

# The Future of Software Radio

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# Overview

- Where are we going in radio design?
  - Applications
  - Requirements
- What are the challenges to get there?
  - Hardware
  - Software
  - Systems



# What are some “Killer Apps” ?

## ➤ Military Requirement

- Full Connectivity
- Sensor Networks
- Better Performance

} Collaborative Radio

## ➤ Commercial

- Lower Cost – subscriber units
- Lower Cost – base unit
- Lower Cost – network

## ➤ Regulatory

- Stretch expensive spectrum
- Build in innovation mechanisms

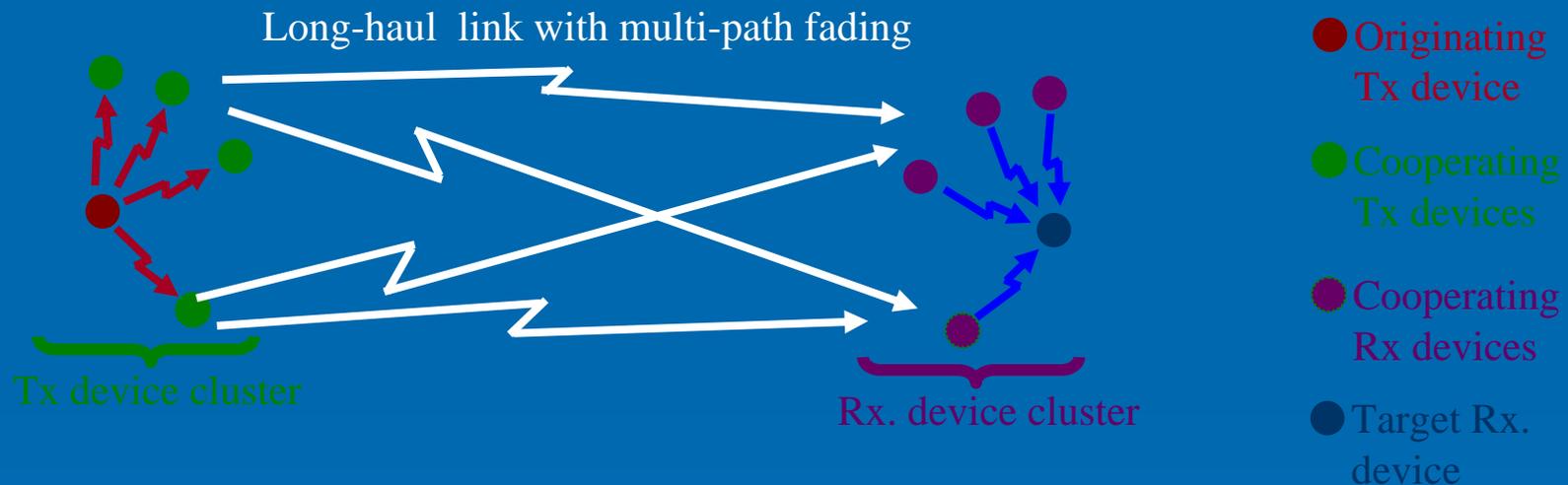
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Tech

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# Example Military Application: Collaborative Radios



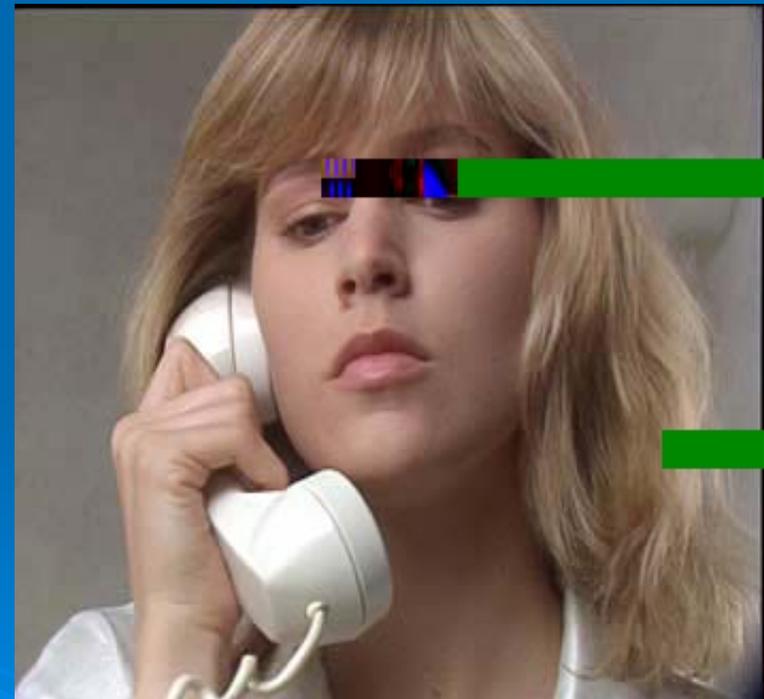
- Example: Sensor systems with UAVs to extend range, reliability, and throughput

# Military Applications: Cross-Layer Optimization

- Example: Optimize the MAC for the Application and Channel
- Error Protection for the Control Bits in MPEG



Matched



Not Matched

(High probability of failure)

# Example Commercial Applications

- LAN and WAN: 802.11a, 802.11b, 802.11g, 802.11n, , 802.16a, 802.16-2004, 802.20?,
- PAN: 802.15.4, 802.15.4a
- 1G: AMPS
- 2G: GSM, IS-95, IS-136?
- 2.5G: EDGE, GRPS
- 3G: WCDMA, IS-95, CDMA2000, EVDO, EVDV, HSPDA, TD-SCDMA

# Commercial Economic Drivers

- Reduce silicon costs: likely soon to be an advantage
- Reduce inventory
- Rapid time to market
- Outsourcing
- Network tweaks
- New applications
- RF compensation and enhancement (smart antennas)
- Product differentiation

# Regulatory Applications

- Applications go beyond waveform development
- Advanced functionality generally associated with application layer
  - Spectrum management
  - Cognitive radio is the key
- Significant research opportunities exist in the development of these applications

# Spectrum Allocation 3 kHz to 300 GHz

## ➤ Unallocated Spectrum

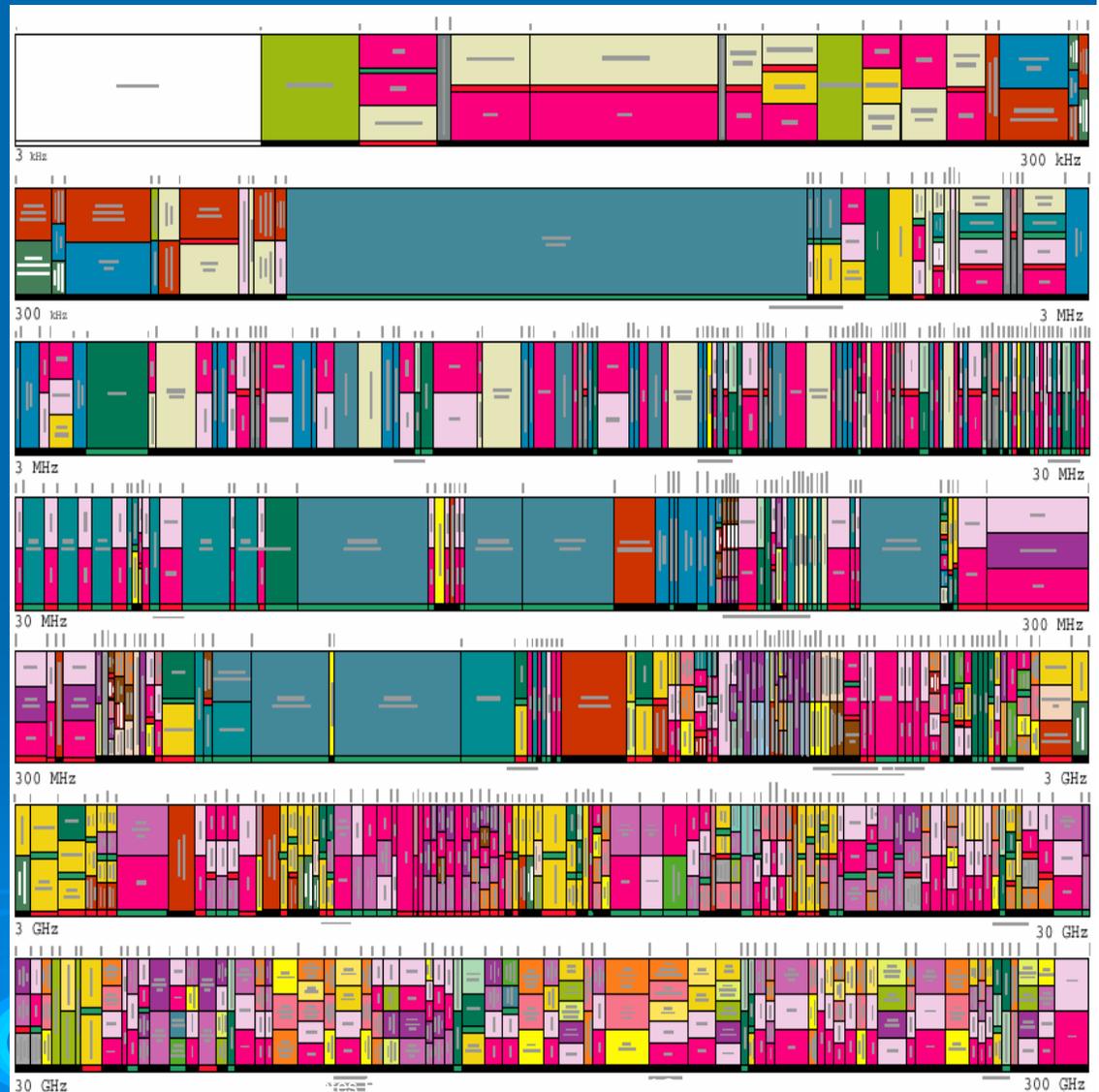
- 3-9 kHz

## ➤ ISM Bands

- $6.78 \pm 0.015$  MHz
- $13.560 \pm 0.007$  MHz
- $27.12 \pm 0.163$  MHz
- $40.68 \pm 0.02$  MHz
- $815 \pm 13$  MHz
- $2450 \pm 50$  MHz
- $5.8 \pm 0.075$  GHz
- $24.125 \pm 0.125$  GHz
- $61.25 \pm 0.250$  GHz
- $122.5 \pm 0.500$  GHz
- $245 \pm 1$  GHz

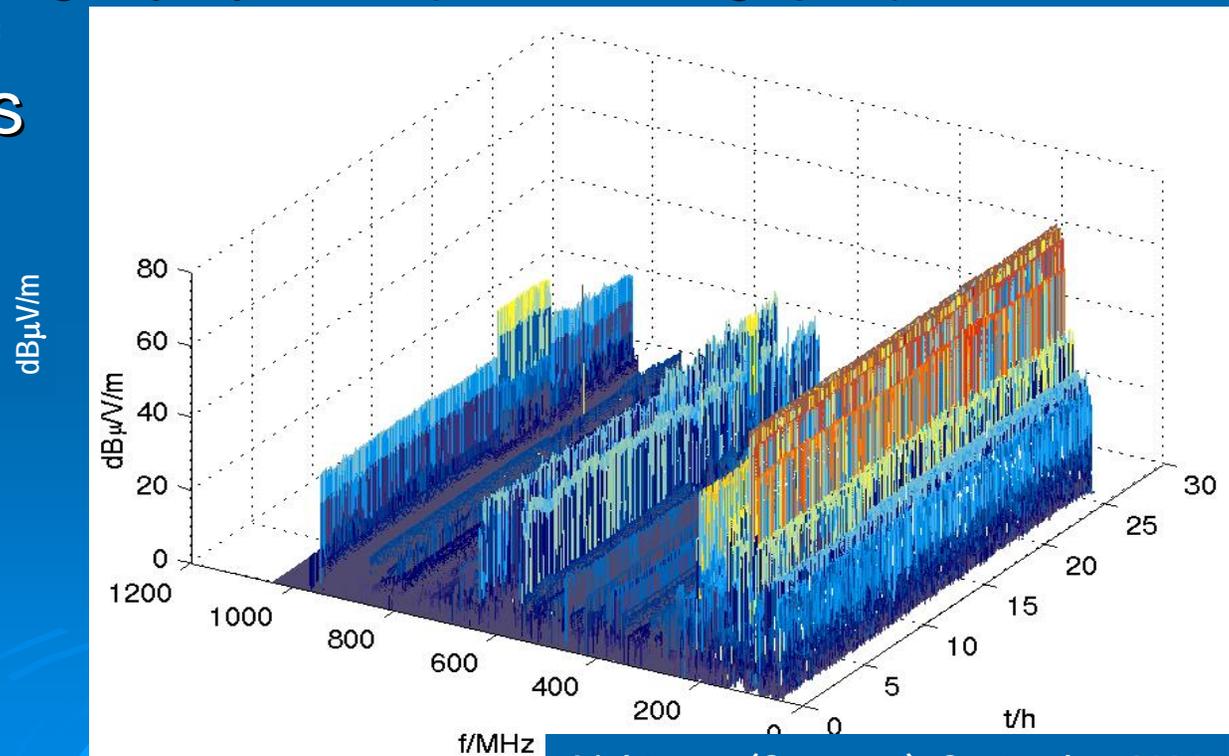
## ➤ Unlicensed

- 1910-1930 PCS
- 59-64 GHz unlicensed



# Spectrum Utilization

- However, spectrum utilization is quite low.
- Concept:
  - Have radios (or networks) identify spectrum opportunities at run-time
  - Transparently (to legacy systems) fill in the gaps (time, frequency, space)
- Considered Bands
  - ISM
  - Public Safety
  - TV (UHF)



From F. Jondral, "SPECTRUM POOLING - An Efficient Strategy for Radio Resource Sharing," Blacksburg (VA), June 8, 2004.

Lichtenau (Germany), September 2001

# Cognitive Radio

- A radio that is aware of “meaning” behind radio parameters
  - Capable of determining the relative effect that each parameter will have
    - FEC, modulation, bandwidth
- Cognitive radio provides a framework for a device to evaluate tradeoffs in the creation of dynamically-created links.
- Fundamental to these processes:
  - Ability to sense environment
  - Evaluate options
  - Implement chosen waveform



# Interest in Cognitive Radio

## ➤ FCC

- Workshop on Cognitive Radio May 19, 2003
- NPRM December 30, 2003  
Explores use of cognitive radio for dynamic spectrum allocation

## ➤ IEEE USA

- Issued statement saying that cognitive radio is a promising implementation approach to spectrum filling.

## ➤ xG program

- Military's attempt to integrate dynamic spectrum allocation into networks

## ➤ Research Issues

- How to implement cognitive radios
- Assuring performance
- Radio etiquette
- Analyzing interactive adaptations (game theory)

# Technology Challenges

- Technology in SDR partitioned into three basic pieces
  - Hardware
    - Physical devices on which processing is performed or interface to “real world”
  - Software
    - Glue holding together system
  - Network
    - Functionality and ultimate value to the end-user
- Advances needed in all three arenas

# Hardware

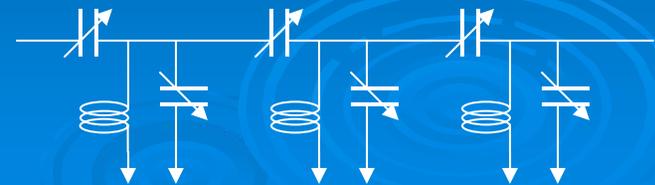
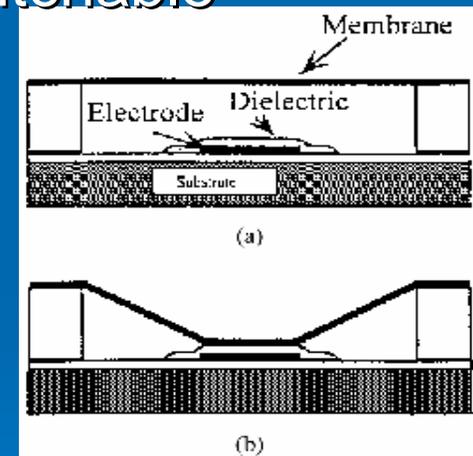
- Significant effort to date in computing HW
  - Non-traditional computing platforms
  - Advanced DSP designs
- Emphasis on computing HW alone can be myopic
  - Other critical areas that require significant further work
    - Flexible (or software controlled) RF
    - Flexible ADC
    - Antennas

# Flexible RF

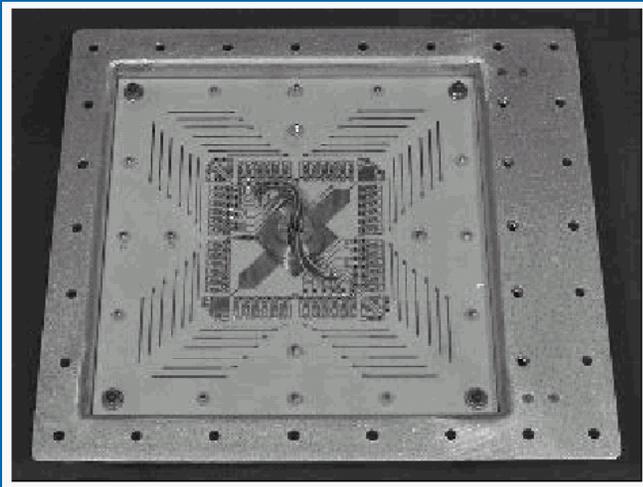
- RF is one of the main limiting factors on system design
  - Places fundamental limits on the signal characteristics
    - BW, SNR, linearity
  - Truly flexible SDR requires flexible RF
    - Difficult task
      - RF is fundamentally analog and requires different a different approach for the management of attributes
    - One method for achieving this is through the use of MEMS

# Micro Electro Mechanical Systems (MEMS)

- RF MEMS is a unique technology that offers a significant impact on RF flexibility, *performance* and *cost*
- Typically used to implement near perfect RF switches
- Design flexible filters using two-value switchable capacitors
- Tunable capacitors
  - Two distinct capacitor values  $C_{on}$  and  $C_{off}$
  - Switching occurs in  $< 10 \mu s$
  - Two value capacitors arranged in parallel to form digitally tunable capacitors
- Inductors
  - Fixed or variable
  - High Q inductors for filters
- Tunable filters

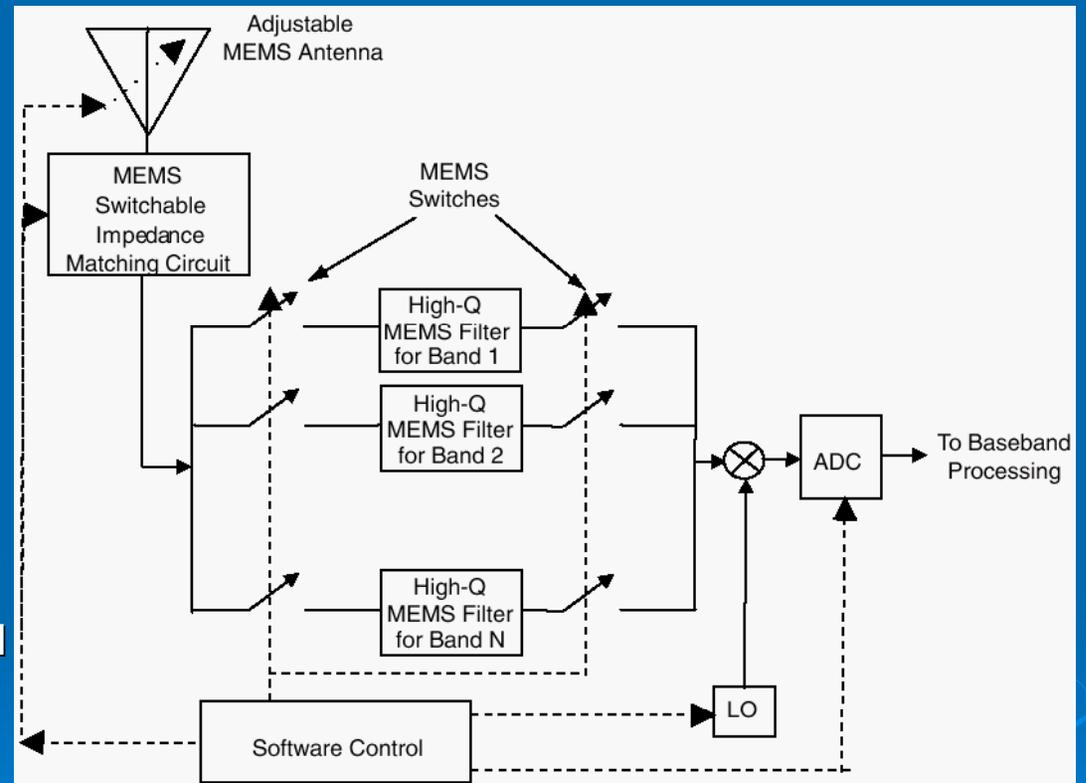


# MEMS Designs for RF Front Ends



E-tenna's Reconfigurable Antenna

- Tunable antenna with narrow fixed bandwidth
- Patch antenna connected by RF switches
- Use MEMS filter banks to create tunable RF filters



Idealized MEMS RF Front-end for a Software Radio

# ADC Challenges

- ADC is the bound between analog and digital world
- SDR requires the tuning of ADC characteristics
  - Number of bits
    - Support adequate SNR and dynamic range
  - Sampling rate
    - Prevent over-sampling (waste power)
- ADC technology trends are not necessarily compatible with these needs

# Software Operating Environment

- Standardized structure for the management of HW and SW components
  - SCA
- Technology to date has been largely derived from existing PC paradigm
  - GPP-centric structure
  - SCA 3.0 Hardware Supplement is an attempt to rectify this problem
- Several challenges remain
  - Power management
  - Integration of HW into structure

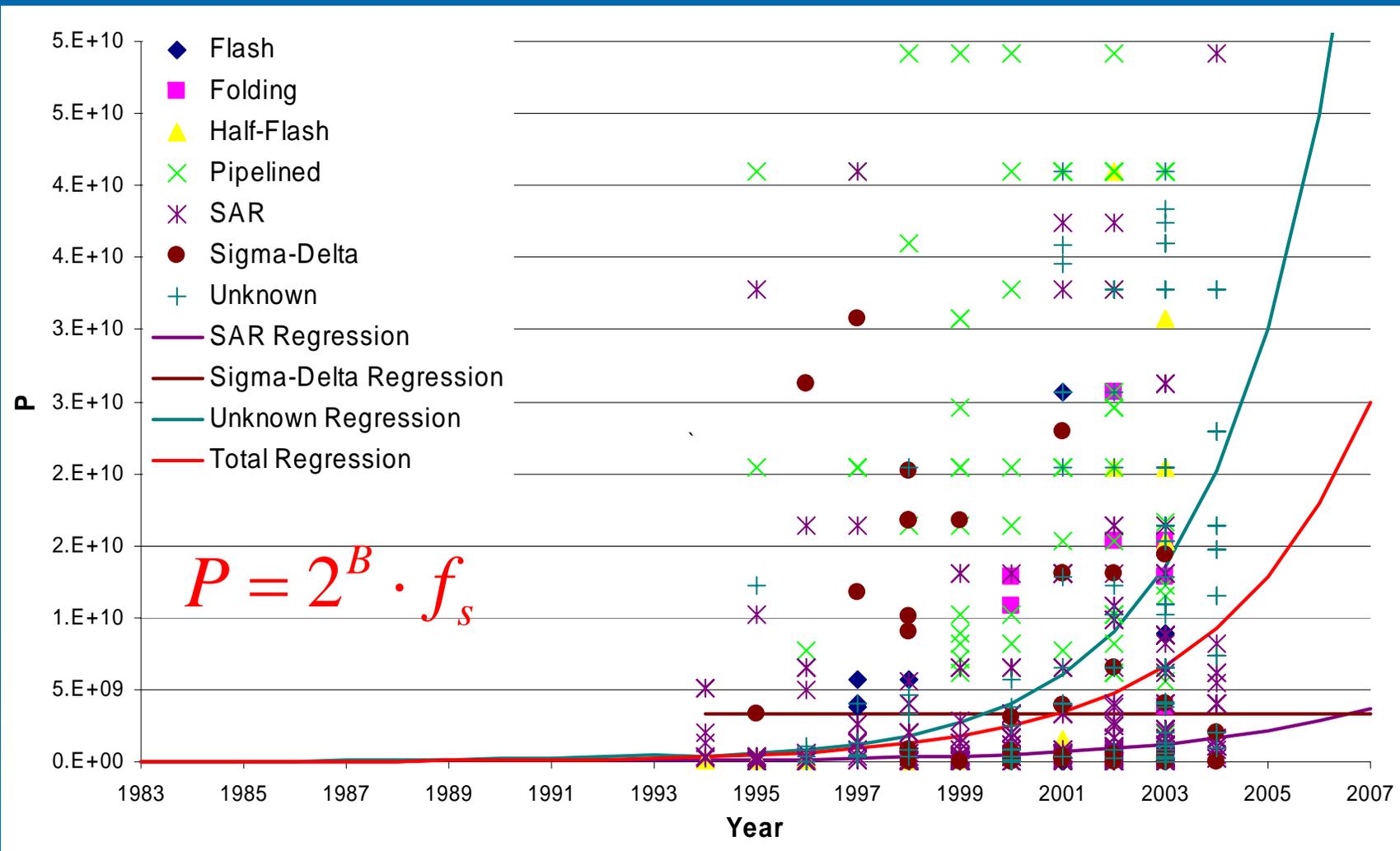
# Power Management

- Integrated structure for the management of system resources
  - Sleep modes, “fast enough” mode
- Standardized interface description
  - Common interface for the management of resources
    - Equivalent to AML (ACPI Machine Language) in ACPI (Advanced Configuration and Power Interface) used in PC
- “Thread” management outside the confines of OS
  - Extend OS functionality outside the bounds of GPP

# Integration of HW

- DSP share traits with GPP
  - Similar programming methods
  - Similar computing concepts
    - Even though implementation may be wildly different
- FPGA and CCM do not share these traits with GPP
  - Completely different programming paradigm
  - Portability is an extremely difficult problem

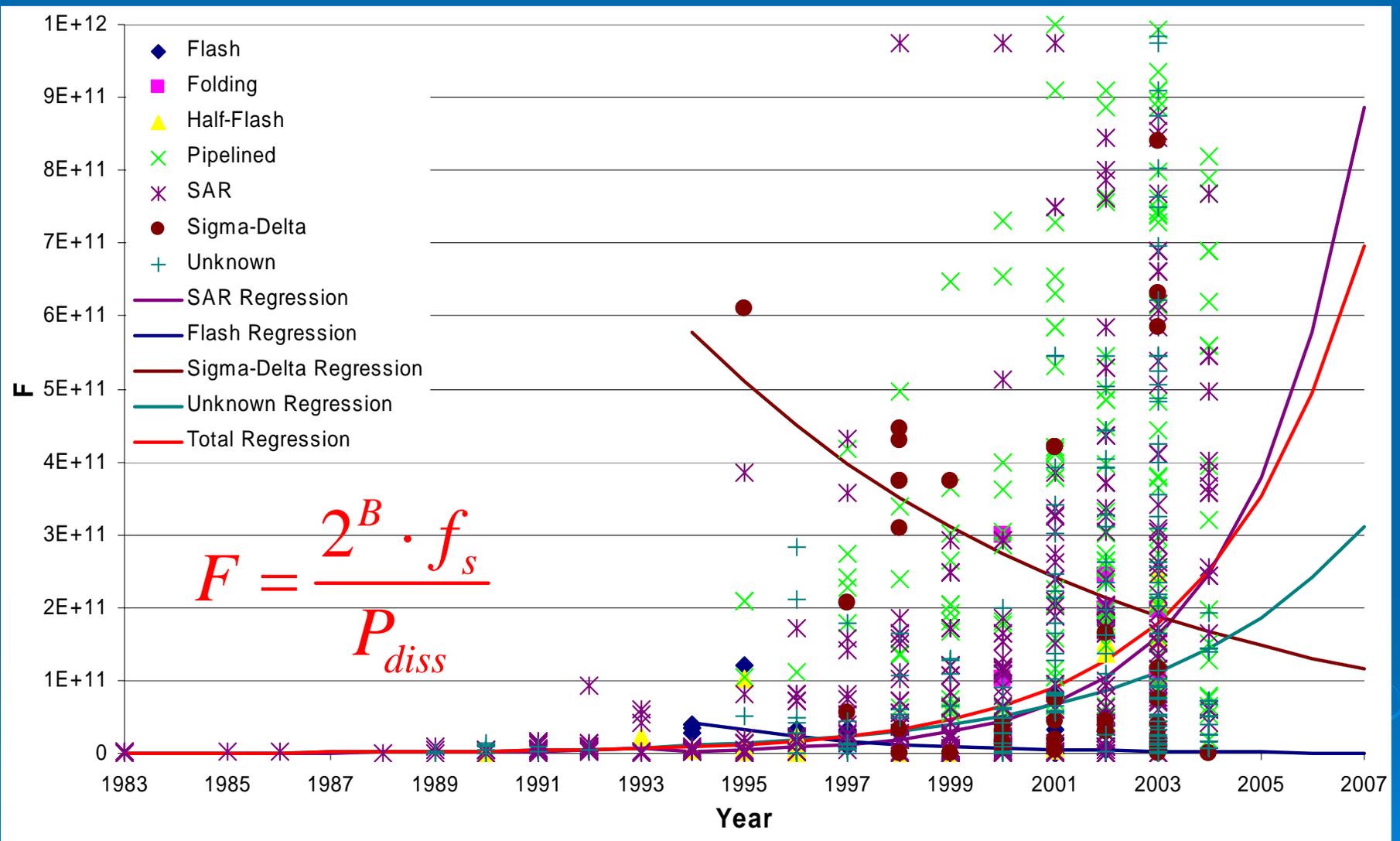
# ADC Trends – P vs. Year



- ◆ 1994 ~ 2004 – a leap of ADC technology
- ◆ Regression curve fit shows exponential increasing trends
- ◆ Trends are quite different for different ADC structures

Bin Lee, Tom Rondeau, Jeff Reed, Charles Bostian, "Past, Present, and Future of ADCs," submitted to IEEE Signal Processing Magazine, August 2004

# ADC Trends – F vs. Year



- ◆ Power-to-sampling-speed ratio favors less number of comparators
- ◆ The choice in selecting an ADC is tied to application requirement

# Conclusion

- SDR contains large number of areas that require significant research
  - Hardware
    - Improving functionality to support additional flexibility
  - Operating Environment
    - Standardize functionality and interfacing to support problems directly relevant to radio design
    - Power sensitive environments
  - Network
    - Develop applications that can break the previous approaches for the management of resources and take full advantage of capabilities of SDR

# Just Remember This

The best way to predict the future is to  
invent it.

- Alan Kay, Author