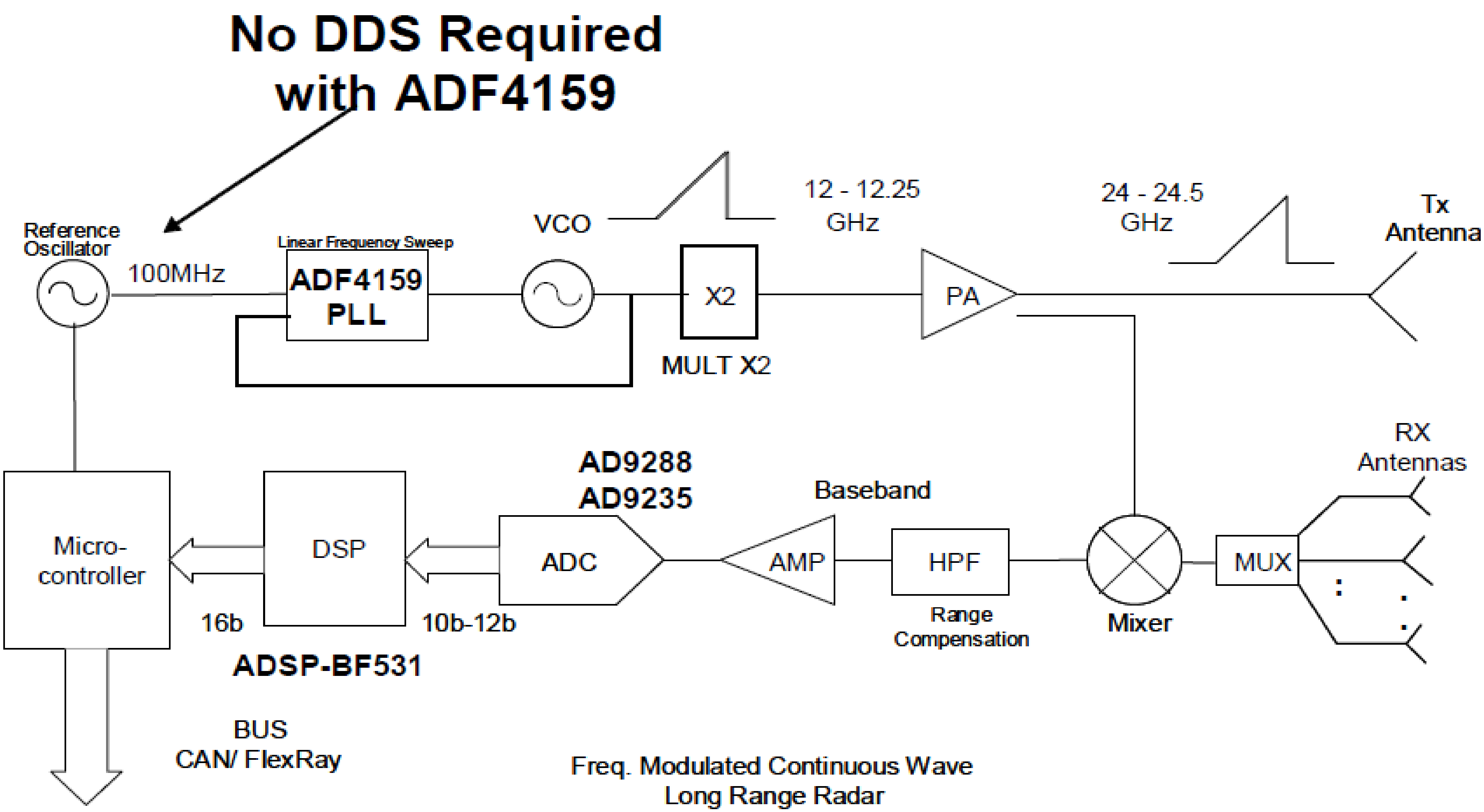
t_s = 2ms

t_{dmax} = 150m → Bandwidth BW=100KHz

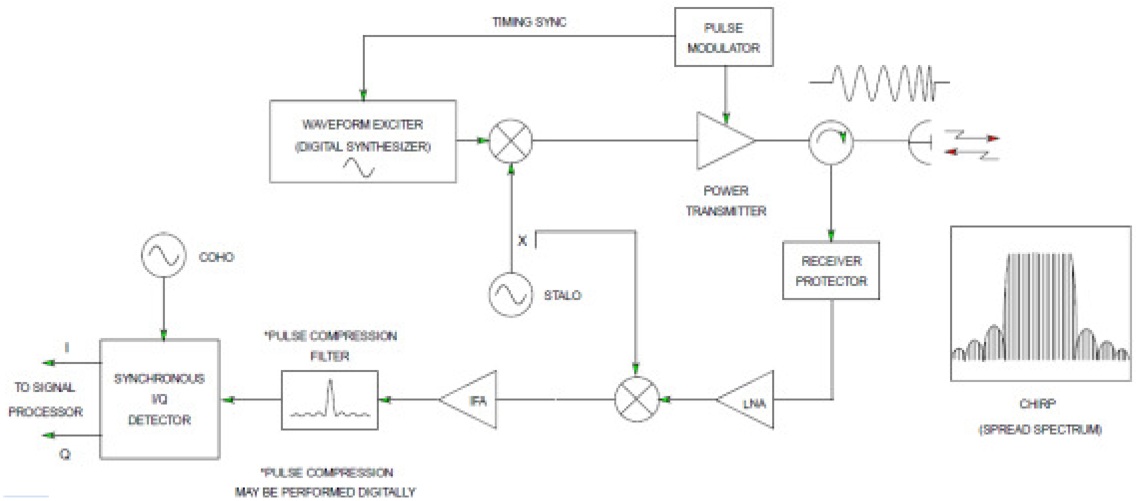
RADAR TECHNIQUES IN AUTOMOTIVE

Automotive Radar		
FMCW		Pulse Doppler Radar
LSR-Low Speed Ramp → Low Bandwidth AFE	HSR-High Speed Ramp → High Bandwidth AFE	Pulse Train
		
Doppler Frequency is usually determined through variable slopes and/or FSK modulation. or CW sections	Increasing slope+ bandwidth makes Doppler Frequency negligibly, Velocity is measured by distance over time.	Velocity and distance are measure instantaneously.
Baseband Frequency Range		
40KHz to 500KHz	1 MHz to 15MHz	Very different baseband processing concept

ADF4159 in FMCW RADAR



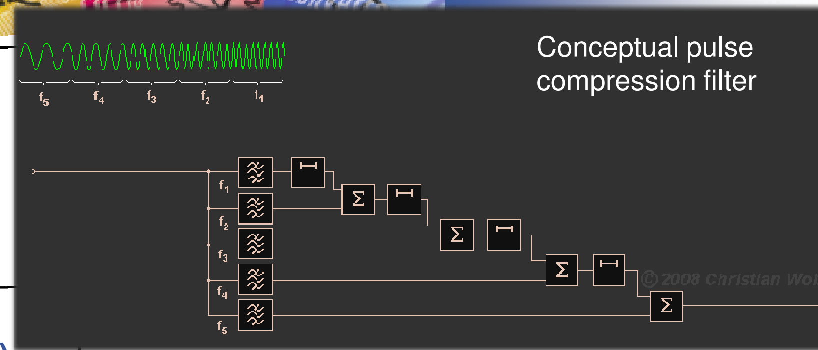
Pulse Compression Radar



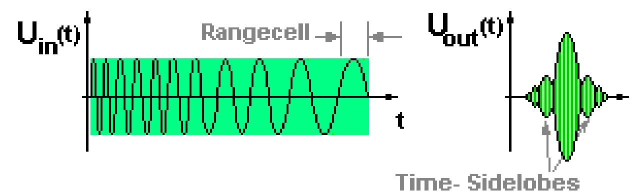
- **Radar Design is always a compromise ....**
  - **Unambiguous range measurements require a low PRF and long pulse BUT range resolution requires a short pulse**
  - **Unambiguous velocity (doppler) measurement requires a medium to high PRF BUT this will result in ambiguous range measurements**
  - **Short pulses increase bandwidth requirements in an already crowded spectrum**
  - **Short pulses also increase peak power requirements from the transmitter and invariably lead to range restrictions**

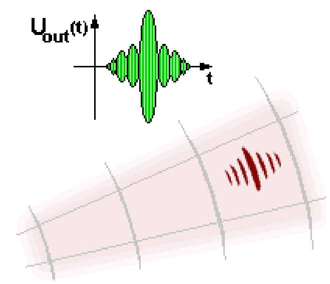
- **Pulse compression can overcome some of these compromises at the expense of processing complexity**
  - **Detection range capability of a low PRF uncoded system**
  - **Maintains or even exceeding the range resolution of a narrow uncoded pulse**
  - **Using longer pulses limits required peak power but without sacrificing range resolution**
  - **The average power of the transmitter can be improved without increasing PRF and compromising unambiguous range**
  - **Less vulnerable to interfering signals that differ from the coded transmitted signal**

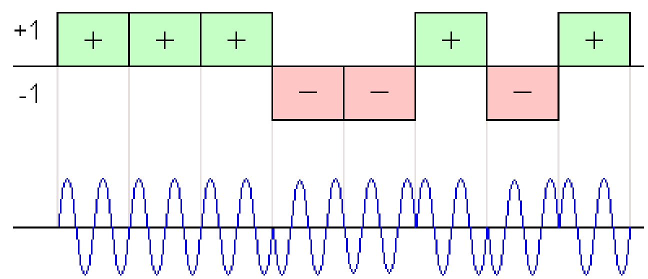
Pulse Compression Radar



- **Pulse Compression Ratio (PCR)**
  - Defined as the product of the modulation bandwidth (B) and the uncompressed pulse width (T)
  - PCR of several 100 is typical
- **Effective transmitted power is PCR x Transmitted Power (note : this is after processing in the receiver)**
- **Typical Modulation Techniques …..**
- **Linear Frequency Modulation (or chirp)**
  - The frequency is swept over the duration of the pulse
  - The matched pulse compression filter in the receiver introduces side lopes that cause range errors but can be minimised by applying a weighted filter at expense of detected pulse amplitude and increased bandwidth
- **Phase coded waveforms**
  - A long pulse is subdivided into a number of shorter pulses, each is transmitted with a particular phase
  - It is common to use binary coding, typically a Barker code length of 13
  - Compression ratio not as good





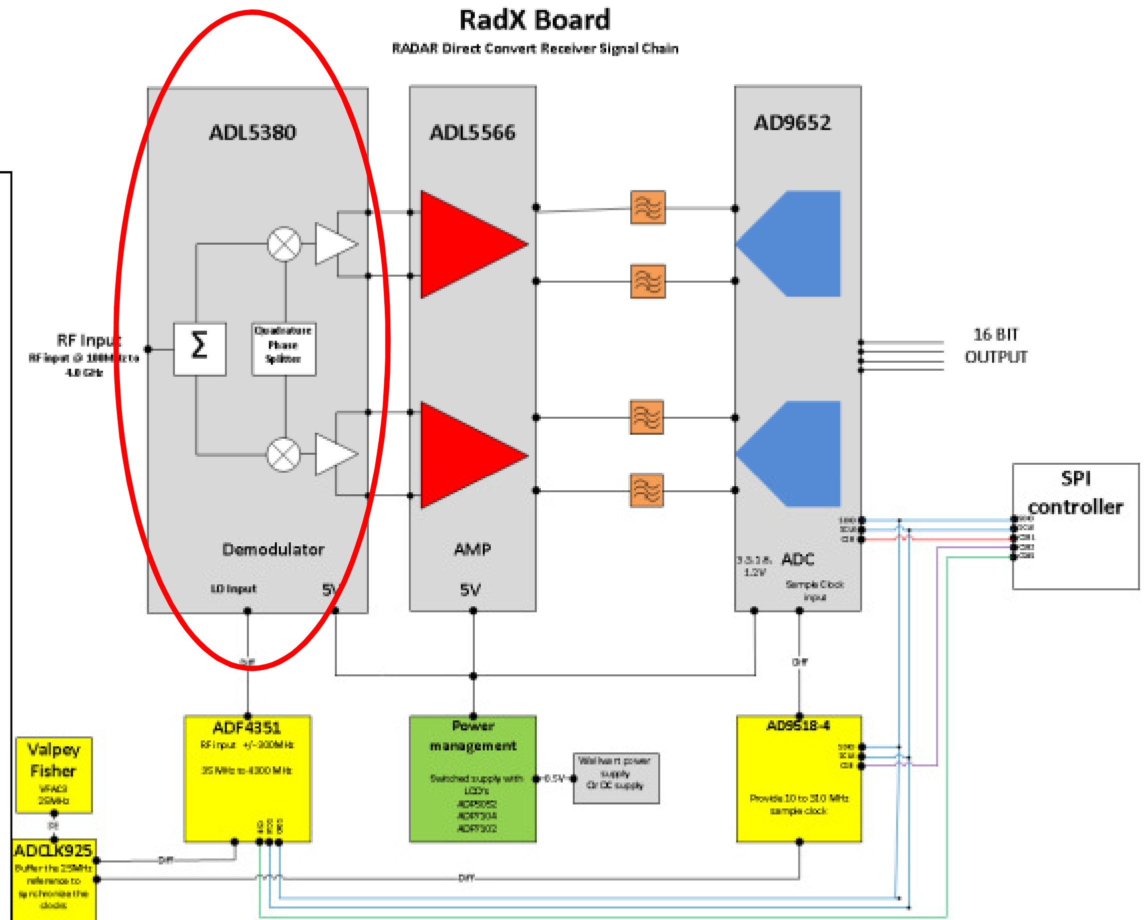


Benefits of Phased Array Radars

- Phased array radars can, in a single antenna, do the jobs of several purpose built antennas – example: track while hold
- There is no longer the need to mechanically point the antenna in the direction of the target
- Phased arrays can rapidly scan a small sector of sky to increase the likelihood of detecting a small and fleeting target over traditional rotating types
- Phased array's have the ability to almost instantaneously change beam direction and shape adding a new dimension to tracking
- Phased arrays allow the system to place a "null", an area of zero receiver sensitivity, over a jammer
- Cons – only scan 120deg, need 3 for 360deg so cost goes up

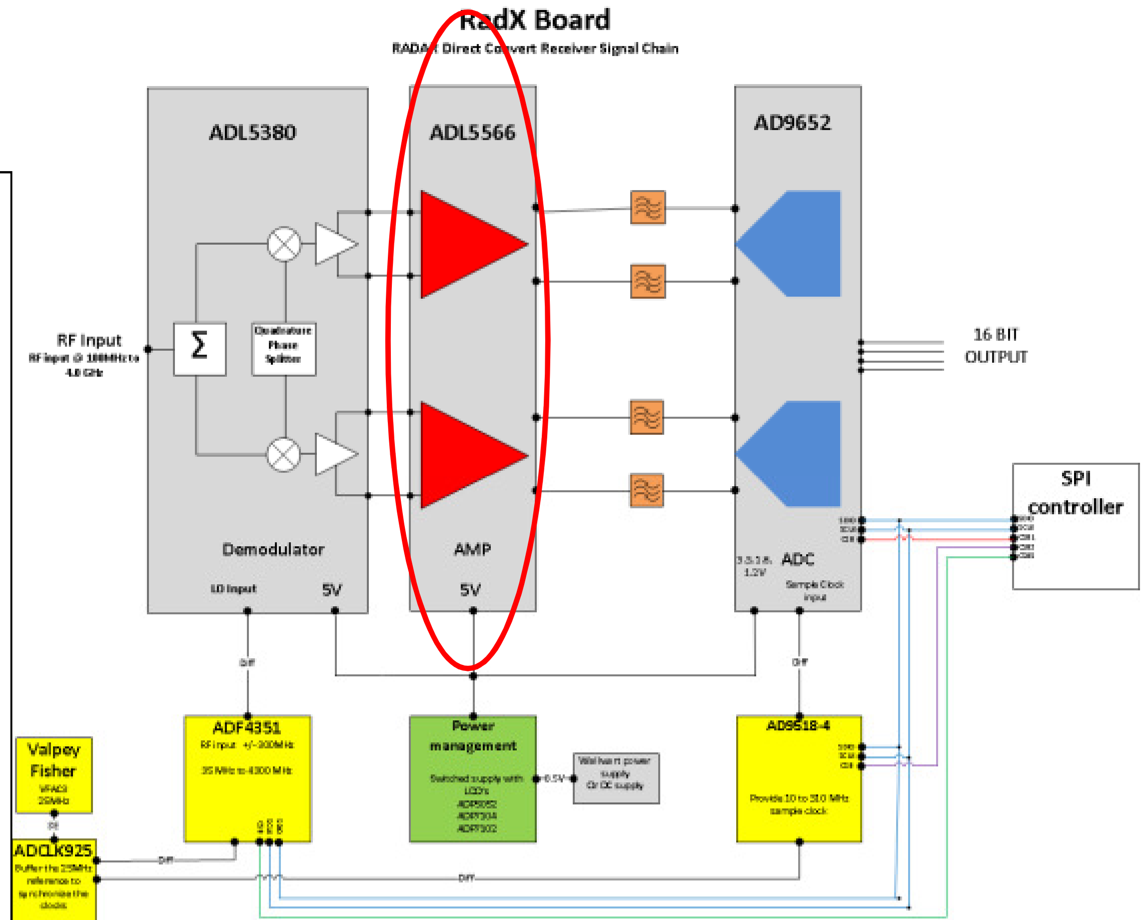
6GHz Quadrature Demodulator

- **Pros**
  - **Direct Conversion**
    - Up to 6GHz RF converted to IF in single stage
    - Very Linear
  - **Proven performance**
    - Used in other platforms
    - Low NF
    - Perfect for Radar
  - **Ease of use**
    - Single 5v supply
    - Dual Channel
  - **Showcase many of ADI's newest and top performing RF components**
- **Cons**
  - **Output Impedance.**
    - 450Ω Baseband output Impedance
  - **RF Input PCB loss**
    - PCB bandwidth may be less than desired RF input frequency.
    - PCB layout



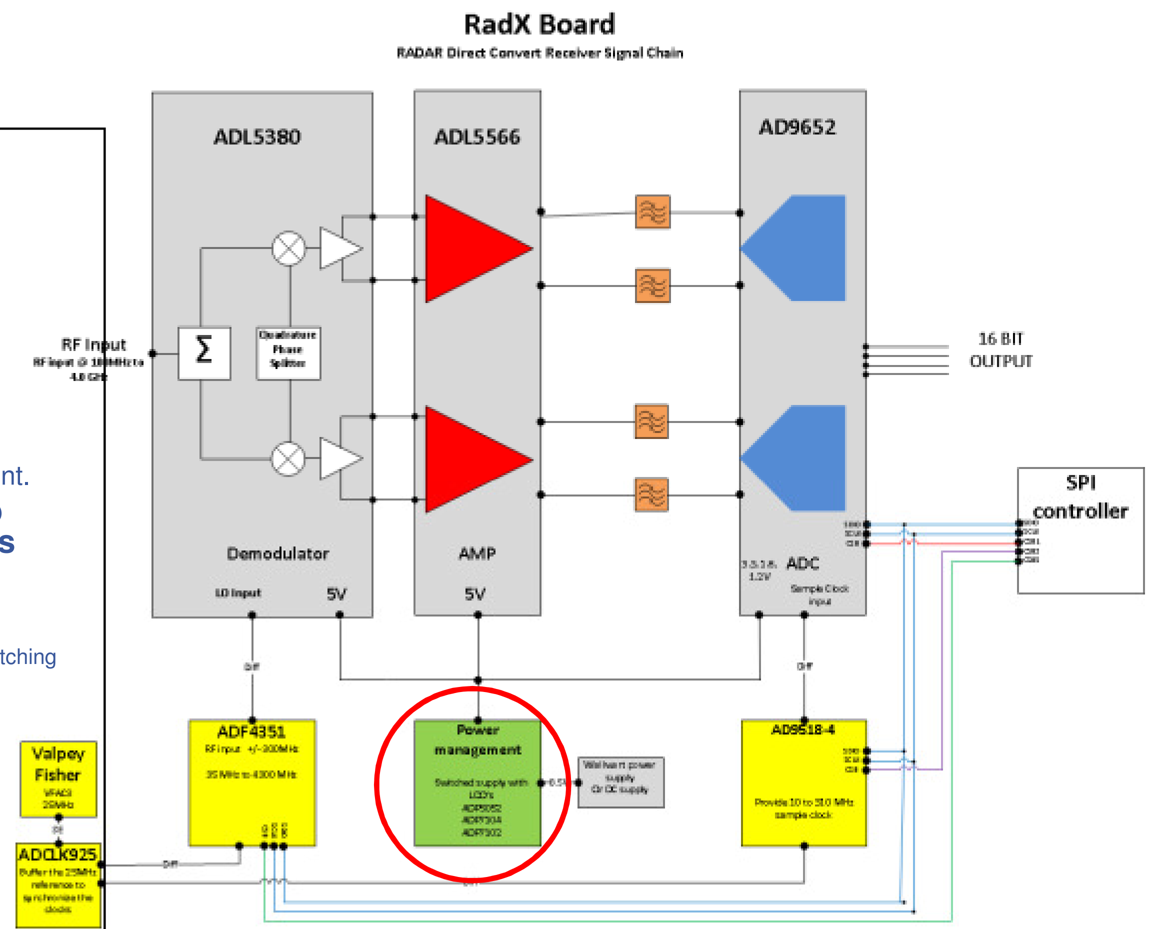
4.5GHz Dual Differential Amplifier

- **Pros**
  - **High Performance**
    - Up to 4.5GHz RF input
    - Very Linear
    - Low NF
    - Up to 16dB gain
  - **Proven performance**
    - Used in other platforms
    - Perfect for Radar
  - **Ease of use**
    - Single 5v supply
    - Dual Channel
  - **Showcase many of ADI’s newest and top performing RF components**
- **Cons**
  - **Input/Output Impedance.**
    - 200Ω output Impedance
    - 150Ω input Impedance



On-Board Power Management

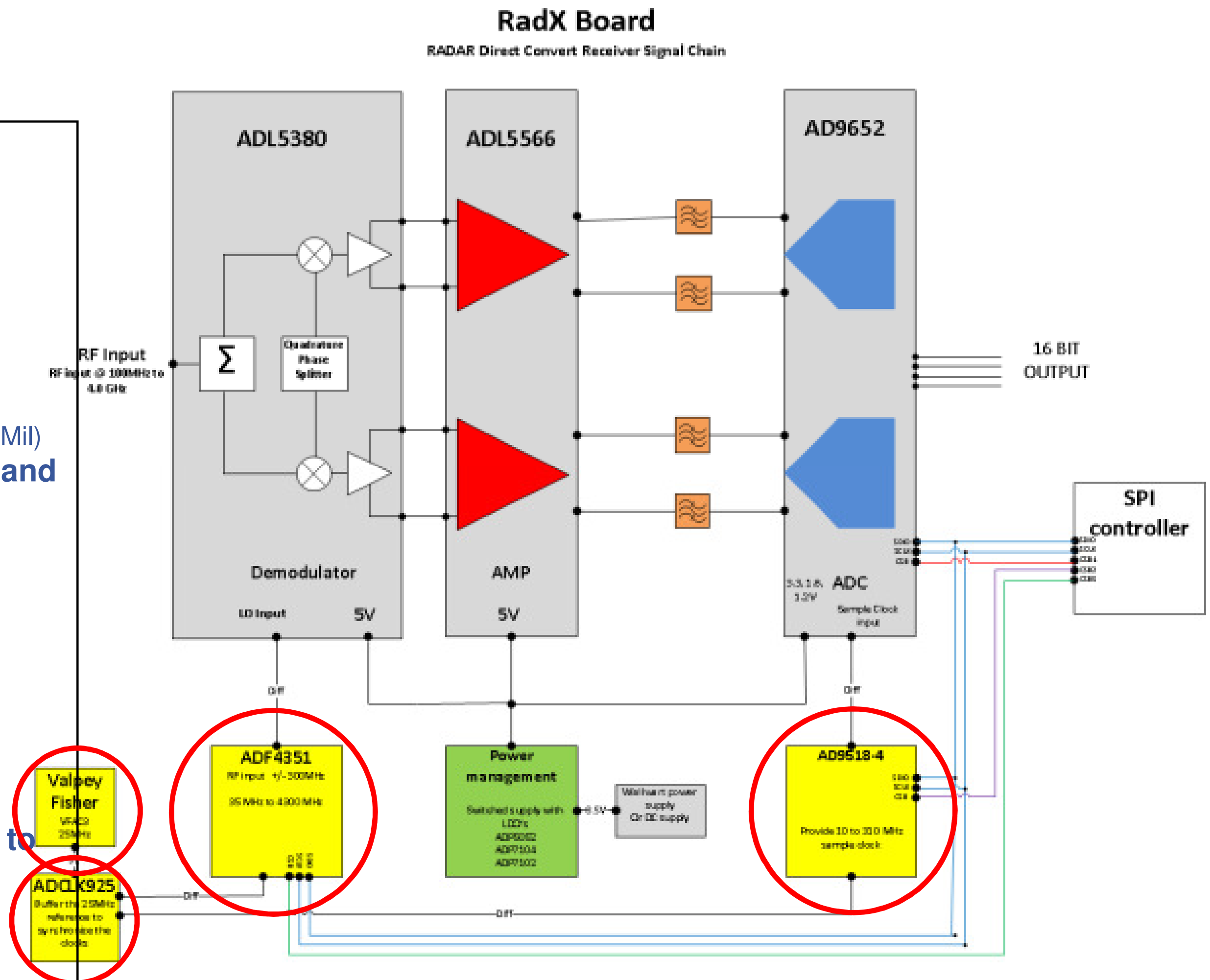
- **Pros**
  - **Integrates all power needs**
    - No DC supply
    - No special cables
  - **Ease of use**
    - Customer evaluation
    - Trade Show Demo
    - Wall-wart
  - **Measurement Repeatability**
    - No concern with customer supply voltage or current.
  - **Showcase many of ADI's newest and top performing power management platforms**
- **Cons**
  - **Switchers are not always well received.**
    - Old school RADAR system designers are reluctant to use switching supplies. (unmerited with our technology)
  - **PSRR may be a problem.**
    - Needs to be measured (build it first)
  - **Power consumption**
    - LDO's by definition will burn some current
  - **Board size will be larger**



On-Board LO/Clock

- **Pros**
  - **Integrates ADC's sample clock**
  - **Integrates Demod LO**
  - **Ease of use**
    - Customer evaluation
    - Trade Show Demo
  - **Tune-ability**
    - Mil/aero and commercial platform
    - No need to know customers exact freq (Mil)
  - **Showcase many of ADI's newest and top performing platforms**

- **Cons**
  - **Jitter/Phase noise will be worse**
    - 0.3pS for ADF4351
    - -120dBc/Hz @ 1kHz for Crystek Osc
  - **Complex SPI controller interface**
  - **Power consumption**
  - **Board size will be larger**
  - **Must sync the LO and ADC clock to avoid smearing.**



ANALOG DEVICES