How Do I Choose?

Evaluating 9 of the Best Single Board Computers for Modern SDR Systems

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A Few Quick Questions

Have you ever written FPGA code?

A Few Quick Questions

Do you know what an FPGA is?

A Few Quick Questions

FPGA

Field ***P***rogrammable ***G***ate ***A***rray

An ***FPGA*** is an array of logic gates and memory elements with a programmable interconnect matrix that allows the gates and memory to be configured at run time.

FPGAs may be used to perform DSP functions in Software Defined Radios, among many other uses

A Few Quick Questions

Have you ever written CUDA code?

A Few Quick Questions

Do you know what CUDA is?

Hint: It has nothing to do with these:

A Few Quick Questions

CUDA

Compute ***U***nified ***D***evice ***A***rchitecture

A ***CUDA*** core is an NVIDIA parallel computing element used in their GPUs to process graphics data

CUDA cores may also be used to perform DSP functions in Software Defined Radios

A Few Quick Questions

<u>Raspberry Pi Class Computer</u>

How many do you own?

A Few Quick Questions

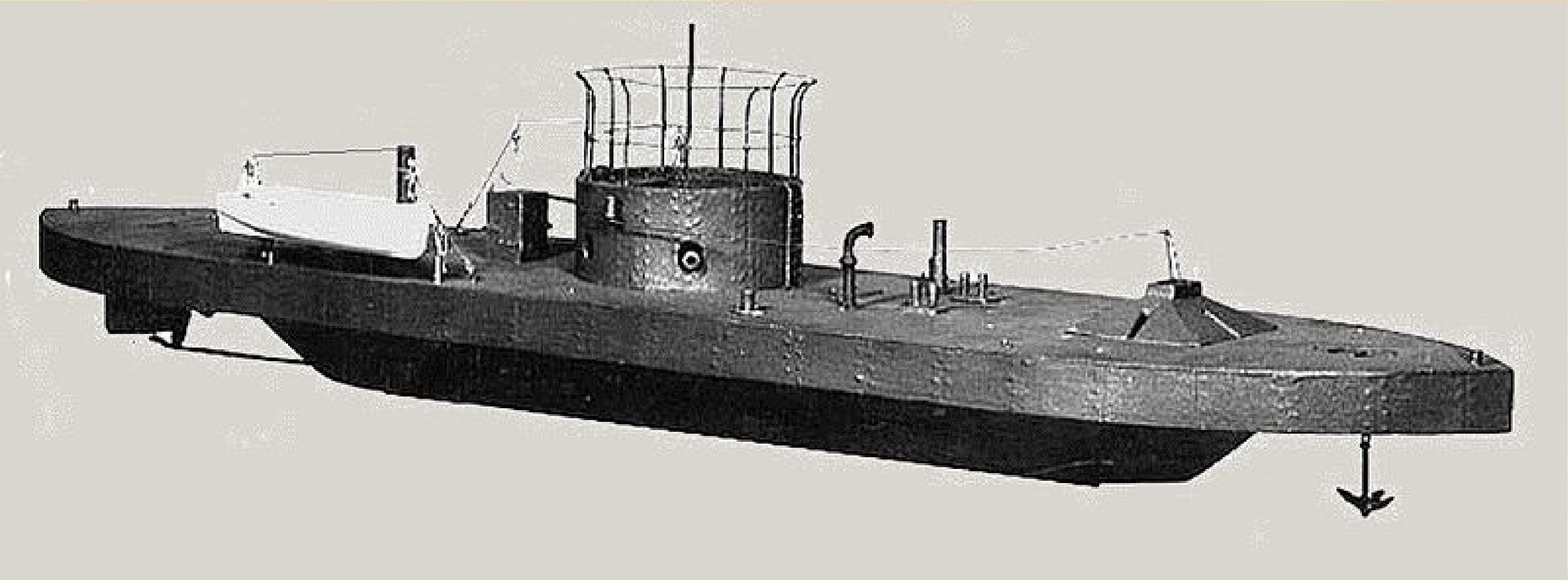
Raspberry Pi Class Computer

How many still in the box?

Monitors Through the Years

Monitor, ca 50,000 B.C.

Monitors Through the Years

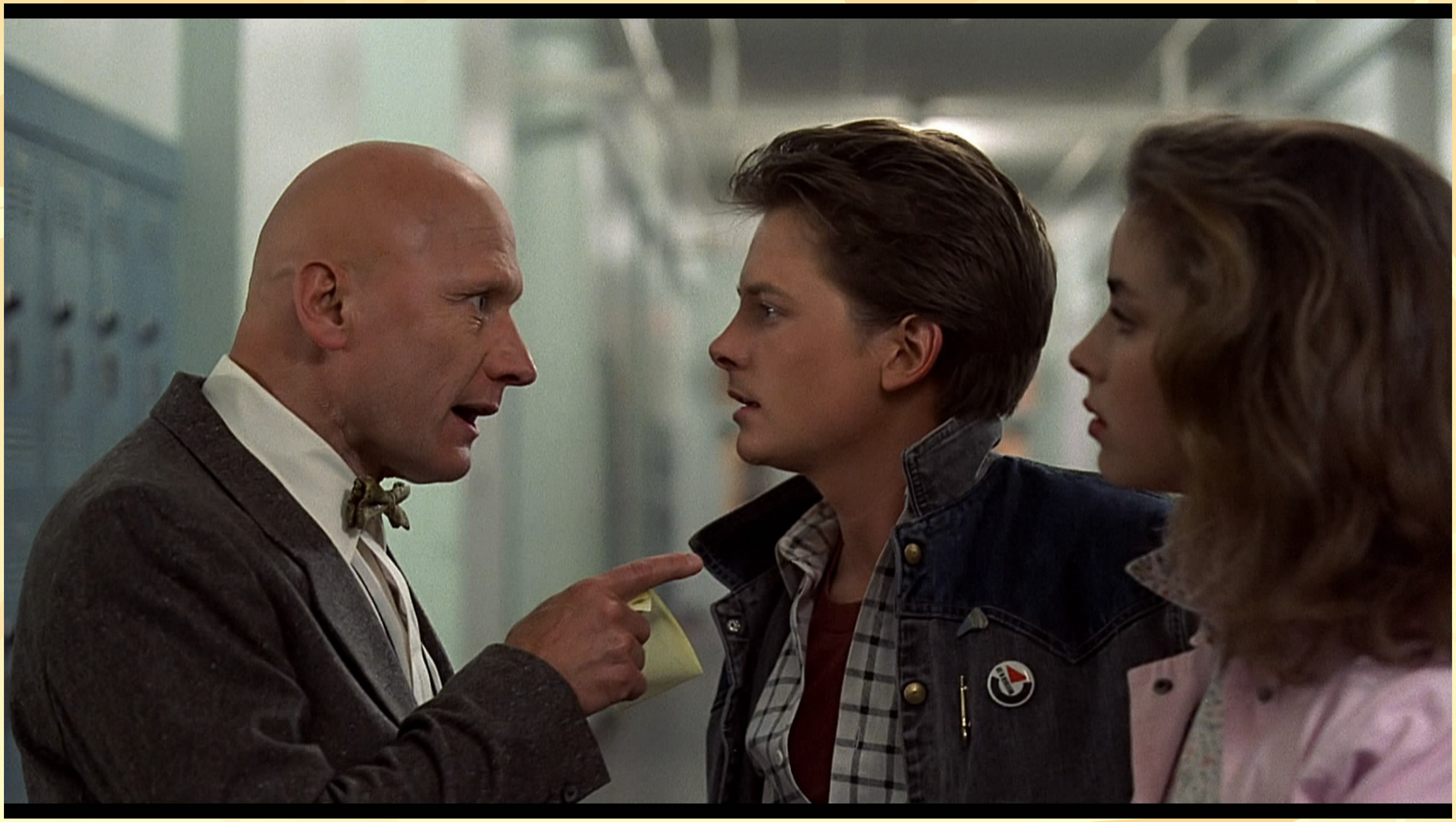


Monitor, ca 1862

Monitors Through the Years

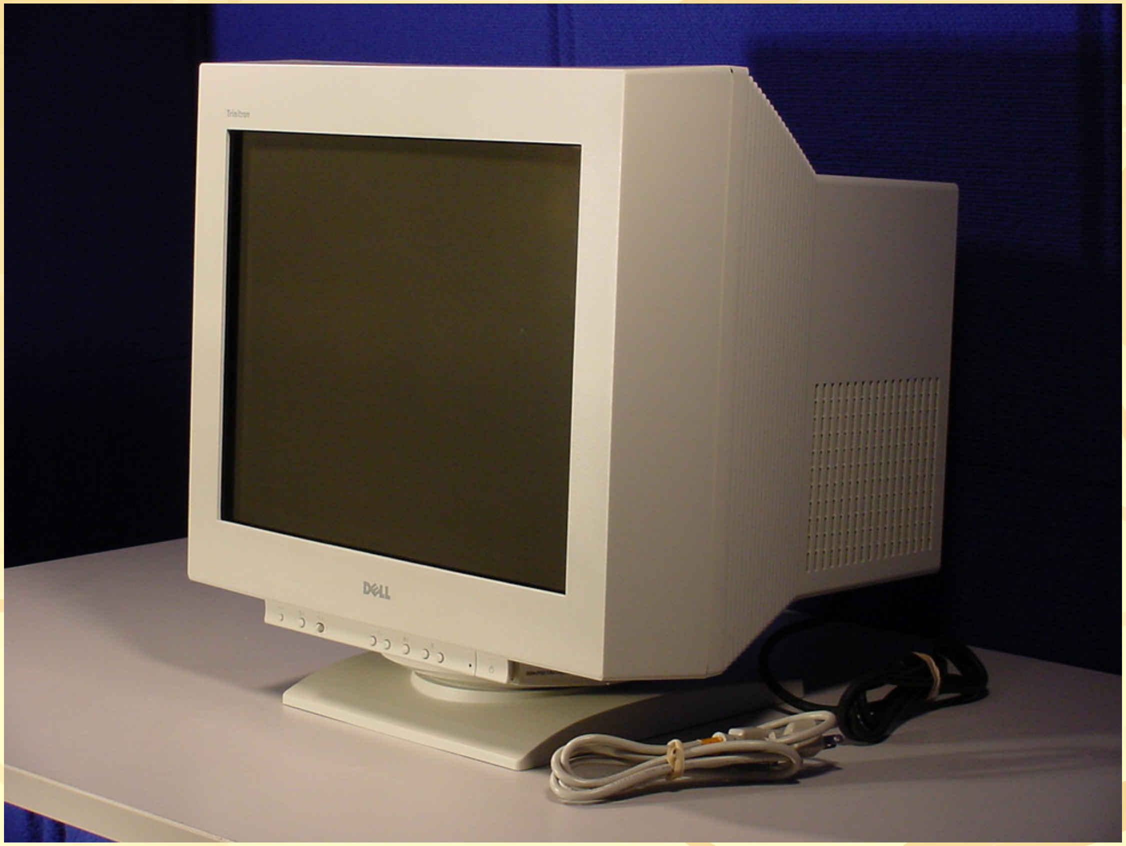
Monitor, ca 1955

Monitors Through the Years



Monitor, ca 1985

Monitors Through the Years



Monitor, ca 1993

Monitors Through the Years

Monitor, ca 2010

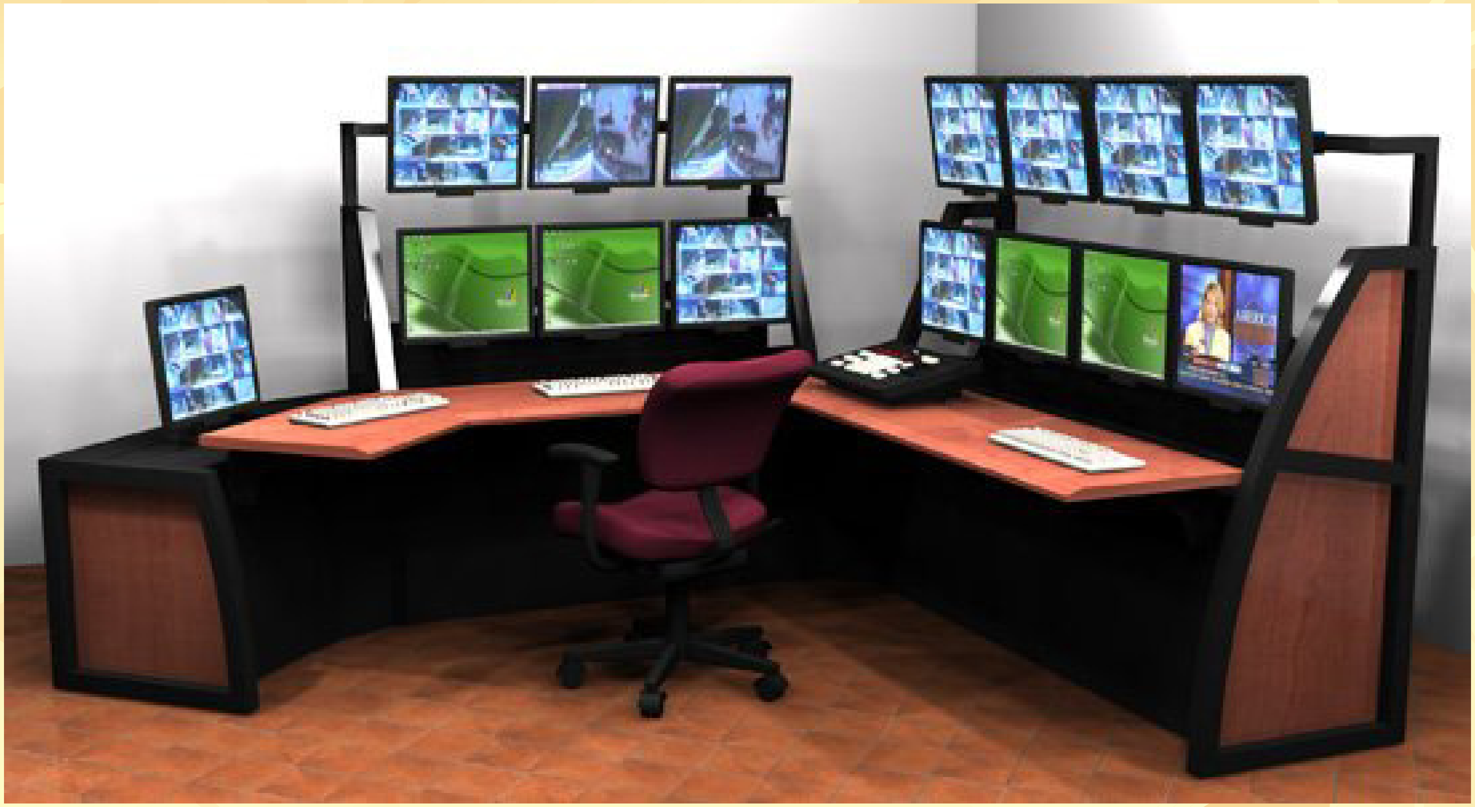
Monitors Through the Years

Monitor, ca 2018

Monitors Through the Years

Monitor(s), ca 2018

Monitors Through the Years



Monitor(s), ca 2018

A Relevant Correlation?

Monitor Resolution

vs

CPU Horsepower

A Relevant Correlation?

Year	Name	Resolution	CPU	MIPS
1981	CGA	320x200	8088 @ 4.77MHz	0.375
1984	EGA	640x350	80286@12MHz	1.28
1987	VGA	640x480	i386DX@16MHz	2.15
1990	XGA	1024x768	i486DX@25MHz	8.7
1994	SXGA	1280x1024	DX4@100MHz	70
1996	UXGA	1600x1200	Pentium Pro@200MHz	541
2000	FHD1080	1920x1080	Pentium III@600MHz	2,054
2008	4K UHD	3840x2160	i7-920@2.93GHz (4 core)	82,300
2016	8K UHD	7680x4320	I7-6950X@3GHz (10 core)	317,900

A Relevant Correlation?

Year	Name	Resolution	Pixels	MIPS	Pixels/MIPS
1981	CGA	320x200	64,000	0.375	170,667
1984	EGA	640x350	224,000	1.28	175,000
1987	VGA	640x480	307,200	2.15	142,884
1990	XGA	1024x768	786,432	8.7	90,394
1994	SXGA	1280x1024	1,310,720	70	18,725
1996	UXGA	1600x1200	1,920,000	541	3,549
2000	FHD1080	1920x1080	2,073,600	2,054	1,010
2008	4K UHD	3840x2160	8,294,400	82,300	101
2016	8K UHD	7680x4320	33,177,600	317,900	104

Not Really…

We did not account for:

- Color depth
- Frame rate
- Cost
- Brightness, Display quality

SDR Components

Narrow-band Amateur System

- RF: antenna to digital domain
- Signal Processing: Decimation, Interpolation, FFT, iFFT
- Pipes: Direct Connect, USB, Ethernet, WiFi, etc
- Modulation/demodulation: CW, SSB, FT8, etc
- DSP filtering: LPF, BPF, Noise Blanker, AGC
- CODEC: translate back to analog domain
- Graphical User Interface (GUI)

SDR Components

RF (hardware)

Receiver

- Antenna & feedline
- Analog LPF, HPF, BPF
- Analog attenuator
- Preamplifier
- A/D converter

Transmitter

- Antenna & feedline
- Analog LPF, HPF, BPF
- Power amplifier
- Analog attenuator
- Buffer amplifier
- Reconstruction filter
- D/A converter

SDR Components

Signal Processing (firmware/software)

- Decimation to reduce bandwidth to fit a pipe
- Decimation to reduce data rate to reduce processing load
- FFT/iFFT: Time ⇔ Frequency domain crossing

Just mathematical operations, can be performed in:

- FPGA hardware
- CUDA Cores (GPU)
- General Purpose CPU

SDR Components

Pipes (software)

- Direct Connect
  - Software or firmware pipes
  - Memory buffers, FIFOs
  - Very fast

SDR Components

Pipes (hardware)

- USB
  - 2.0 High speed 480mbps (60MByte/sec)
  - 3.1 Gen 1 Superspeed 4.8gbps (600MByte/sec)
  - 3.1 Gen 2 Superspeed+ 10gbps (1250MByte/sec0
- Ethernet
  - Gigabit Ethernet – 1000Mbps

SDR Components

Pipes (hardware)

- PCIe (x1, x2, x4, x8, x16 lanes)
  - 1.0 – 250MByte/sec per lane
  - 2.0 – 500MByte/sec per lane
  - 3.0 – ~1000MBye/sec per lane
  - 4.0 – ~2000MByte/sec per lane
- WiFi
  - 802.11n 2.4GHz/5GHz – 450Mbps
  - 802.11ac 5GHz – 1300mbps

SDR Components

Modulation/Demodultaion (software)

- More mathematical operations
- CW, SSB, FT8, etc
- New modes not even thought of yet

SDR Components

DSP Filtering (software)

- Filtering: low pass, high pass, band pass
- Noise gating and reduction
- AGC

SDR Components

Back to Analog (hardware)

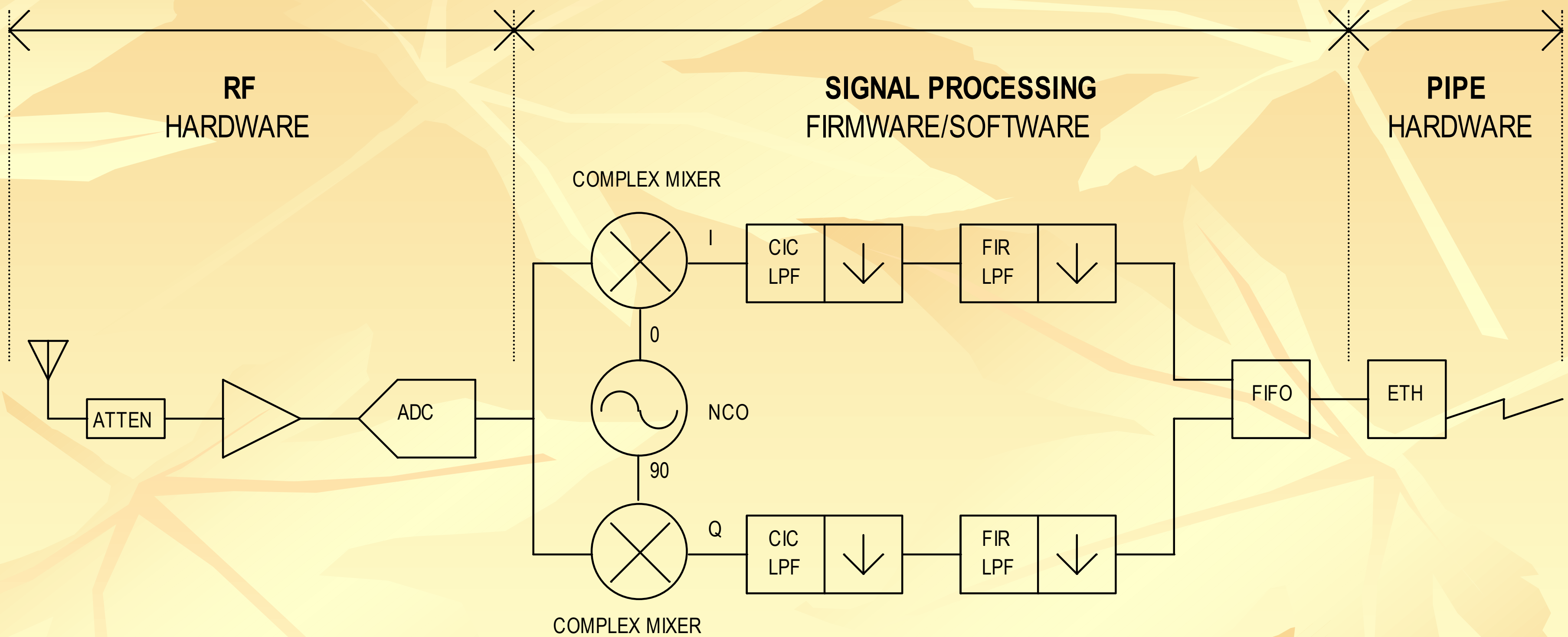
- D/A conversion (receive audio output)
- A/D conversion (microphone audio input)
- Can use sound card hardware
- Typically mono sound, stereo allows some enhancements
- CW key/paddle hardware interface included here

SDR Components

GUI (software & hardware)

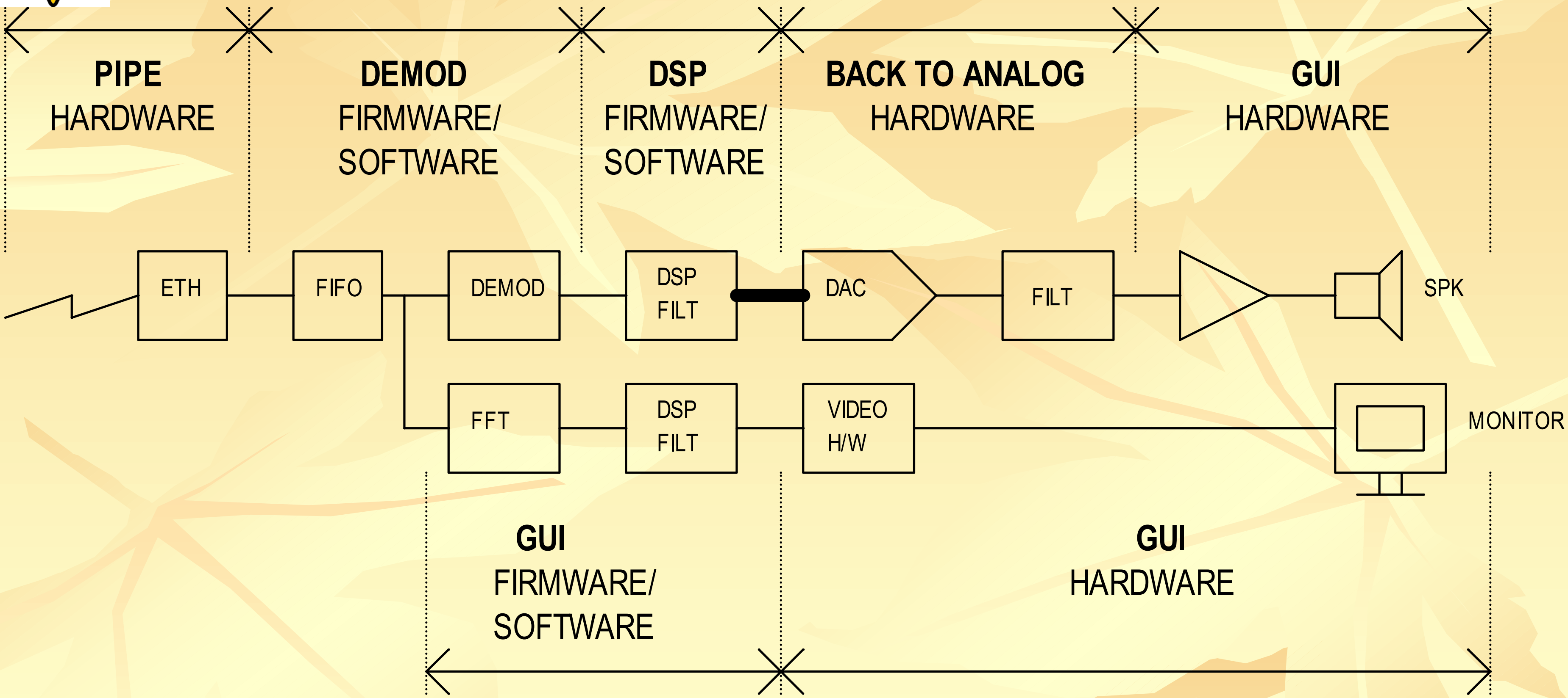
- Panadapter (spectrum display)
- Waterfall display
- Radio control: band/mode/antenna select, etc
- Hardware control: antenna selection, etc
- DSP filter control: BW, center frequency, PBT, etc
- Contest & awards logging (CW Skimmer)
- Interface to monitor(s), keyboard & mouse

Building a Radio



Receiver Block Diagram

Building a Radio



Receiver Block Diagram, cont'd

Building a Radio

Where do we draw the lines between components?

What gets done in hardware?

What gets done in software?

Building a Radio

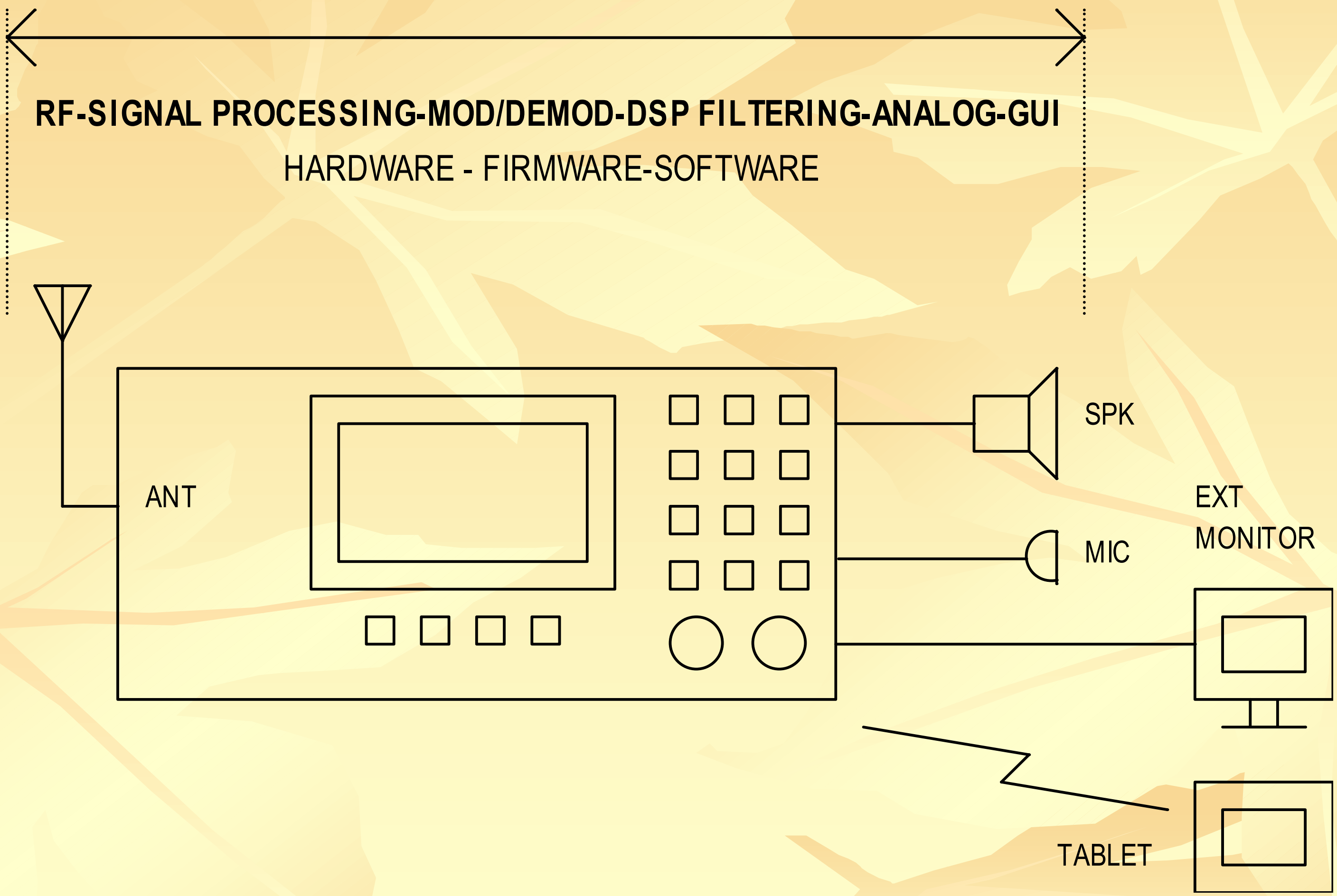
Who Cares?

Two SDR “Evolution Paths”

Conventional

- Single box, ever expanding features/performance
- One or two monitors, ever increasing resolution
- Multiple virtual receivers, but limited user interfaces
- Difficult to accommodate more than one user at a time
- Performance tied to ever increasing PC performance

Two SDR "Evolution Paths"



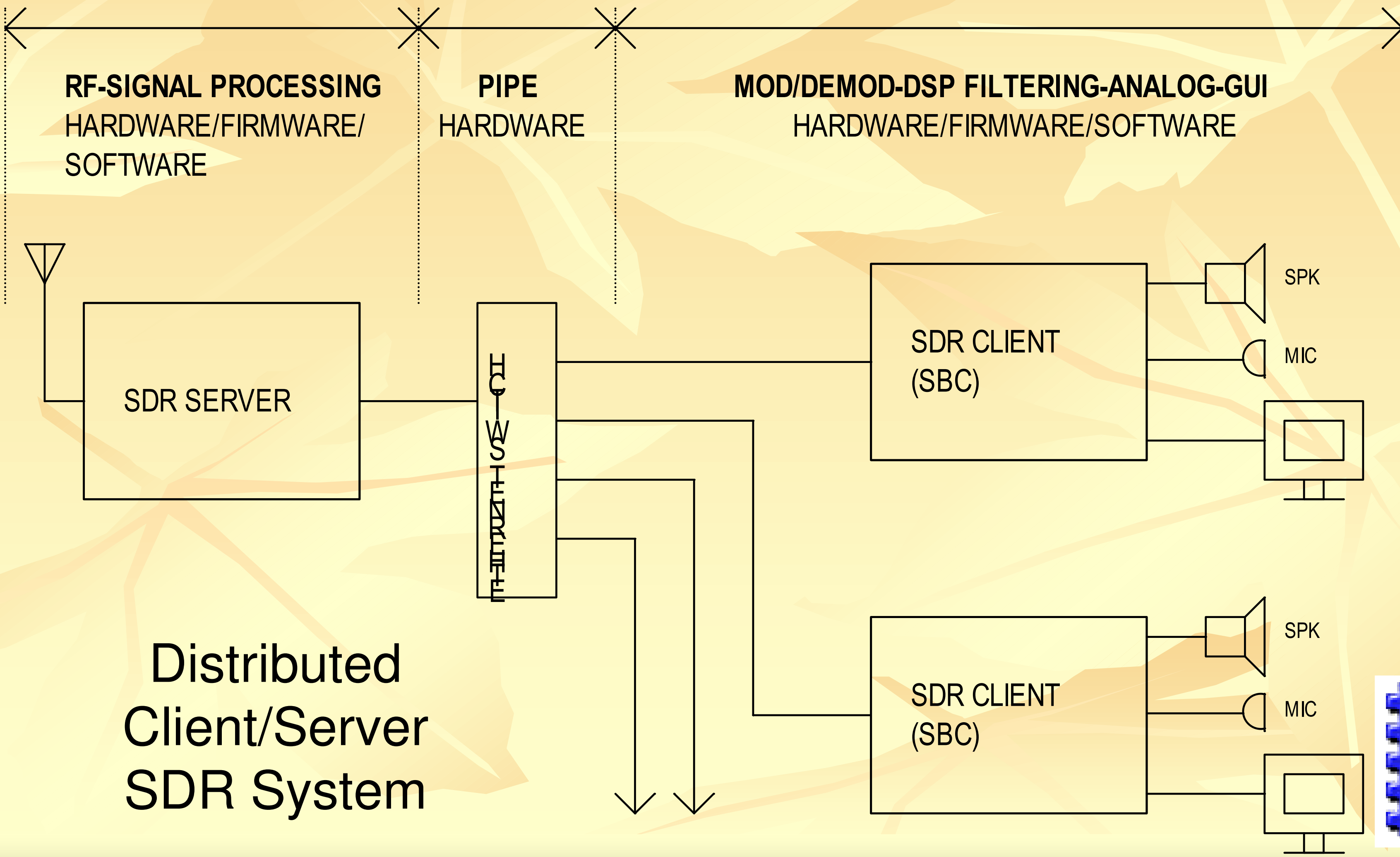
Conventional SDR System

Two SDR “Evolution Paths”

Distributed Client/Server System

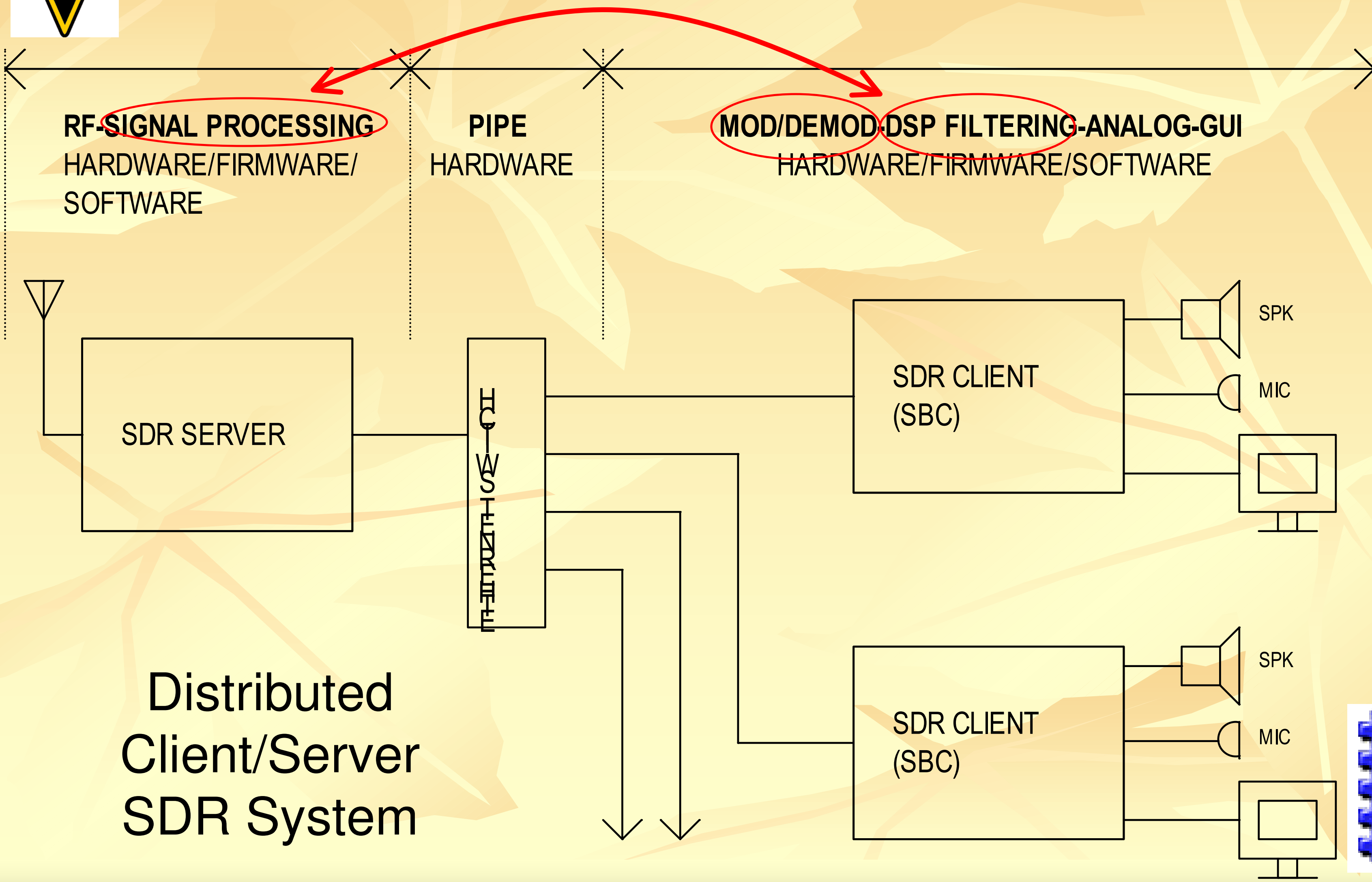
- Many boxes, ever expanding system features/performance
- Many monitors, ever increasing resolution
- Multiple receivers and transmitters
- Unlimited user interfaces
- Easy to accommodate more than one user at a time
- Performance tied to increasing component performance

Two SDR "Evolution Paths"



Distributed Client/Server SDR System

Two SDR “Evolution Paths”



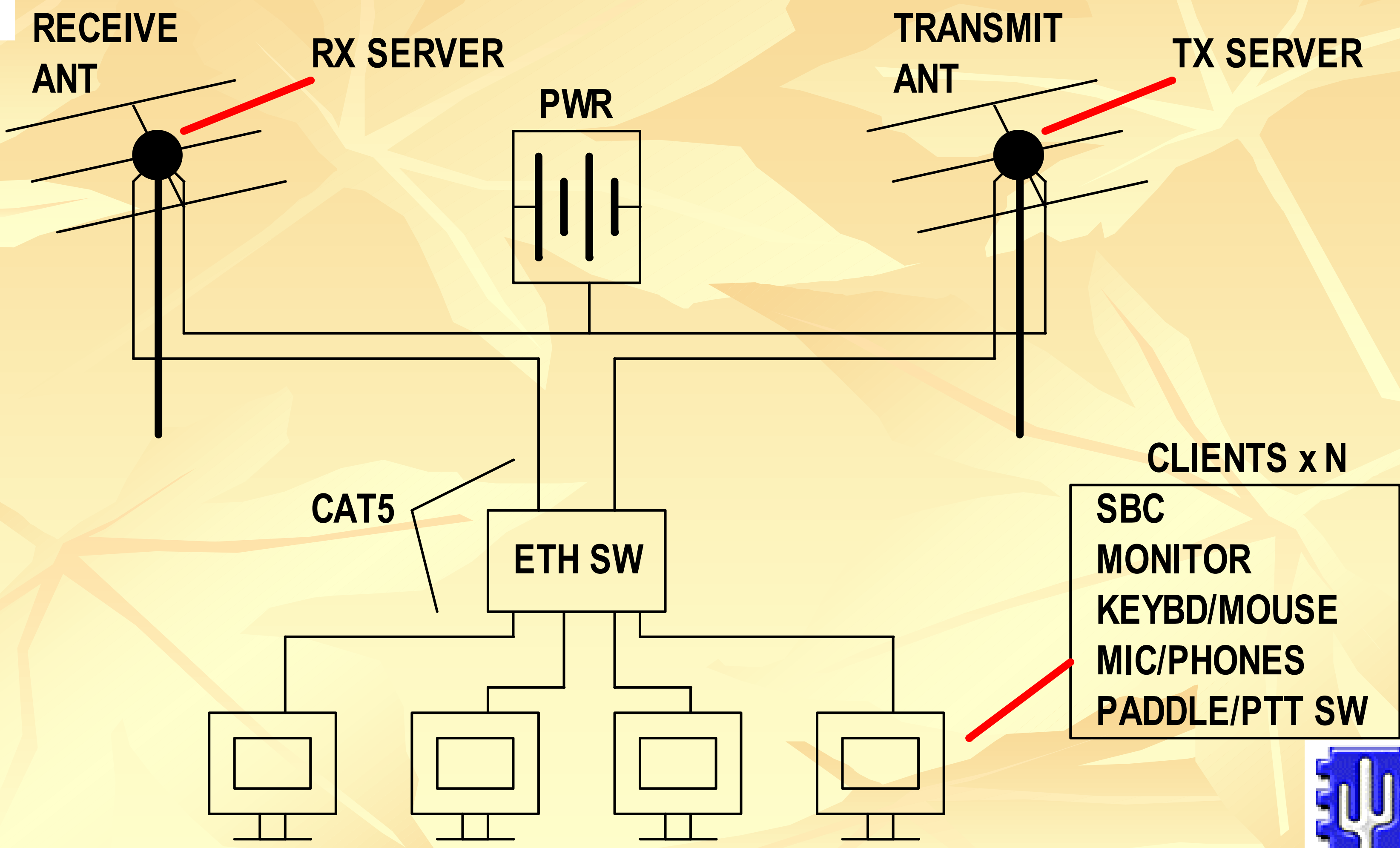
Distributed
Client/Server
SDR System

20th Century FD Setup

Start with this

See how many QSOs you can make.

21st Century FD Setup



SBCs for SDR Use

- SBC acts a Client to SDR Server hardware
- Provides GUI
  - Panadapter/waterfall display
  - Band/mode/filter/passband/RIT/etc control
  - Logging/dupe checking
- Connection point for radio hardware
  - Speaker/headphones (with sidetone)
  - Microphone/PTT
  - Key/paddle

SBC Requirements for SDR Use

- Mainstream Linux Support (e.g., Ubuntu, Debian, Mint)
- Gigabit Ethernet (native or via USB)
- HDMI video (HD 1920x1080 minimum resolution)
- Solid-state boot media (μSD, SSD, eMMC or mVME)
- Sound hardware (native or via USB)
- Keyboard & mouse connection (BT or USB)

SBC Preferences for SDR Use

- 64-bit multi-core CPU (vs 32-bit or dual-core)
- Fast boot media (eMMC or mVME vs µSDC)
- Nominal 12V power (11-15V vs 5V)
- Bluetooth (keyboard/mouse) ← NOT AUDIO
- Native sound hardware

The Boards - CPU

Board Mfr & Model	CPU	Cores (32-bit) (64-bit)
Hardkernel Odroid C1	Amlogic S805	4-A5@1.5G
Raspberry Pi 3B	Broadcom BC2837	4-A53@1.2G
Hardkernel Odroid XU4	Samsung Exynos 5422	4-A15@2G + 4-A7@1.4G
ASUS Tinker S	Rockchip RK3288	4-A17@1.8G
FriendlyElec NanoPC-T4	Rockchip RK3399	2-A72@2G + 4-A53@1.5G
Pine64 RockPro64	Rockchip RK3399	2-A72@2G + 4-A53@1.5G
96 Boards Mediatek X20	Helio X20	2-A72@2.3G + 4-A53@1.95G + 4-A53@1.4G
96 Boards HiKey 960	Huawei Kirin 960	4-A73@2.4G + 4-A53@1.8G
UDOO X86 Ultra	Intel N3710	4-Pentium@2.56G

ARM Core Comparisons

Core	Arch	Bus	L1	L2	Year	Board(s)
A5	v7-A	32	32K/32K	512K	2009	C1
A7	v7-A	32	32K/32K	512K	2011	XU4
A15	v7-A	32	32K/32K	2M	2010	XU4
A17	v7-A	32	32K/32K	1M	2014	Tinker
A53	v8-A	64	32K/32K	512K	2012	Pi3B, T4, Pro64, X20, 960
A72	v8-A	64	48K/32K	1M	2015	T4, Pro64, X20
A73	v8-A	64	64K/64K	2M	2016	960

The Boards – GPU

Board Mfr & Model	GPU	Freq
Hardkernel Odroid C1	Mali 450	600MHz
Raspberry Pi 3B	Broadcom VideoCore IV	400MHz
Hardkernel Odroid XU4	Mali T-628 MP6	600MHz
ASUS Tinker S	Mali T-760 MP4	600MHz
FriendlyElec NanoPC-T4	Mali T-860 MP4	650MHz
Pine64 RockPro64	Mali T-860 MP4	650MHz
96 Boards Mediatek X20	Mali T-880 MP4	700MHz
96 Boards HiKey 960	Mali G71 MP8	900MHz
UDOO X86 Ultra	Intel HD405	700MHz

The Boards – Memory

Board Mfr & Model	RAM	Boot ROM (on-board)
Hardkernel Odroid C1	1GB DDR3	µSDHC, eMMC4.5
Raspberry Pi 3B	1GB SDRAM shared, 400MHz	µSDHC
Hardkernel Odroid XU4	2GB LPDDR3-933 dual ch	µSDHC, eMMC5.0
ASUS Tinker S	2GB LPDDR3 dual ch	µSDHC, 16GB eMMC
FriendlyElec NanoPC-T4	4GB LPDDR3-1866 dual ch	µSDHC, 16GB eMMC5.1
Pine64 RockPro64	4GB LPDDR4	µSDHC, eMMC5.1
96 Boards Mediatek X20	2GB LPDDR3-933 dual ch	µSDHC, 8GB eMMC5.1
96 Boards HiKey 960	3GB LPDDR4-1866	µSDHC, 32GB UFS2.0
UDOO X86 Ultra	8GB DDR3L	µSDHC, 32GB eMMC, M.2 SSD

The Boards – I/O

Board Mfr & Model	USB 3.0	USB 2.0	USB C	HDMI	Eth
Hardkernel Odroid C1	-	4	-	1	1G
Raspberry Pi 3B	-	4	-	1	100M
Hardkernel Odroid XU4	2	1	-	1	1G
ASUS Tinker S	-	4	-	1	1G
FriendlyElec NanoPC-T4	1	2	1	1	1G
Pine64 RockPro64	1	2	1	1	1G
96 Boards Mediatek X20	-	2	-	1	via USB
96 Boards HiKey 960	2	-	otg	1	via USB
UDOO X86 Ultra	3	-	-	1	1G

The Boards – I/O

Board Mfr & Model	BT	WiFi	PWR	Sound
Hardkernel Odroid C1	-	-	5V	-
Raspberry Pi 3B	4.1, BLE	b/g/n	5V	HP out
Hardkernel Odroid XU4	-	via USB	5V	I2S out
ASUS Tinker S	4.0+EDR	b/g/n	5V	HD I/O
FriendlyElec NanoPC-T4	4.1	dual band	12V	ob mic/HP
Pine64 RockPro64	4.2 opt	dual band opt	12V	mic/HP
96 Boards Mediatek X20	4.1 HS	dual band	12V	line in/HP
96 Boards HiKey 960	4.1 HS	dual band	12V	I2S I/O
UDOO X86 Ultra	4.2 opt	dual band opt	12V	mic/HP

The Boards – O/S Support

Board Mfr & Model	O/S Image	Kernel
Hardkernel Odroid C1	Ubuntu 18.04.1 LTS	3.10.107
Raspberry Pi 3B	Raspbian Stretch (Debian)	4.14
Hardkernel Odroid XU4	Ubuntu MATE 18.04 LTS	4.14.37 LTS
ASUS Tinker S	Linaro Stretch	
FriendlyElec NanoPC-T4	Lubuntu	4.4
Pine64 RockPro64	Ubuntu 18.04 LXDE	
96 Boards Mediatek X20		
96 Boards HiKey 960		
UDOO X86 Ultra	Ubuntu 18.04 LTS	

The Boards - No Free Lunch

Board Mfr & Model	Supplier	Board
Hardkernel Odroid C1+	hardkernel.com	$35
Raspberry Pi 3B	newark.com	$35
Hardkernel Odroid XU4	hardkernel.com	$59
ASUS Tinker S	amazon.com	$85
FriendlyElec NanoPC-T4	friendlyarm.com	$109
Pine64 RockPro64	pine64.org	$80 (4GB)
96 Boards Mediatek X20	amazon.com	$199
96 Boards HiKey 960	amazon.com	$239
UDOO X86 Ultra	shop.udoo.org	$267

Benchmarks

How do we know that an SBC is adequate?

- Will it run the required software?
- CPU gauge(s) not at maximum
- No pops and crackles (missed samples)
- Panadapter and waterfall both update smoothly
- GUI remains responsive
- Latency is acceptable

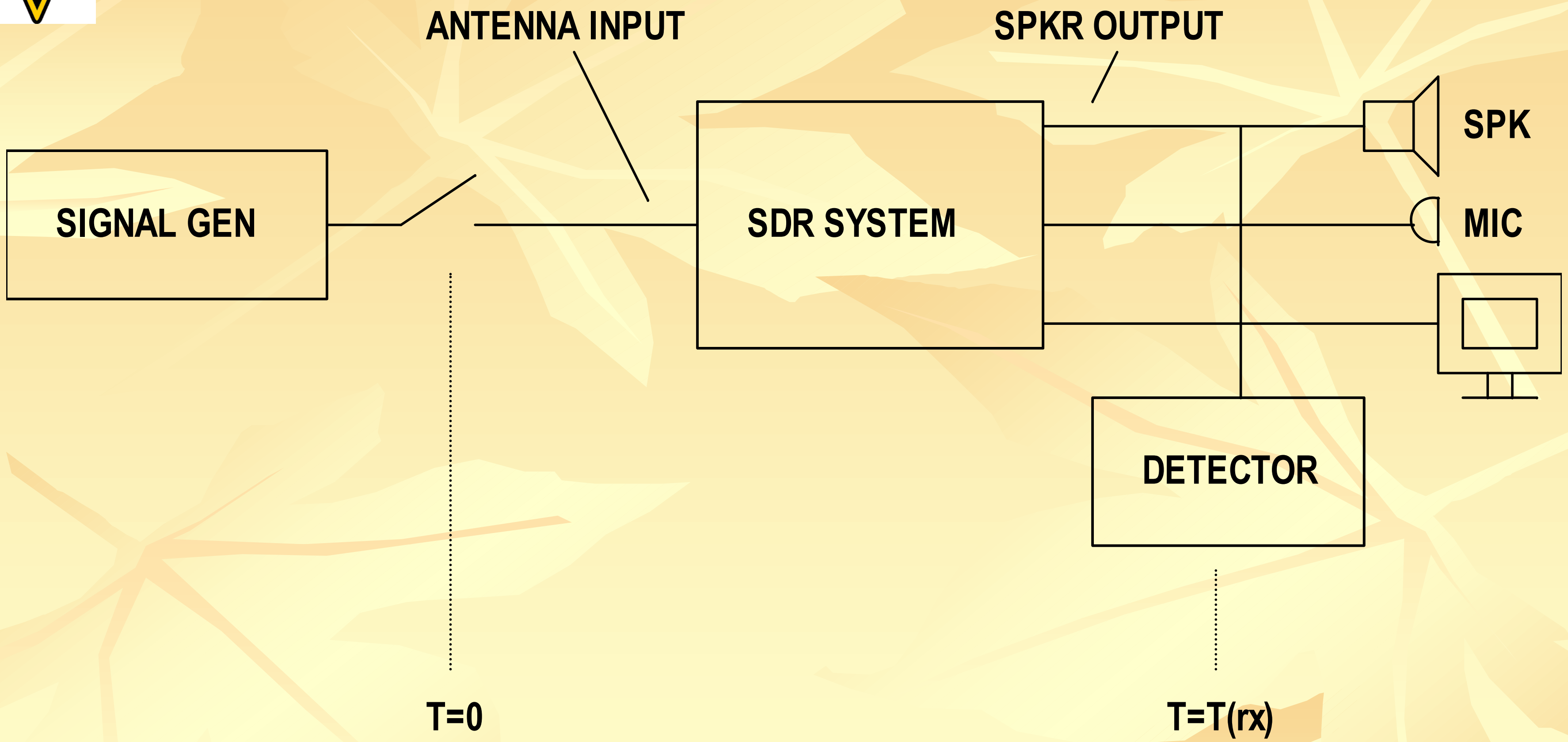
Latency

What is acceptable latency?

- CW at 30 WPM, one dit = 40 ms
- To hear between dits, latency < 30 ms ← NOT TRUE!
- To use receiver as sidetone, latency <5 ms?

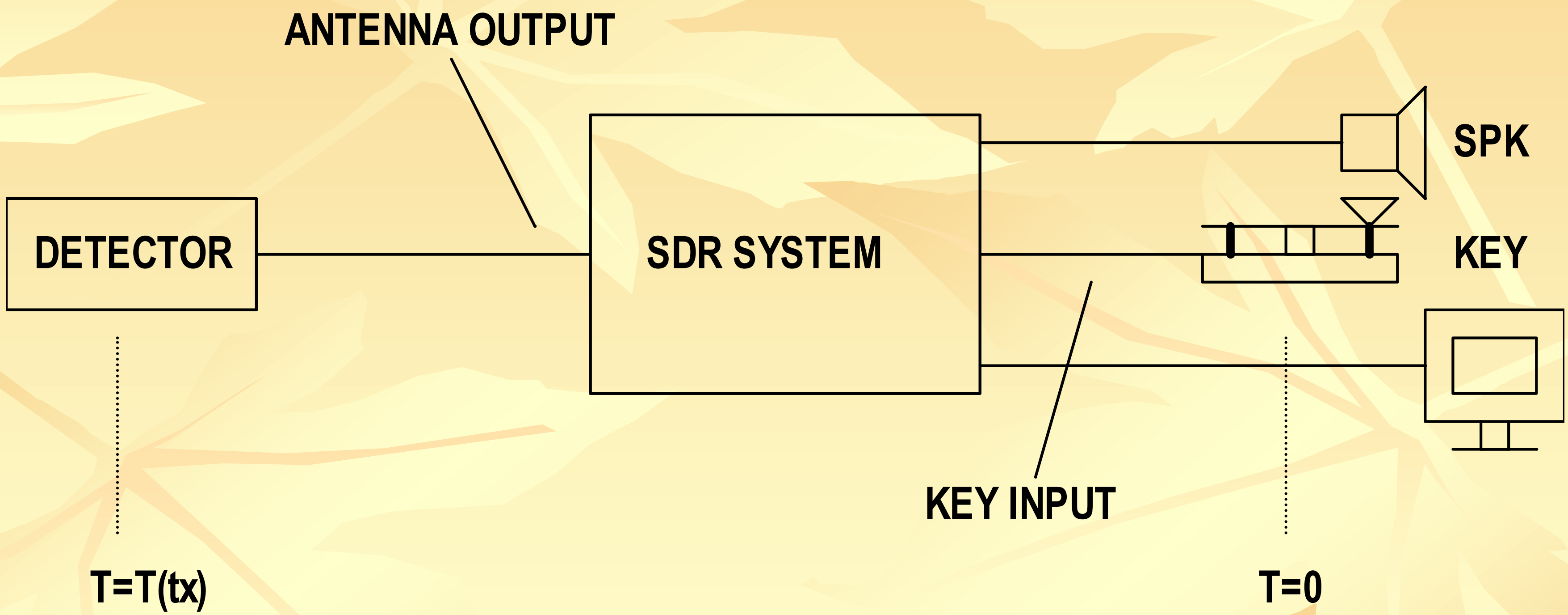
- SSB in a contest (fast pace)
- Latency < 100+ ms
- Voice sidetone, latency < 50 ms

Receiver Latency Benchmark



Receiver Benchmark test setup

Transmitter Latency Benchmark



Transmitter Benchmark test setup

Thank you!

See all 9 SBCs in Operation

in the Demonstration Room