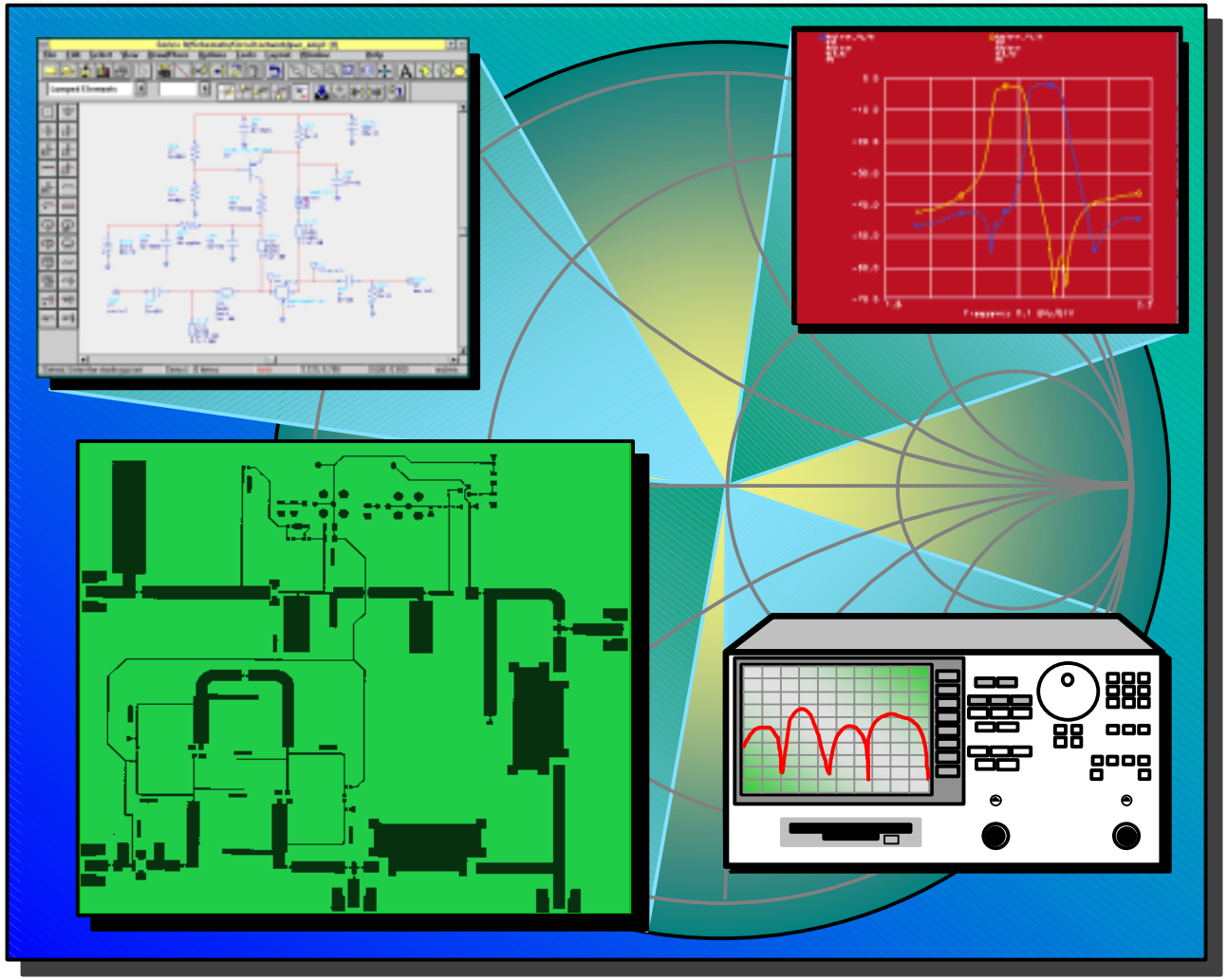
HP RF Design and Measurement Seminar



Creators:

David Ballo
Andy Potter
Boyd Shaw
My Le Truong
Joe Civello
Ed Henicle
Sara Meszaros

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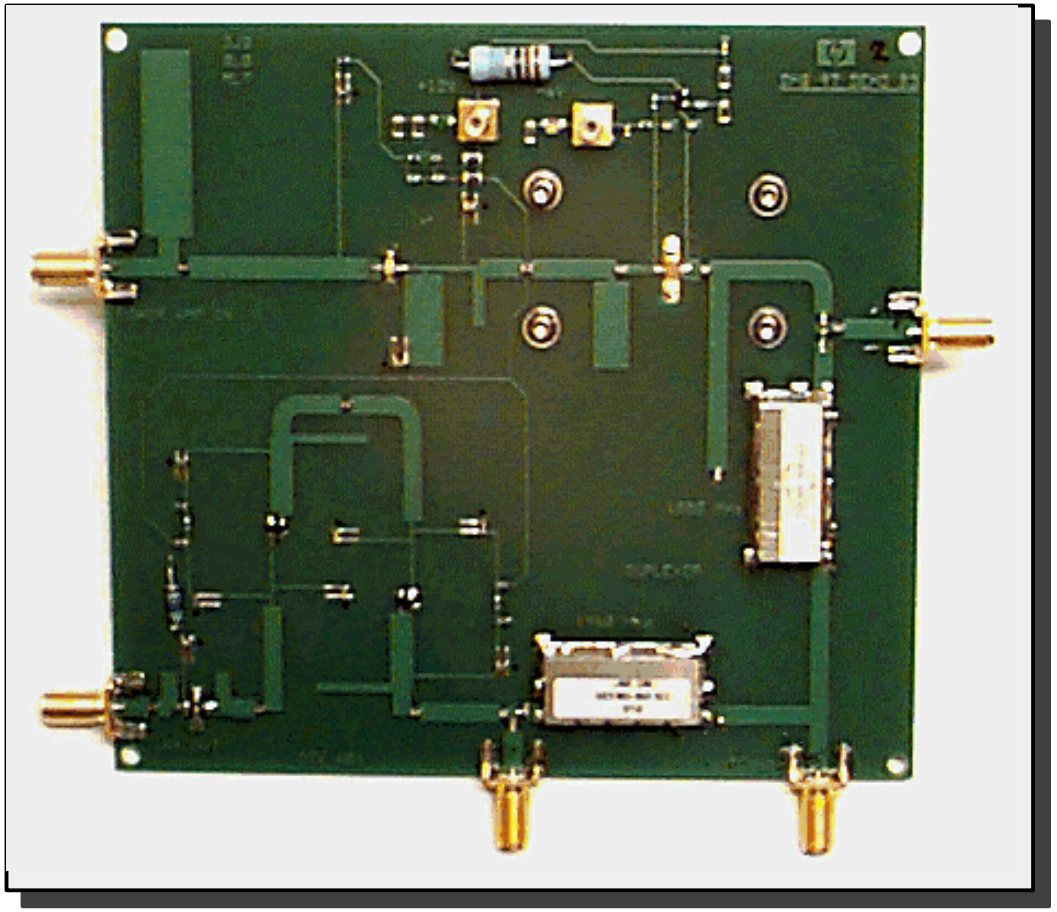
Goals of the Seminar

- Introduce new engineers to the modern RF design process
- Document predictive RF design process
- Focus on design methodology, not button pushing
- Provide practical design tips based on our case study



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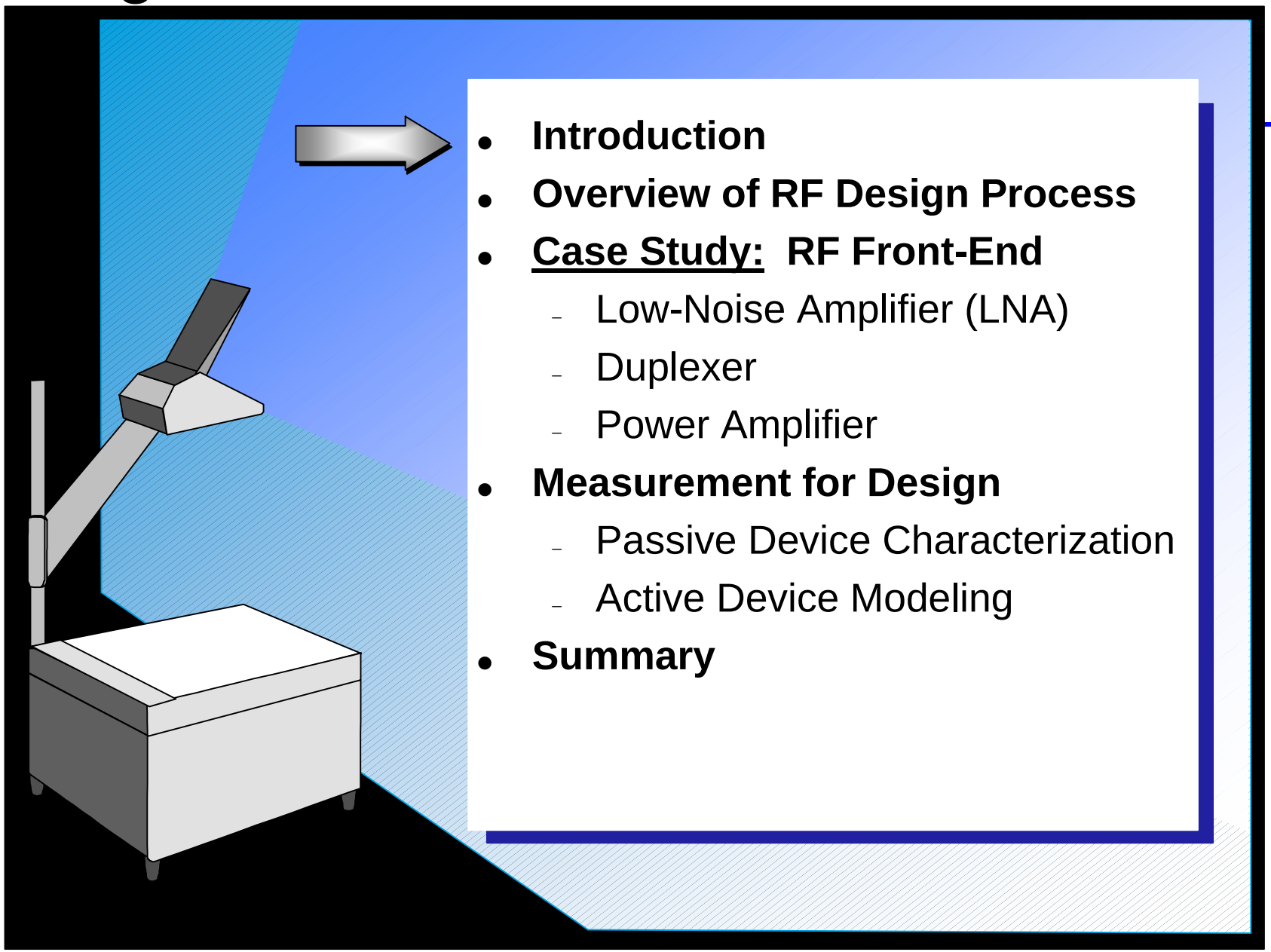
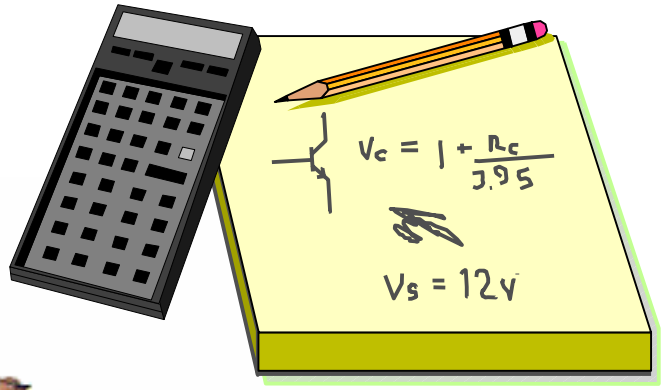
Agenda

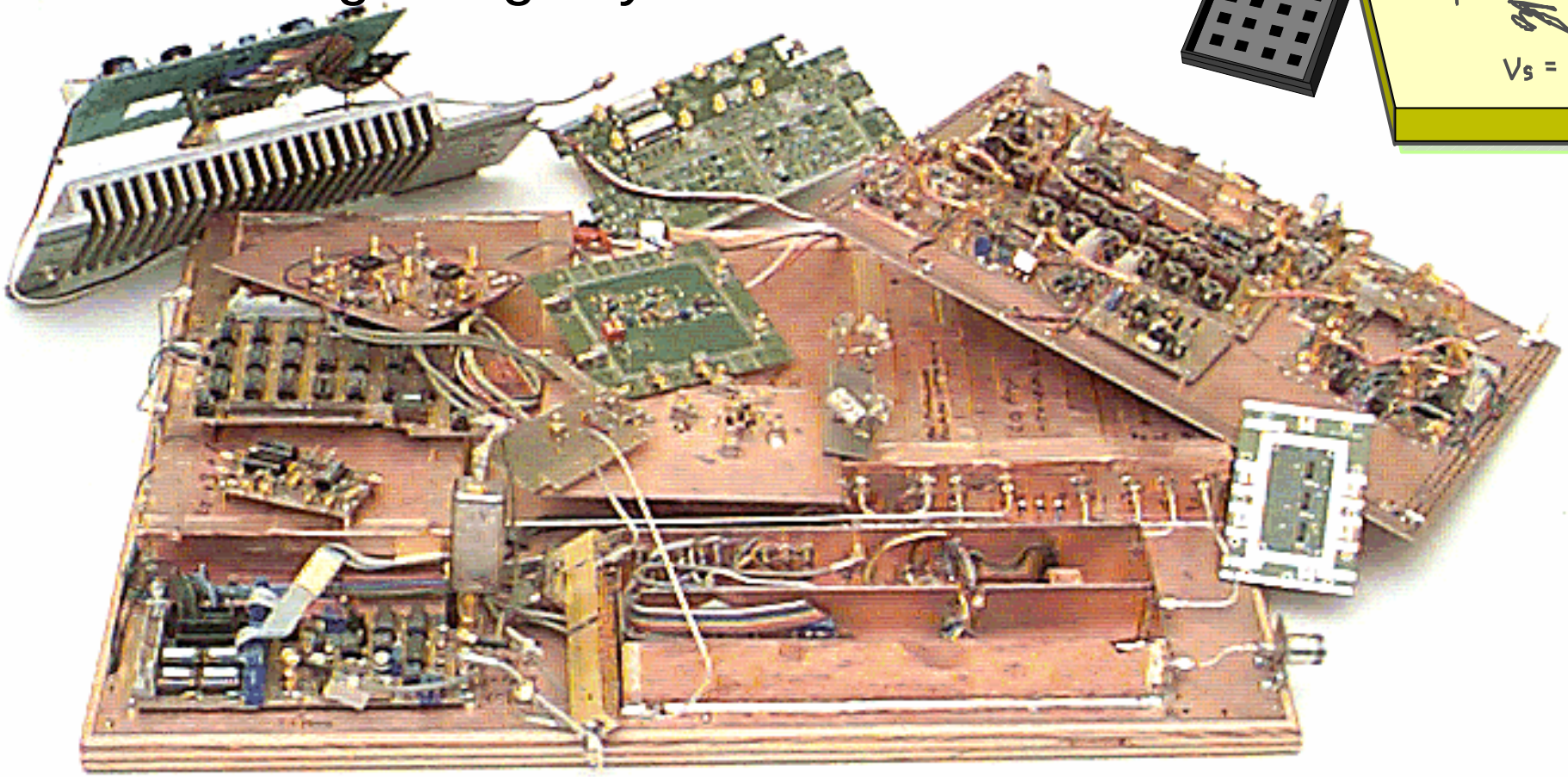


- **Introduction**
- **Overview of RF Design Process**
- **<u>Case Study:</u> RF Front-End**
  - Low-Noise Amplifier (LNA)
  - Duplexer
  - Power Amplifier
- **Measurement for Design**
  - Passive Device Characterization
  - Active Device Modeling
- **Summary**

Traditional RF Design Process

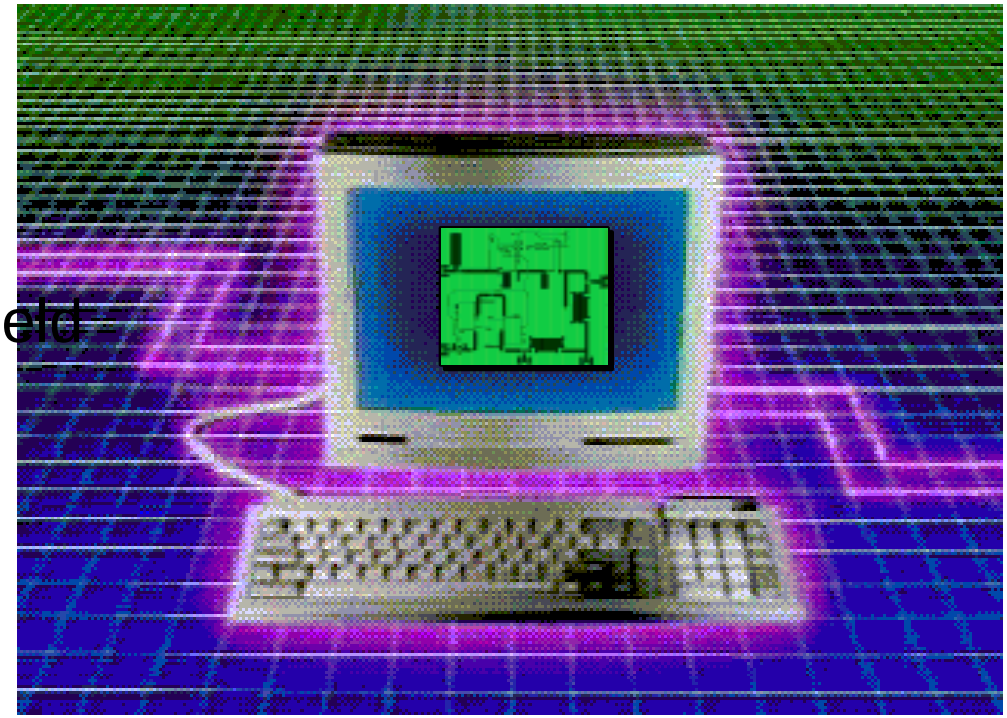
- Paper, pencil, calculator
- Many board turns (cut and try)
- Long design cycles





Modern, Predictive RF Design Process

- Combination of:
  - EDA (electronic design automation) software
  - Measurement equipment (e.g., network & signal analyzers)
- Design iterations now performed via software
- Fewer board turns (faster time to market)
- Accurate circuit performance - minimize over engineering
- Improve manufacturability with yield analysis and optimization



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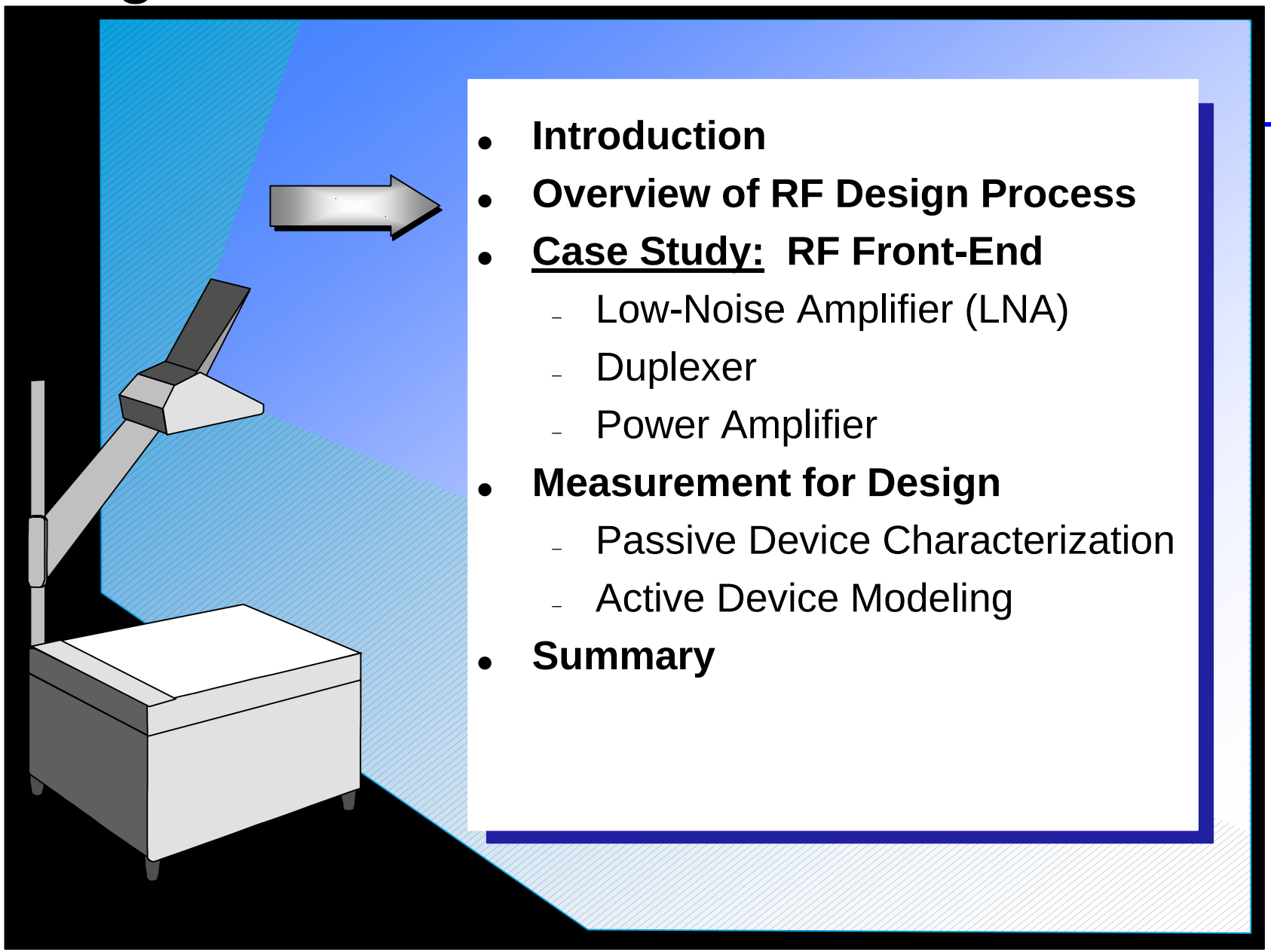
Agenda



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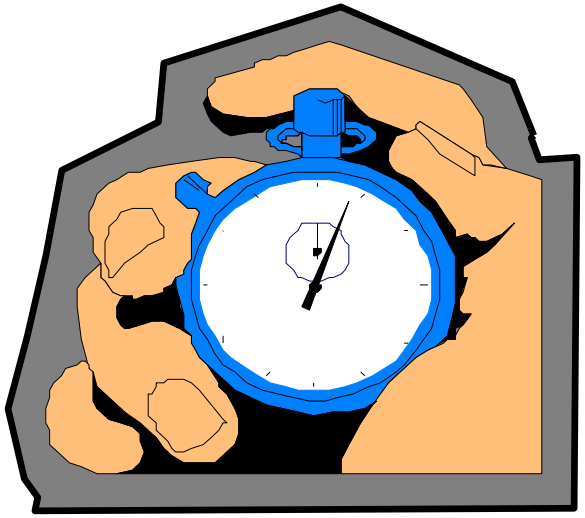
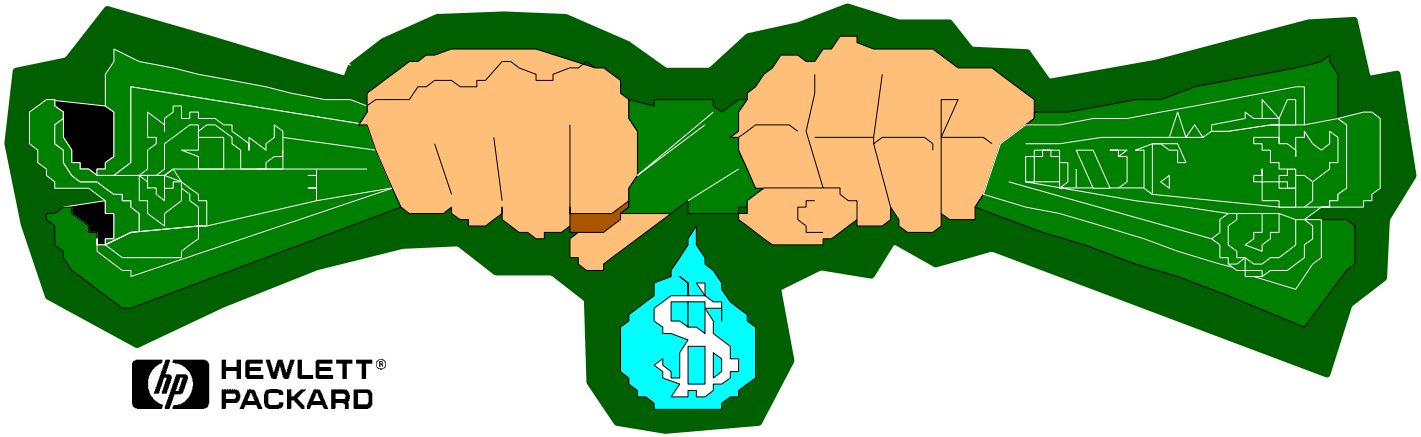
Three Critical Design Considerations

Time to Market



Performance

Cost



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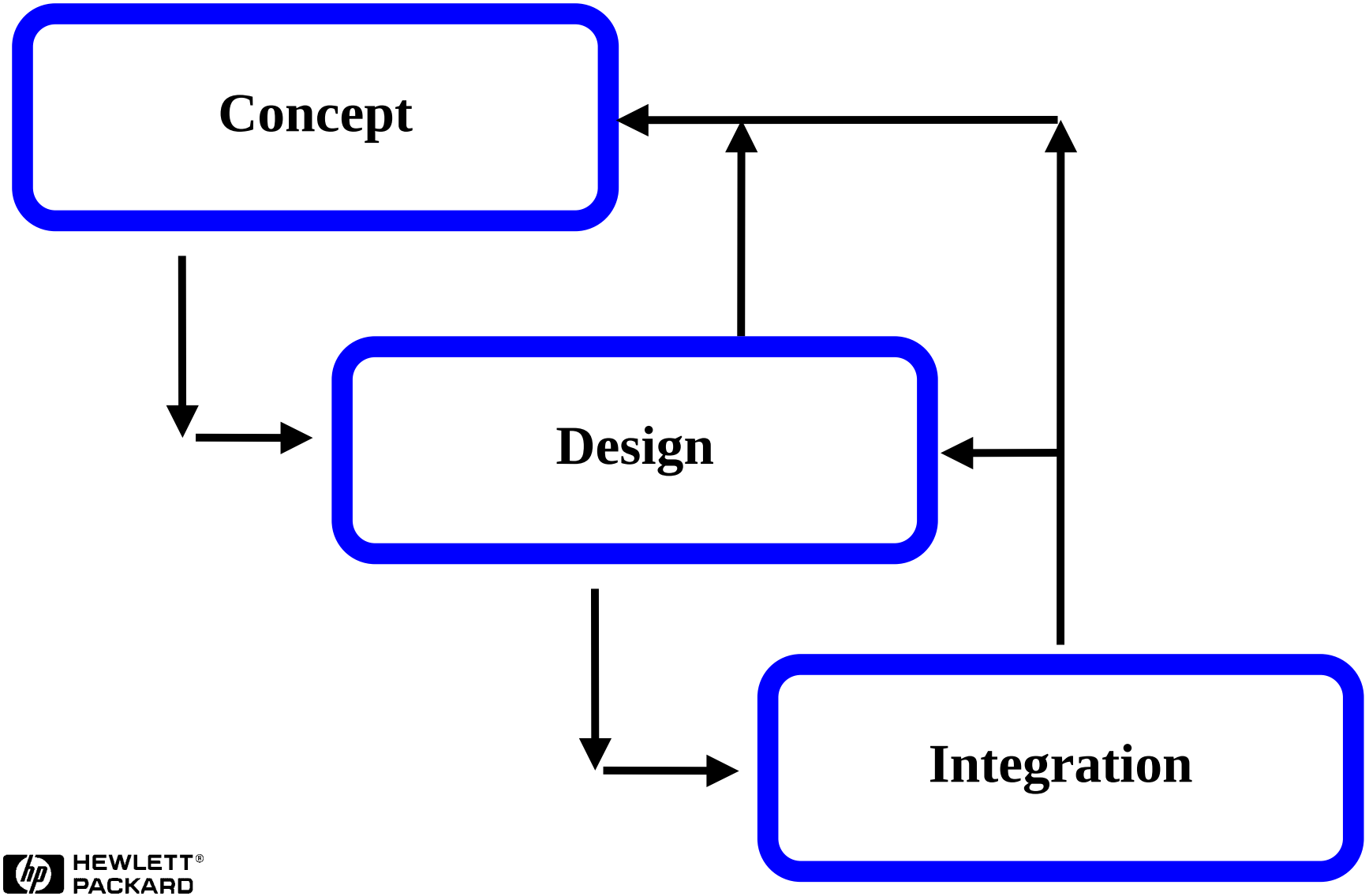
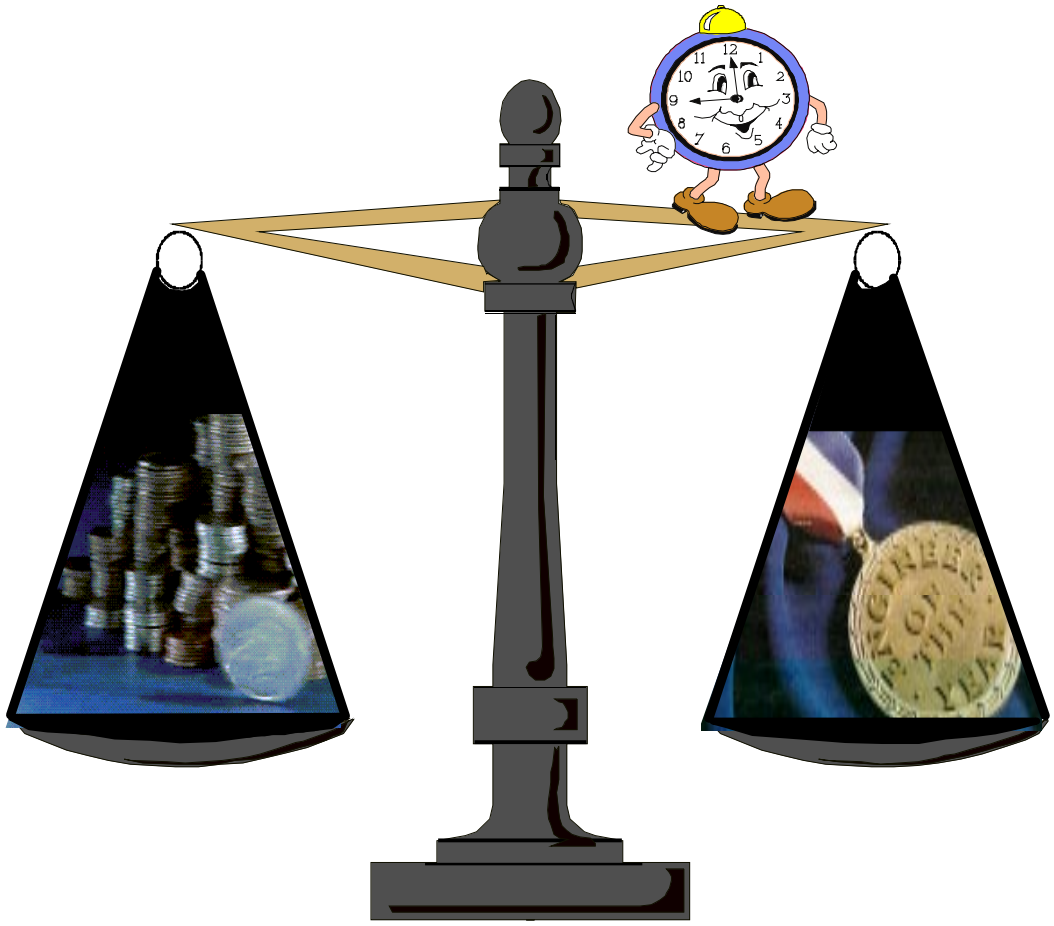
General RF Design Process



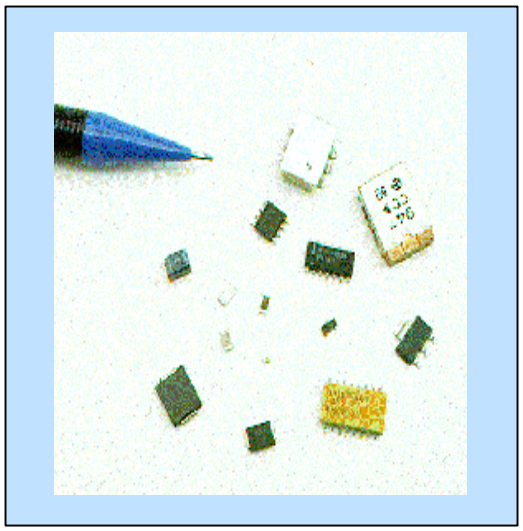
Concept:
System Design\Analysis\Partition

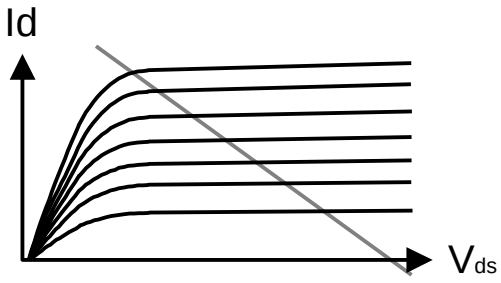
- Assess goals
- Set priorities
- Explore possible system configuration
- Design partitioning
- Allocate circuit specifications

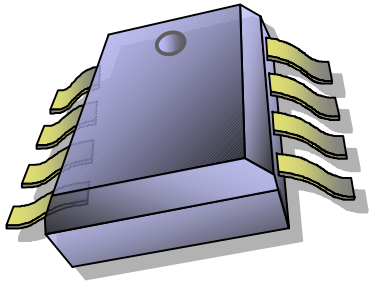


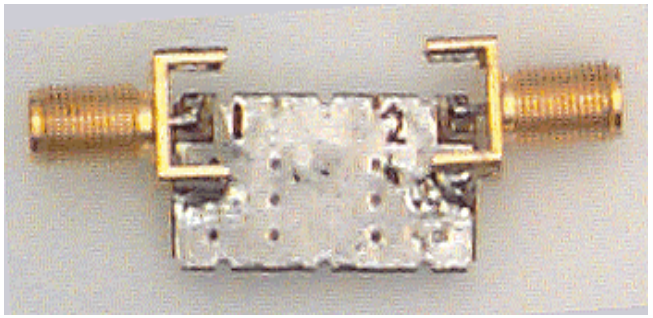
Circuit Level Design

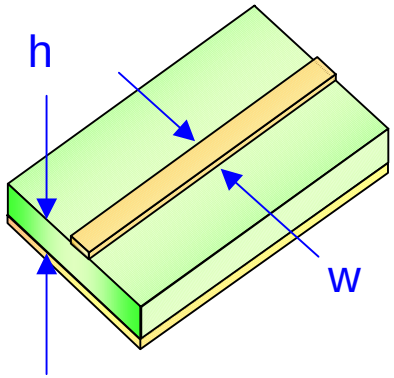
- Explore possible circuit topologies
- Investigate and select components
- Make build vs. buy decisions
- Determine whether desired circuit Specifications are realizable
- Verify system performance











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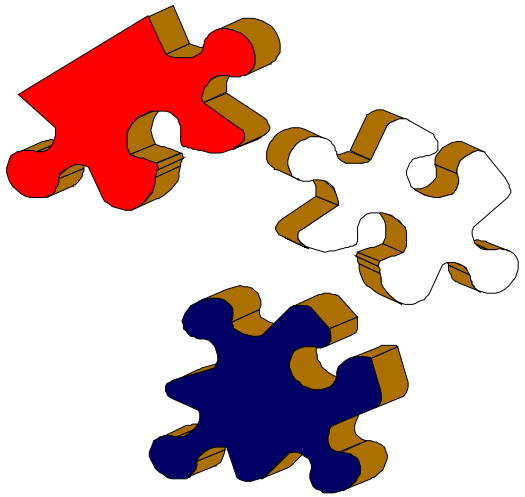
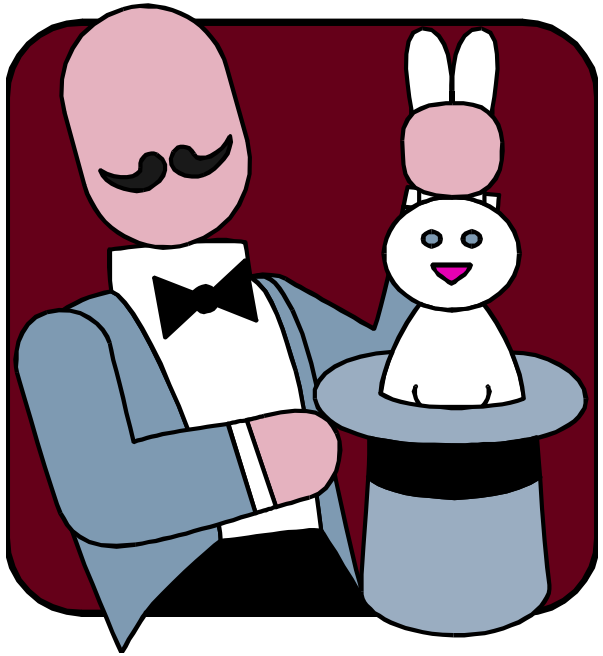
Integration

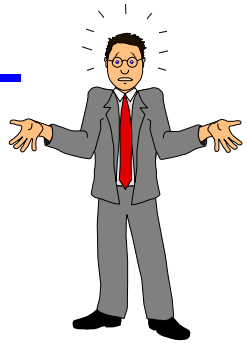
- Combine individual circuits
- Troubleshoot
  - System redesign, as needed
  - Circuit redesign
  - Circuit reallocation
  - System reconfiguration
- Modify system specification, as needed
- Re-define project definition, as needed

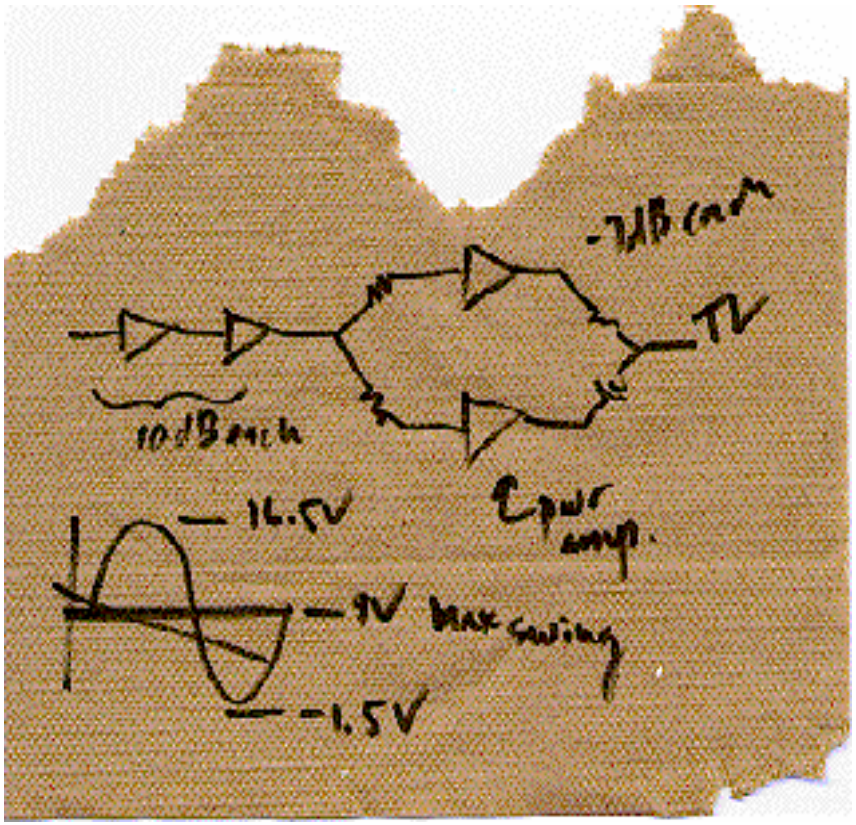


The Traditional Design Process



Concept:
System Design/Analysis/Partition

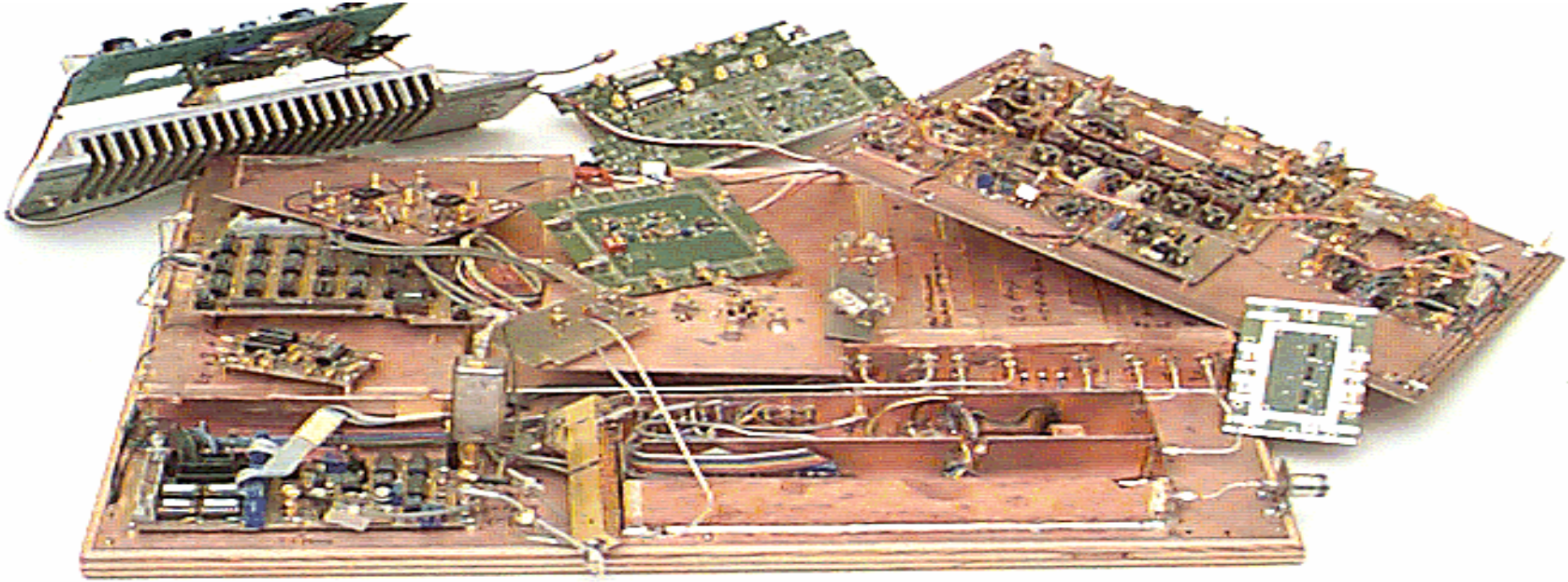




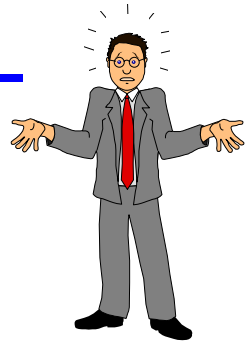
- Understand needs and goals
- Paper study
  - Prone to errors
  - Incomplete system analysis
  - Difficult to analyze circuit interactions

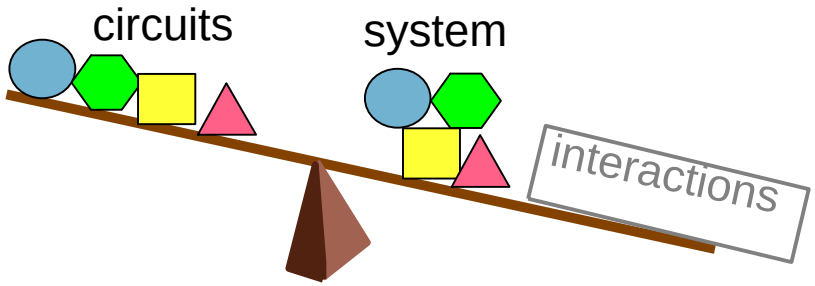
Circuit Level Design

- Reliance on physical breadboards (prototypes)
- Trial-and-error circuit design (cut & try)
- Difficult to verify circuit's performance on system level
- Difficult to predict interactions & manufacturing yield
- Expensive & time consuming!!!



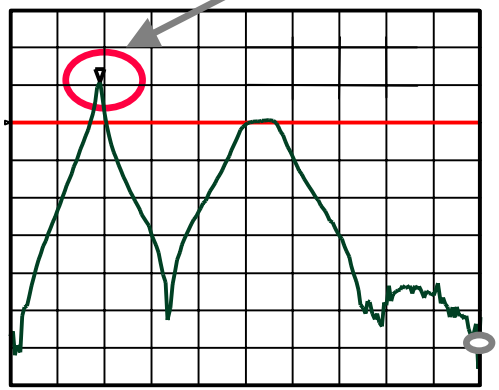
Integration & Test

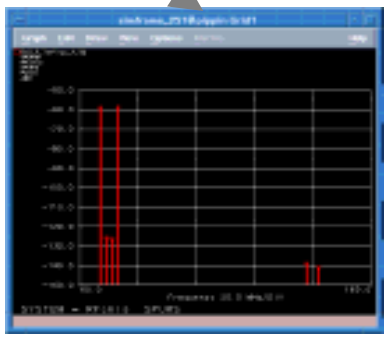




Once integrated, system =
Σ circuit + circuit interactions

- Trouble shooting
  - System level
  - Circuit level
- Little flexibility
- Expensive changes
- Inefficient process





When do I go home?

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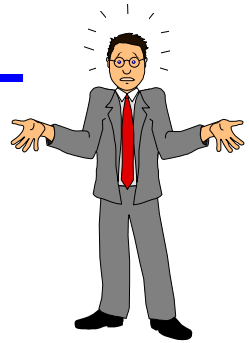
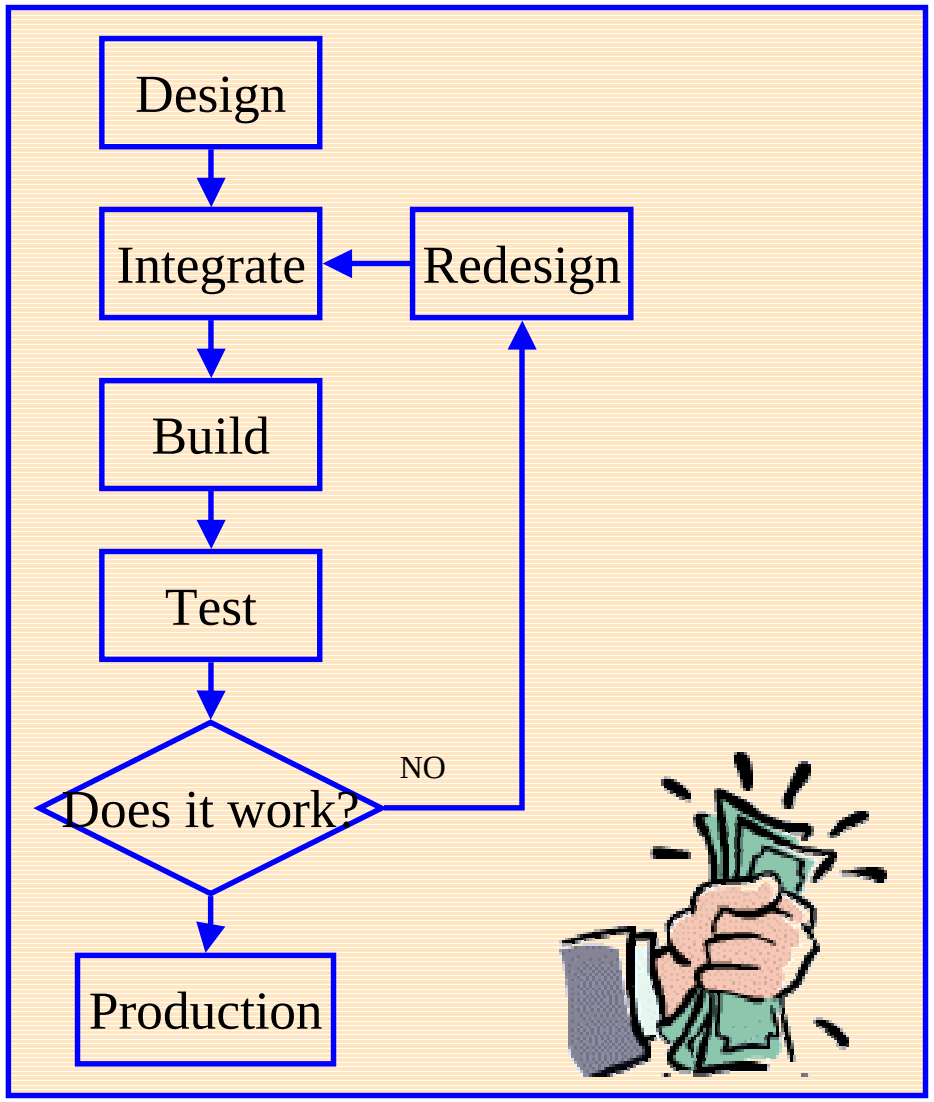
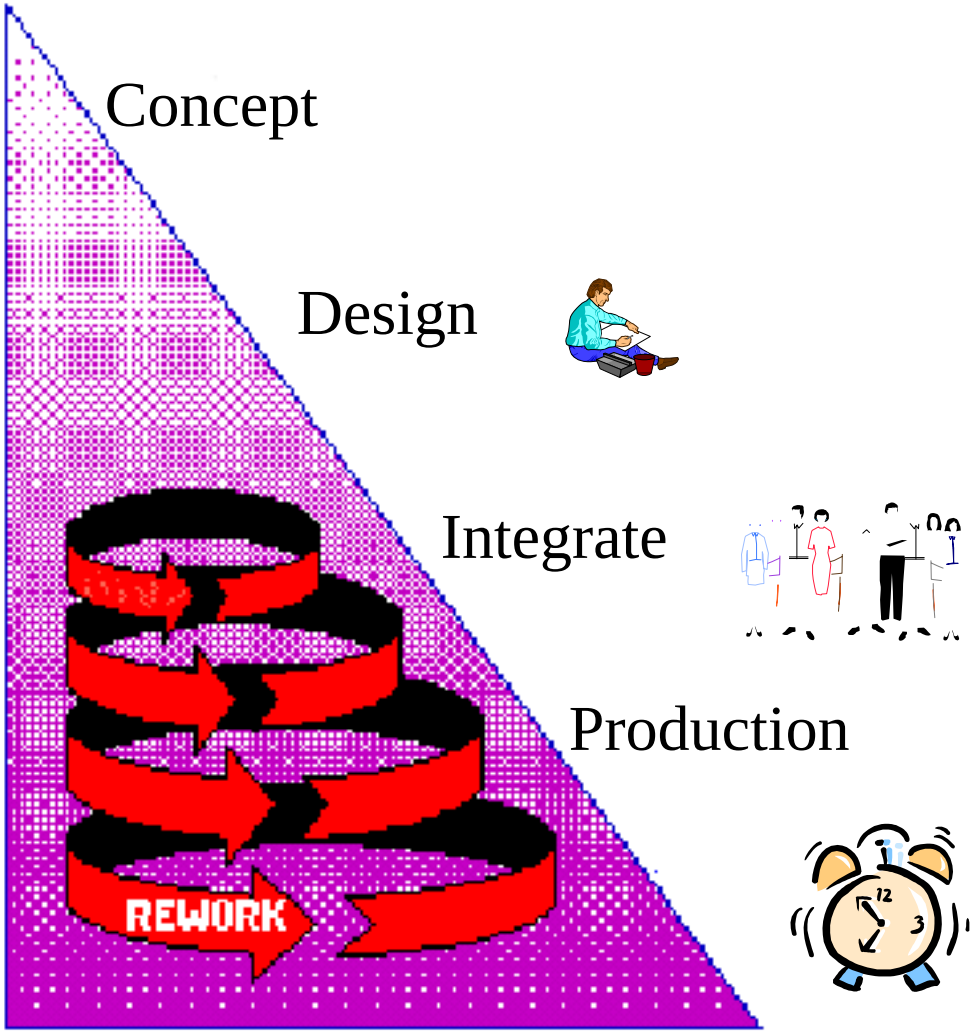
Traditional Design Process







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Modern, Predictive RF Design Process

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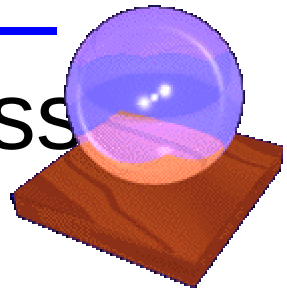
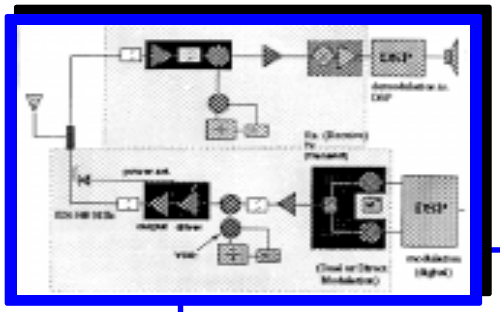
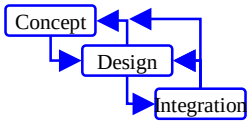


Combine test equipment and EDA software for fast, efficient design!



Concept

Design



Integration

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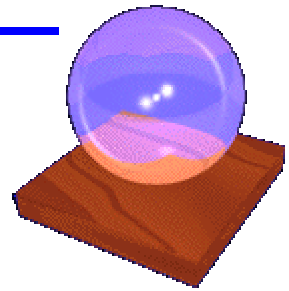
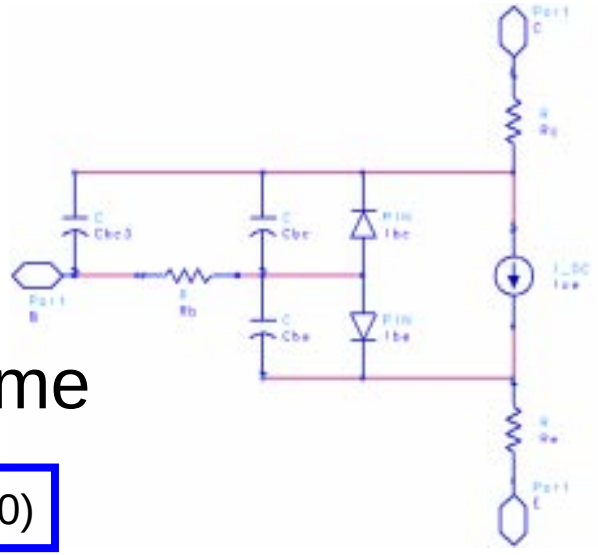
Investment in Models



- Dedicate modeling team
- Use available parts libraries
- Measure individual parts
  - Different operating conditions
  - Improve individual parts models with time



$$I_{be}=(IBbif(\exp(Vbe/NbfVT)-1.0))+I_{se}(\exp(V_{be}/(N_{ex}V_t))-1.0)$$

```
BJT_Model
BJTM2
NPN=yes        Br=     Cjc=    Rc=
PNP=no         Ikr=    Vjc=    Kf=
Bf=            Isc=    Mjc=    Af=
Ikf=           Nc=     Xcjc=   Kb=
Ise=           Var=    Fc=     Ab=
Ne=            Nr=     Cje=    Fb=
Vaf=           Tr=     Vje=    Ffe=
Nf=            Eg=     Mje=    Lateral=no
Tf=            Is=     Cjs=    AllParams=
Xtf=           Imax=   Vjs=
Vtf=           Xti=    Mjs=
Itf=           Tnom=   Rb=
Ptf=           Nk=     Irb=
Xtb=           Iss=    Rbm=
Approxqb=yes   Ns=     Re=
```

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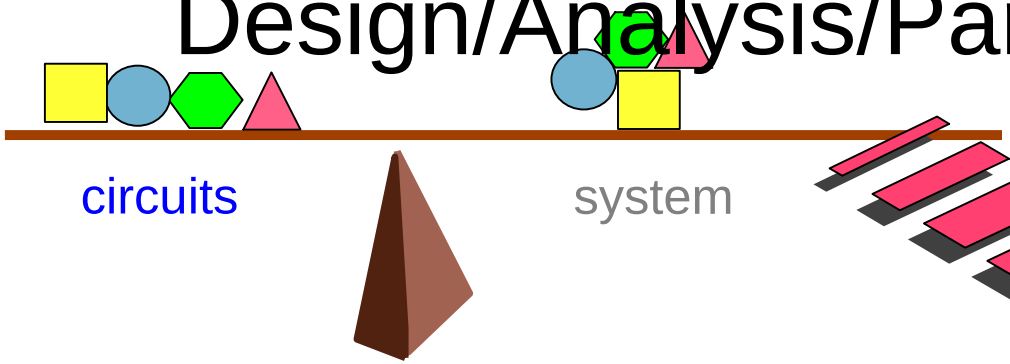
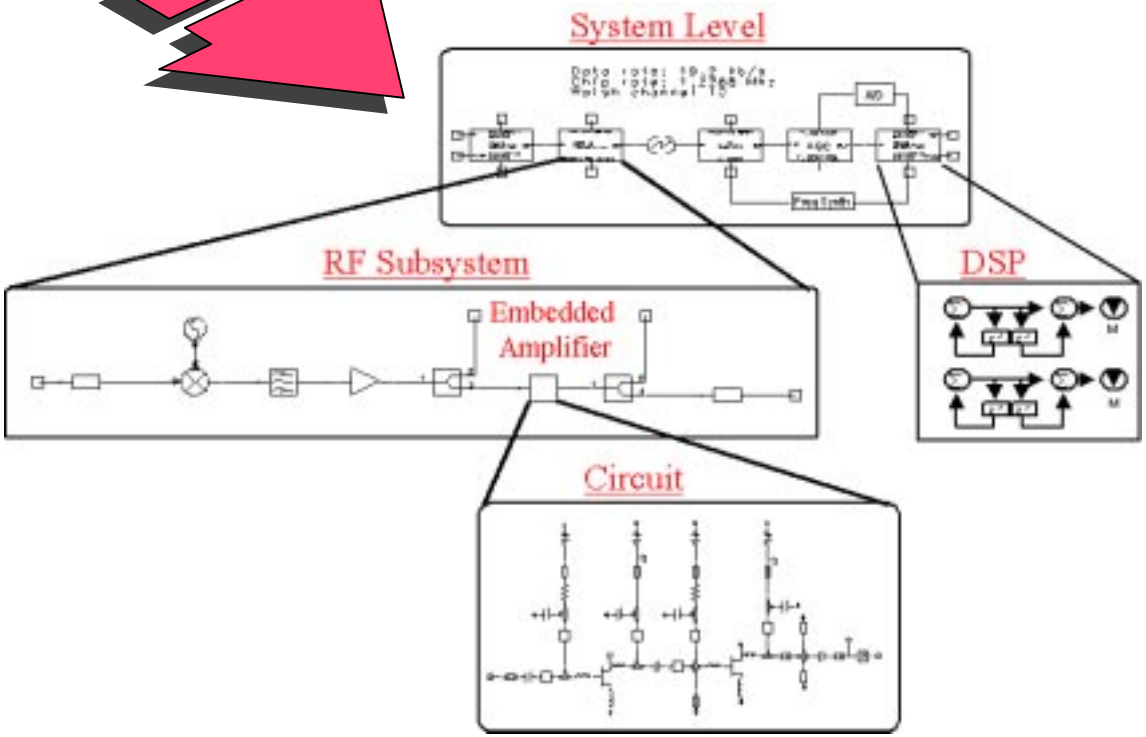
!Freq.[Hz]	MagS11[dB]	PhaseS11[DEG]	MagS21[dB]	PhaseS21[DEG]	MagS12[dB]	PhaseS12[DEG]
300000	-5.986E-07	-1.151E-02	-7.394E+01	8.997E+01	-7.394E+01	8.997E+01	-5.986E-07	-1.151E-02
315229	-6.384E-07	-1.210E-02	-7.351E+01	8.997E+01	-7.351E+01	8.997E+01	-6.384E-07	-1.210E-02
331231	-6.812E-07	-1.271E-02	-7.308E+01	8.997E+01	-7.308E+01	8.997E+01	-6.812E-07	-1.271E-02
348046	-7.273E-07	-1.336E-02	-7.265E+01	8.997E+01	-7.265E+01	8.997E+01	-7.273E-07	-1.336E-02
365714	-7.769E-07	-1.403E-02	-7.222E+01	8.997E+01	-7.222E+01	8.997E+01	-7.769E-07	-1.403E-02
384279	-8.303E-07	-1.475E-02	-7.179E+01	8.997E+01	-7.179E+01	8.997E+01	-8.303E-07	-1.475E-02
403787	-8.879E-07	-1.550E-02	-7.136E+01	8.997E+01	-7.136E+01	8.997E+01	-8.879E-07	-1.550E-02
424285	-9.501E-07	-1.628E-02	-7.093E+01	8.997E+01	-7.093E+01	8.997E+01	-9.501E-07	-1.628E-02
445823	-1.017E-06	-1.711E-02	-7.050E+01	8.997E+01	-7.050E+01	8.997E+01	-1.017E-06	-1.711E-02
468455	-1.090E-06	-1.798E-02	-7.007E+01	8.997E+01	-7.007E+01	8.997E+01	-1.090E-06	-1.798E-02
492235	-1.168E-06	-1.889E-02	-6.964E+01	8.997E+01	-6.964E+01	8.997E+01	-1.168E-06	-1.889E-02
517223	-1.252E-06	-1.985E-02	-6.921E+01	8.997E+01	-6.921E+01	8.997E+01	-1.252E-06	-1.985E-02
543479	-1.344E-06	-2.086E-02	-6.878E+01	8.997E+01	-6.878E+01	8.997E+01	-1.344E-06	-2.086E-02

Concept: System Design/Analysis/Partition



system-level interactions

- Top-level system brainstorming
- Quick analysis of circuit interactions
- Budget analysis to allocate circuit specifications
- Design partitioning



Quickly and accurately analyze system performance !

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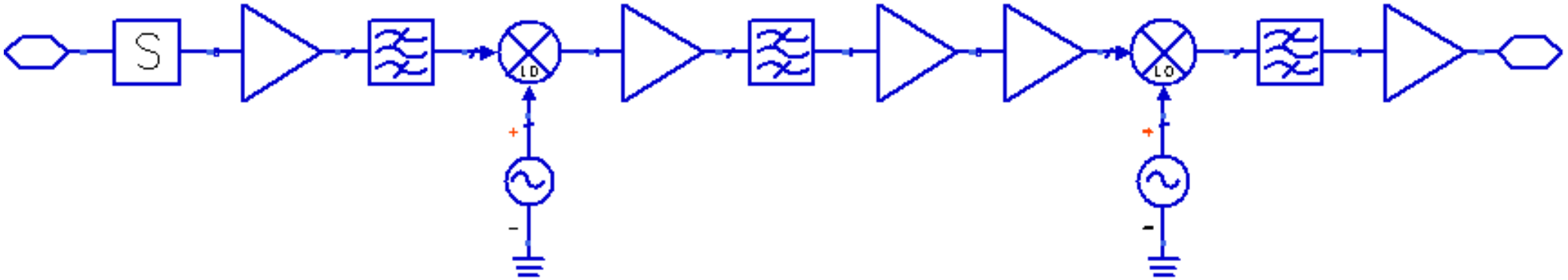
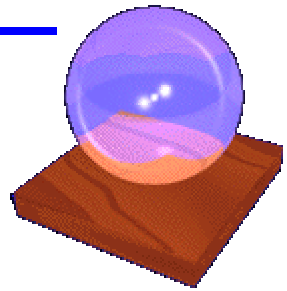
Block & Level System Budget Analysis

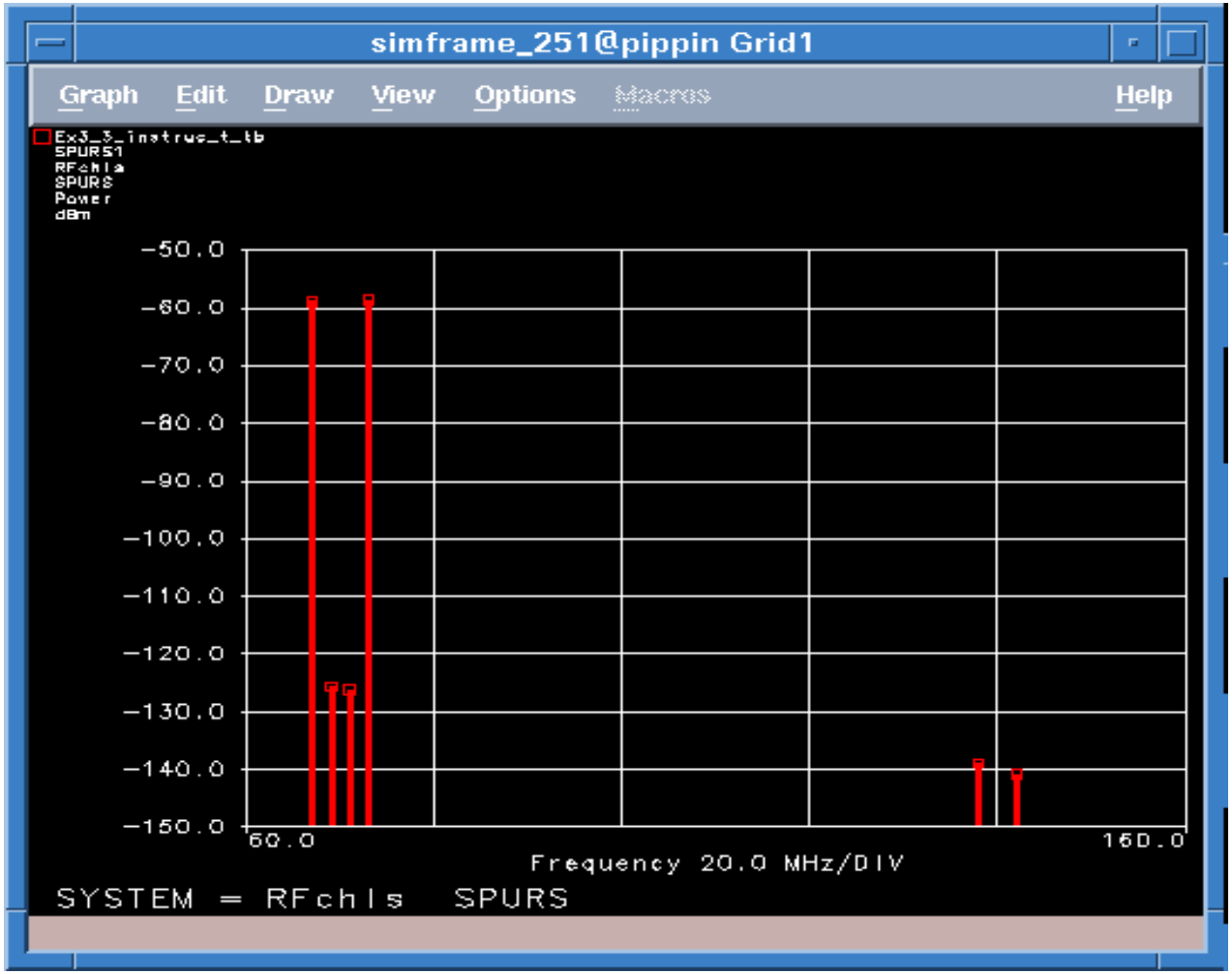


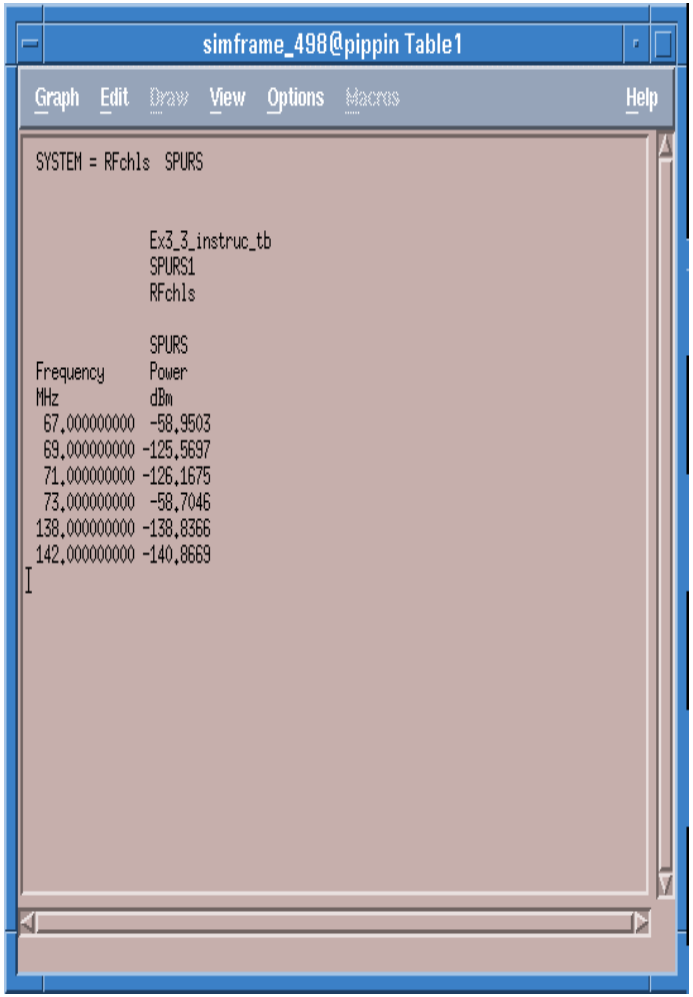
Element	Duplexer	LNA	BPF	Mixer	AMP #1	BPF	AMP #2	AMP #3	Mixer	BPF	AMP
Gain (dB)	-3	20	-2.7	-7	20	-17.4	30	30	-6	-6	45
Noise Figure (dB)	2.7	1.5	2.7	7.5	4	17.4	4	6	6	6	5
NFO (dB)	2.7	4.2	4.3	4.7	5.1	5.3	5.6	5.6	5.6	5.6	5.6
Power (dBm)	-125.3	-103.9	-107	-114.4	-94.1	-111.5	-81.5	-53.2	-58.9	-65	-19.9
SNR (dB)	6.5	4.9	4.9	4.5	4	3.9	3.6	3.6	3.6	3.6	3.6
TOI @ Output (dBm)		3.2	0.5	-7.5	8	-9.4	9.1	24.2	15.8	9.8	20

Classic Example: Spur Analysis



Select frequency plan based on predicted performance





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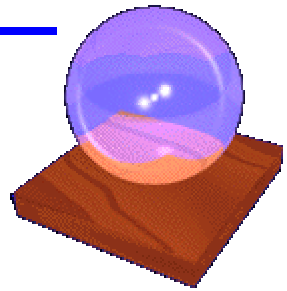
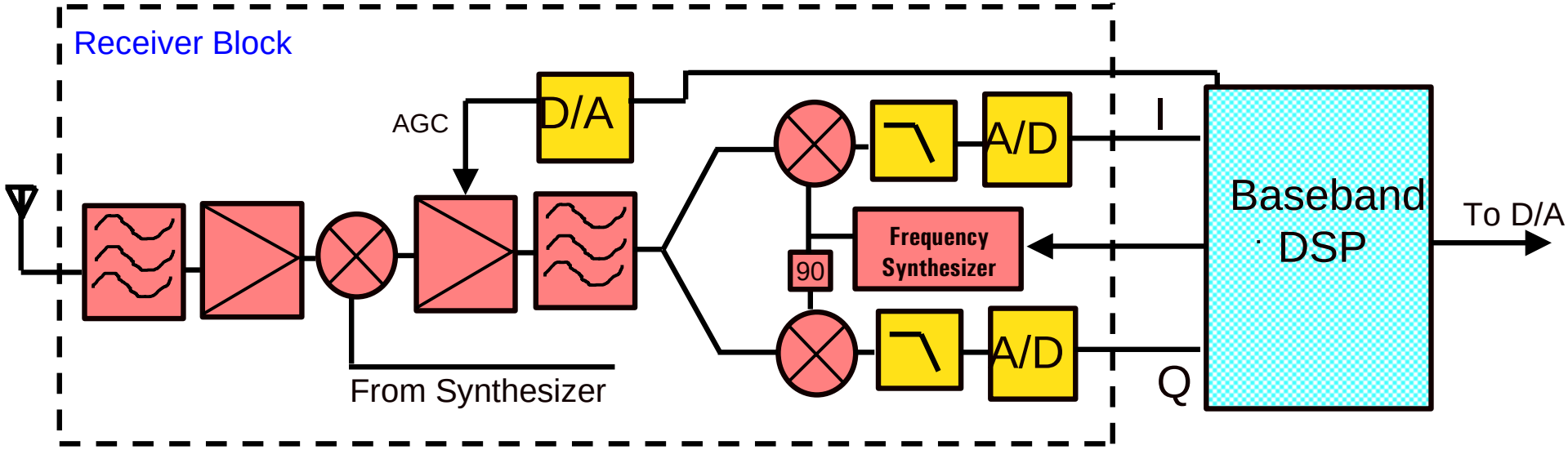
Integrated Design Environment





Circuit Envelope Simulation
Transient Simulation
HP Ptolemy Simulation

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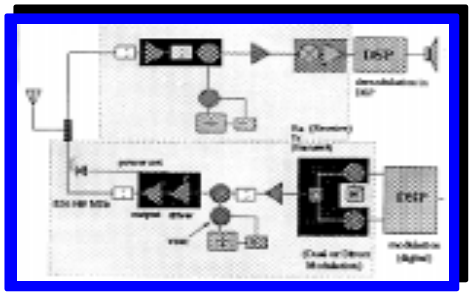
Circuit Design Cycle



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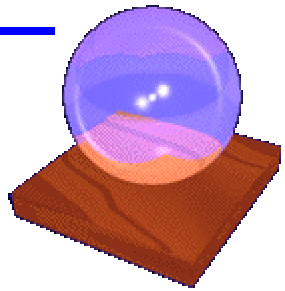


Design

Simulate (Circuit & System)

Good

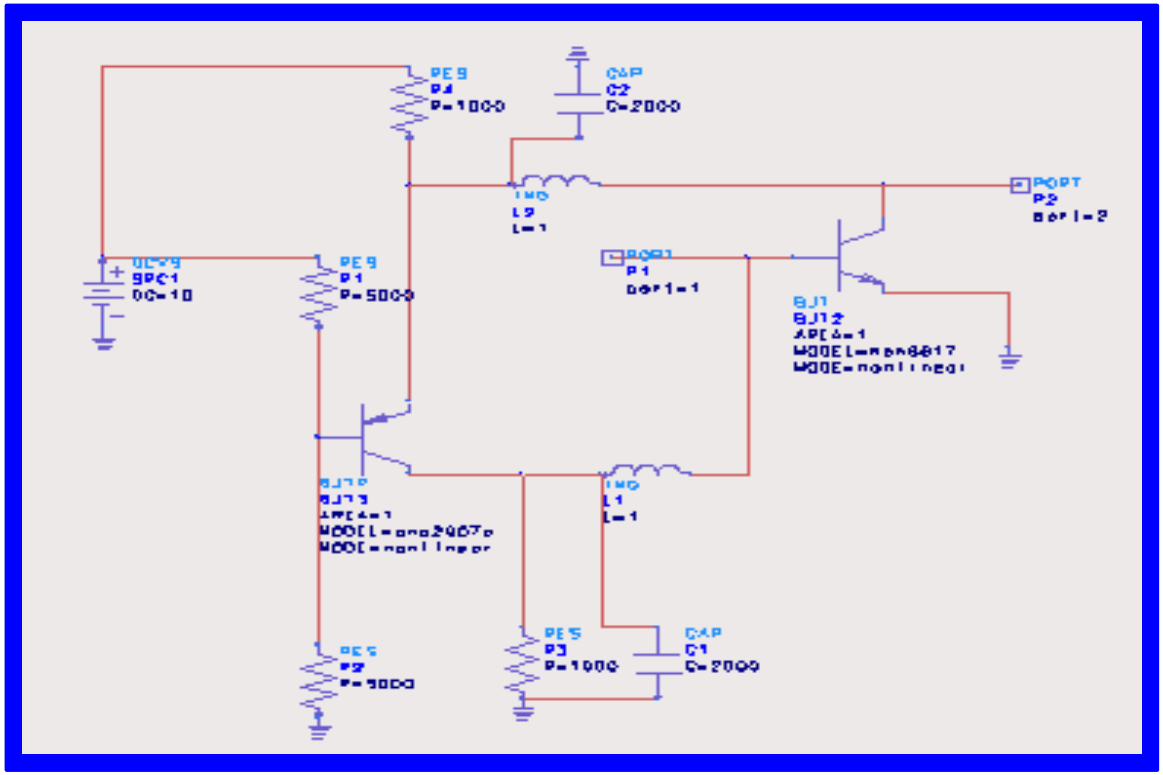
Build physical proto & test

Good

Integrate

Modify design to match proto

Circuit Design
Brainstorm



- Experiment with possible biasing schemes
- Explore different circuit configurations
- Make many different analyses quickly

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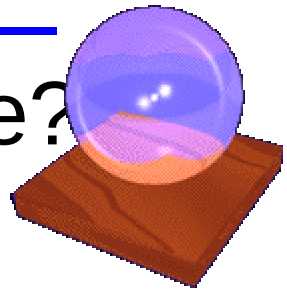
Why Modify Design to Match Prototype?



First, verify that there are no errors in the fabrication or measurement of the prototype.

Why modify the design to match the prototype?

- Provides starting point to refine design
- Gives good assurance that design changes will indeed improve design

right direction!

Continuing to optimize without a physical prototype

The closer prototype matches the model, the greater the probability for success :

$Ps = (k) \bullet x^{c} \bullet 100$

where
Ps= success probability
c = # of changes
k = guru factor (<1.0)

Careful! Proceed with caution.

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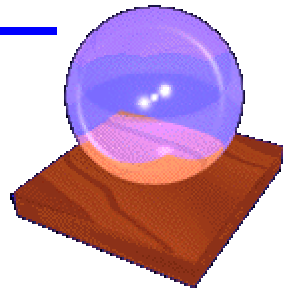
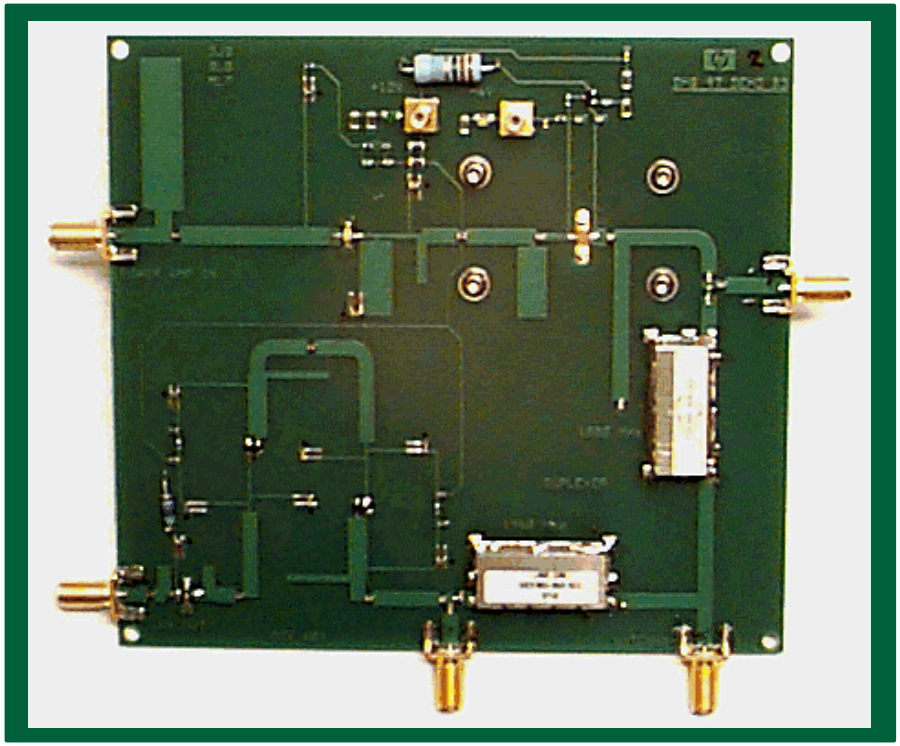
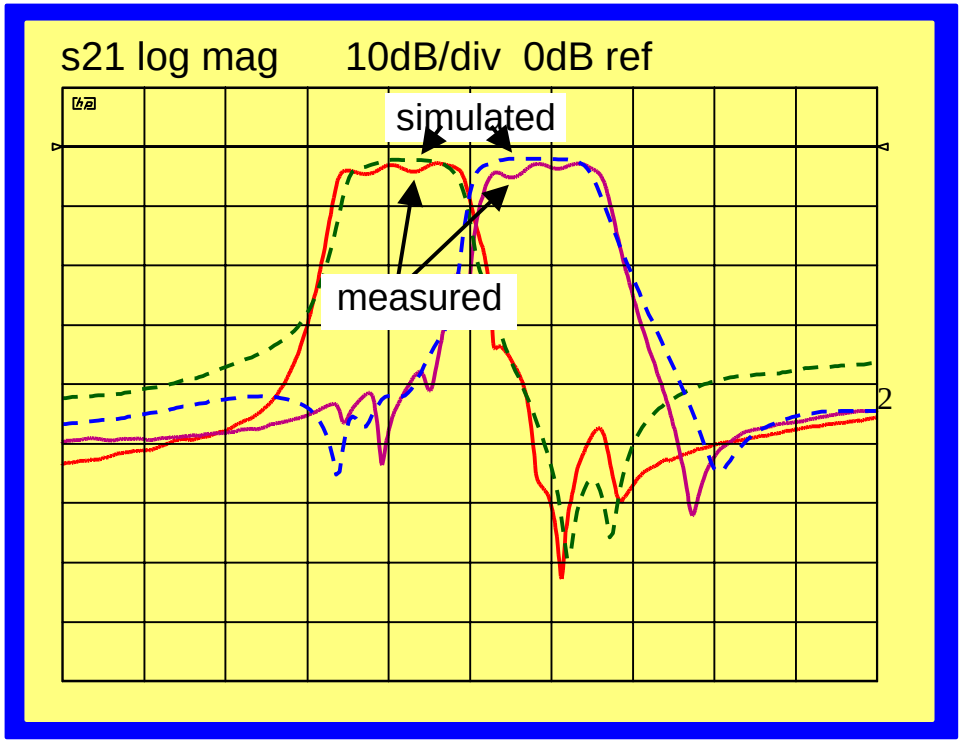
Integration: Layout & Prototype

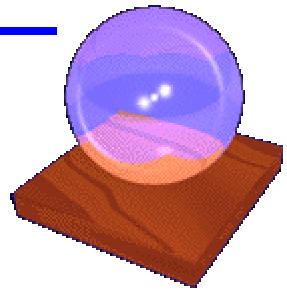


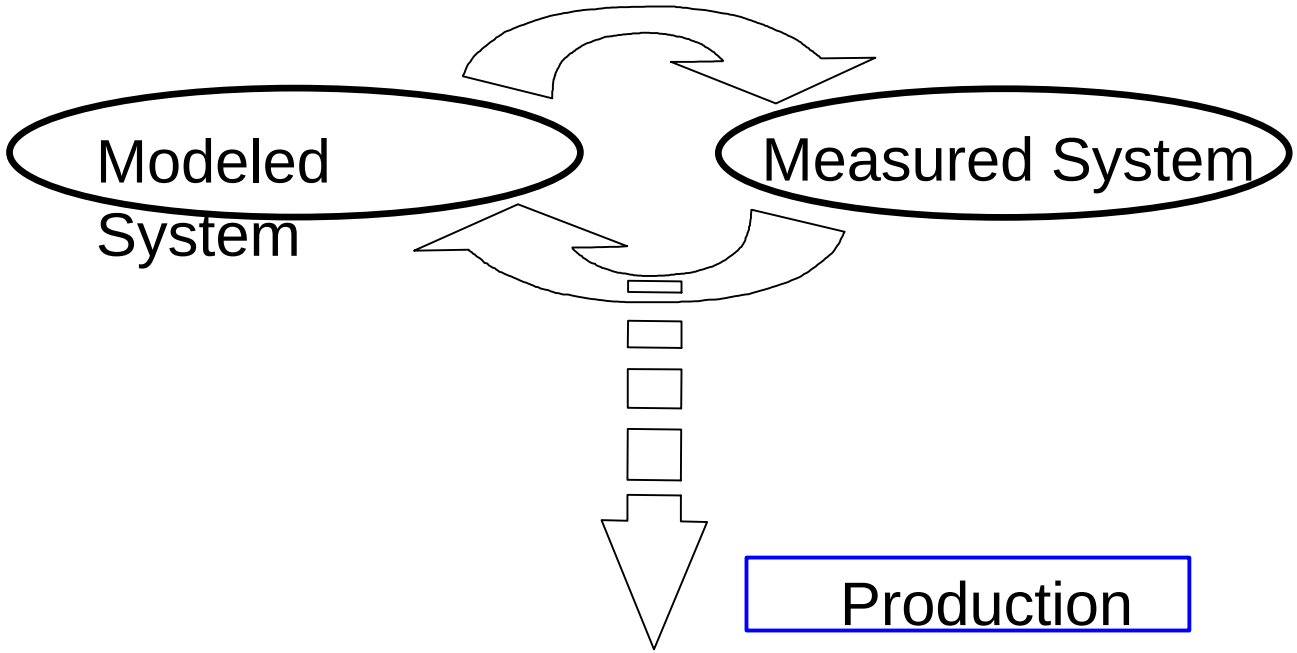
- Interconnect designs and measure performance
- Modify design to reflect measured results (if necessary)



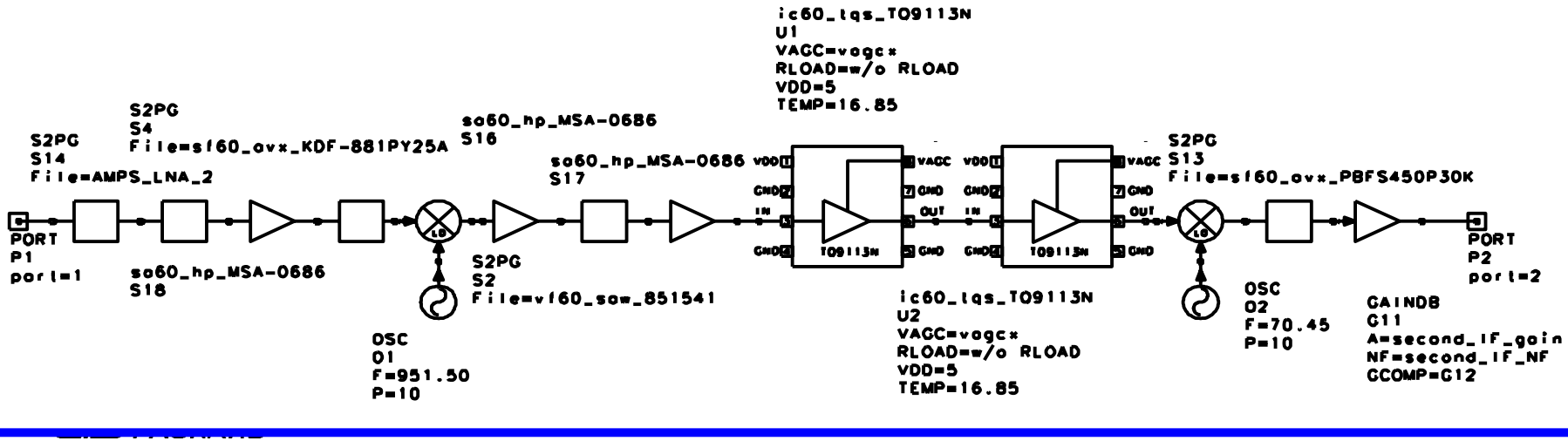


Success!
Measured = Modeled & Exceeds Spec

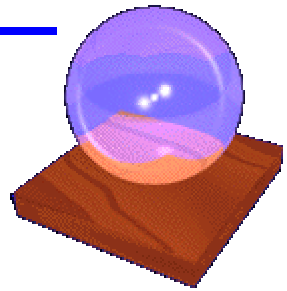


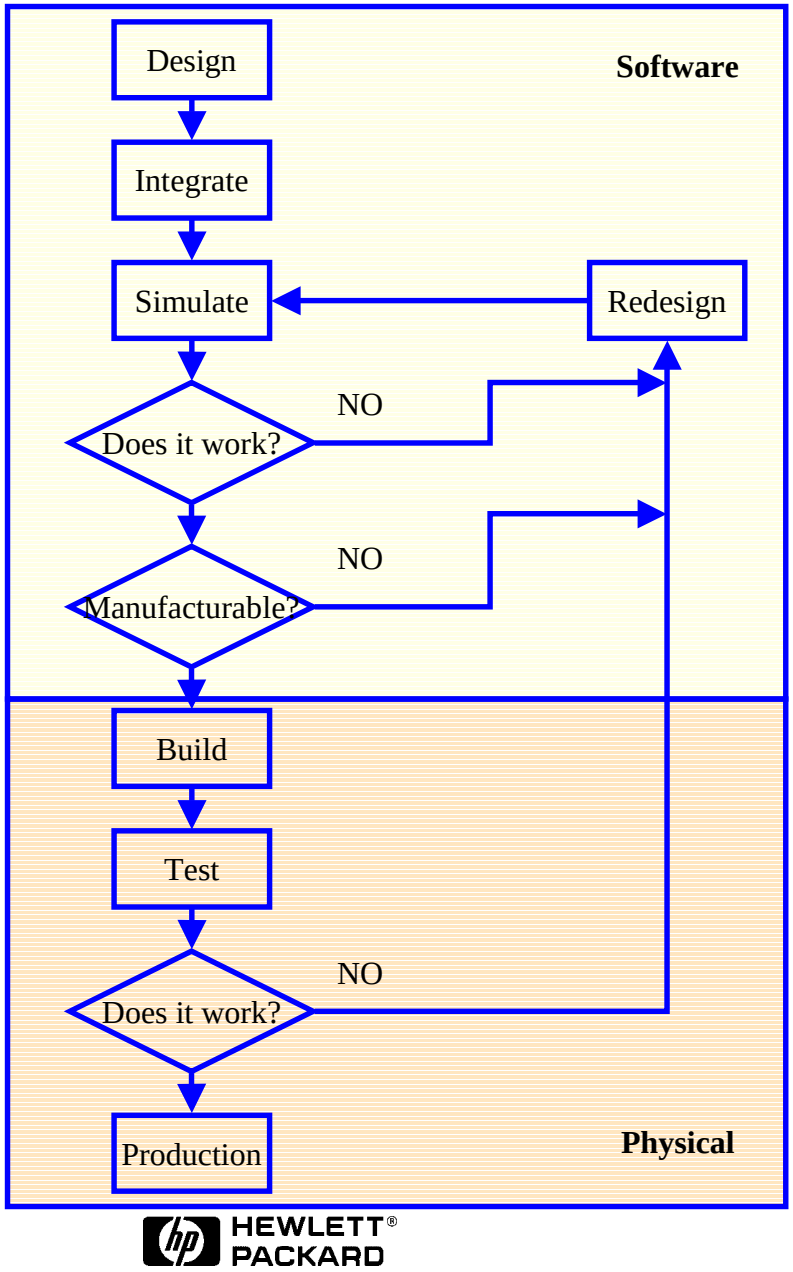


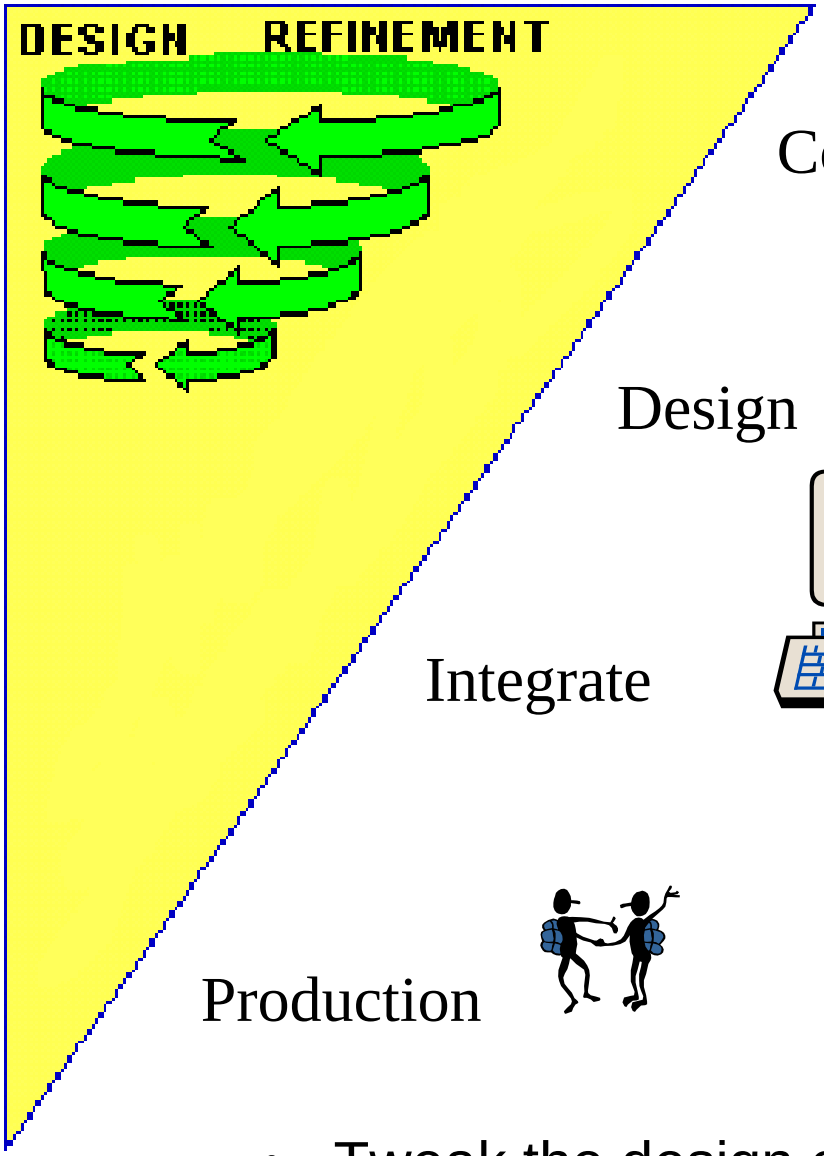
Production

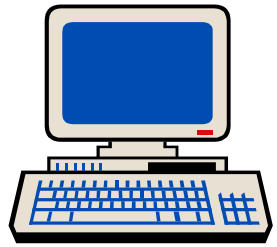


The Predictive RF Design Process









- Tweak the design on the work station, not on the bench!

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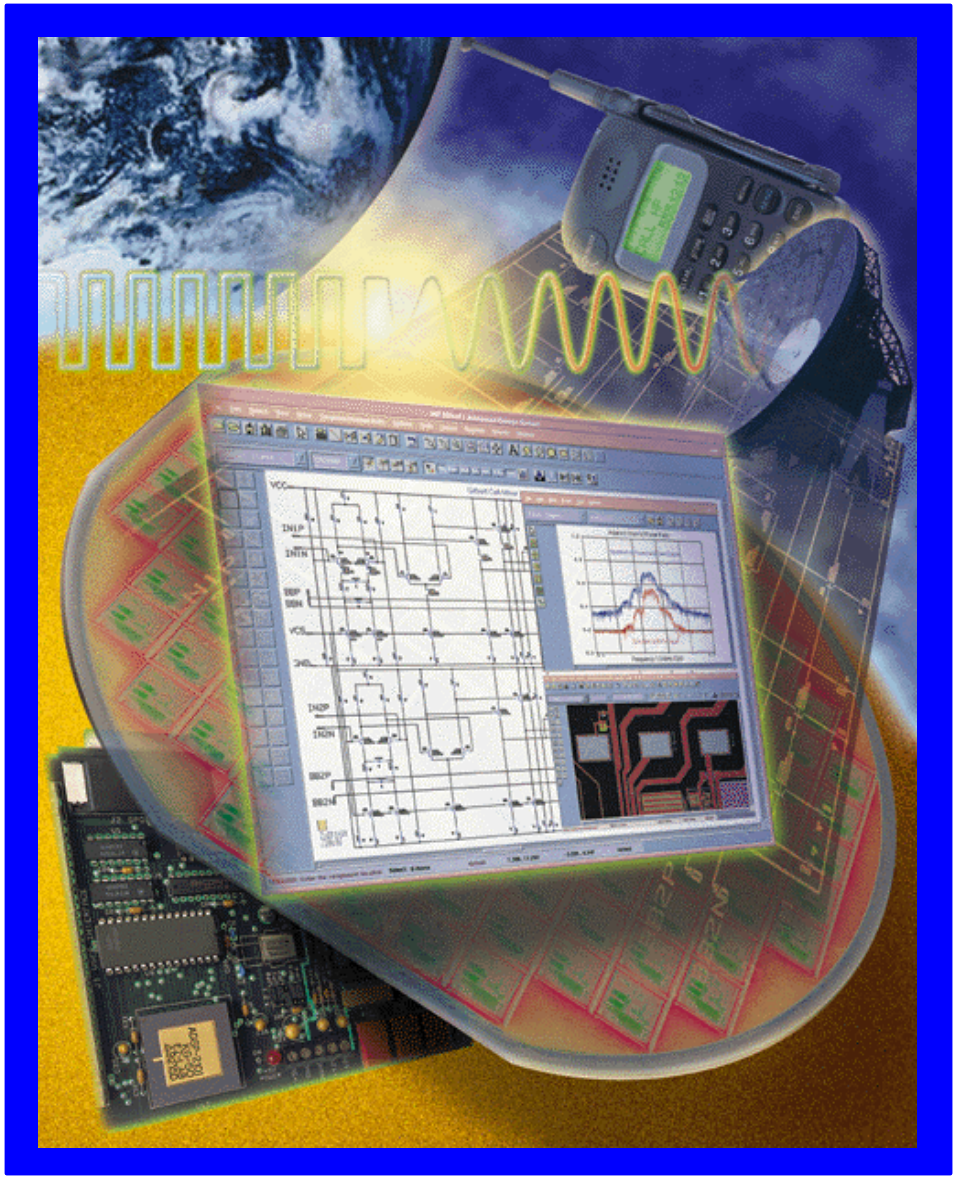
Solutions from Hewlett-Packard



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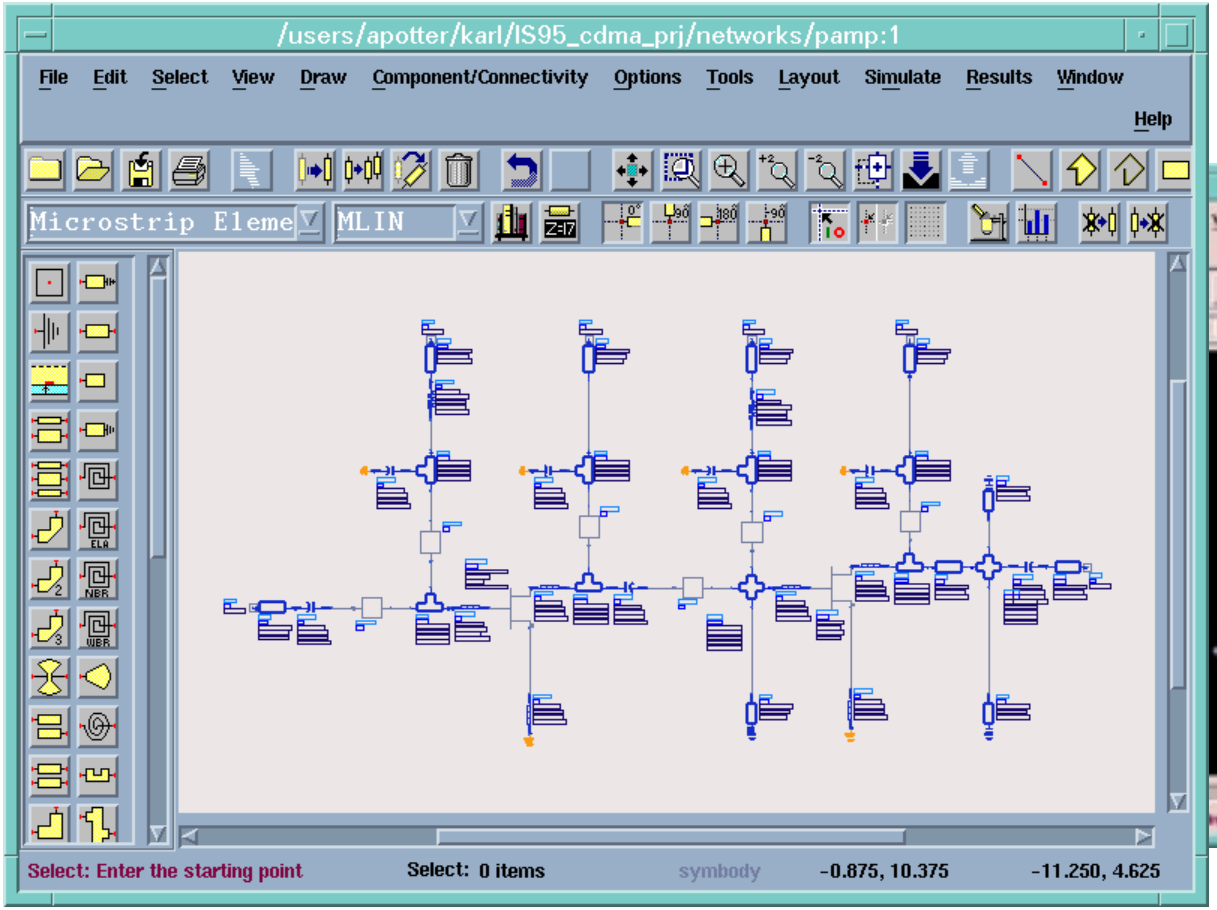
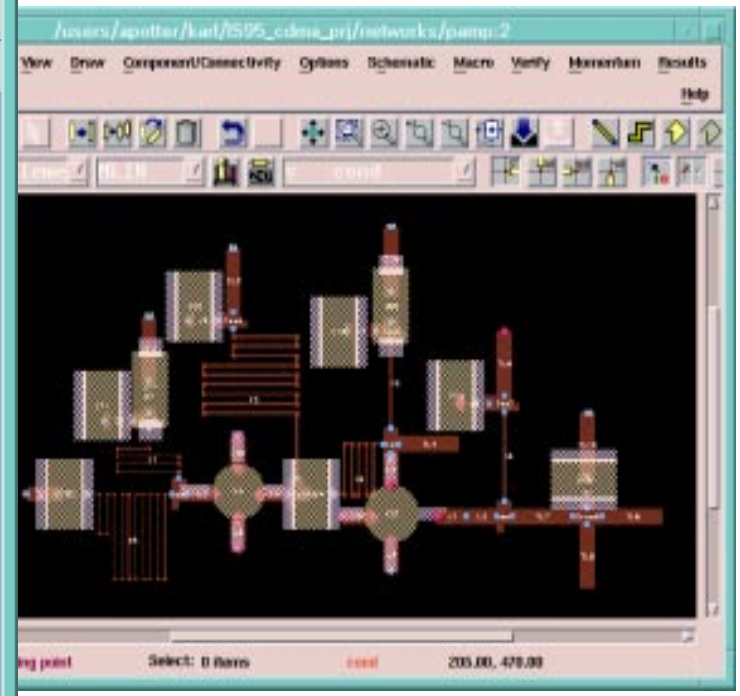
HP Advanced Design System

Total integration of schematic, simulation, and layout





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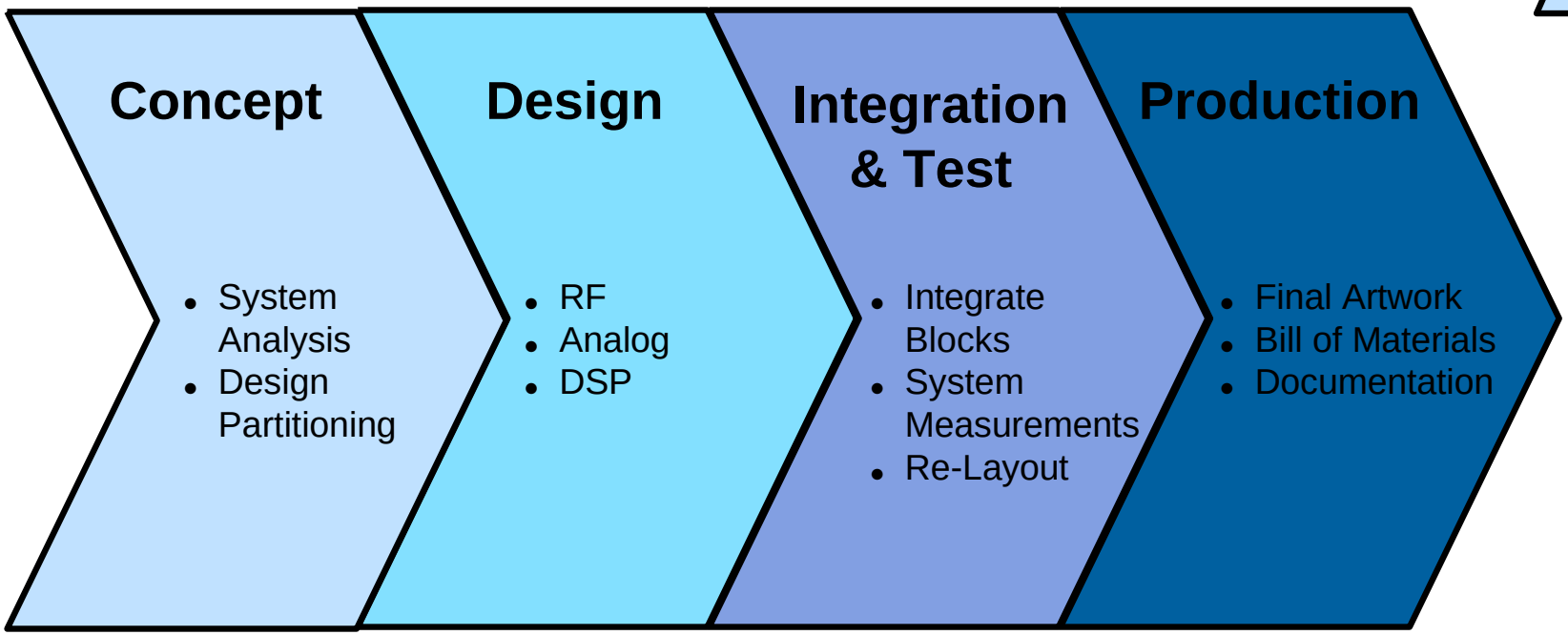
The RF Design Process



- Co-Simulation
- System Simulation

- Integrated Simulators
- Faster Simulators
- Optimizers
- Instrument I/O
- Parts Libraries

- Layout
- EM Simulation
- Parts Libraries
- Third Party Links

- Artwork Generation

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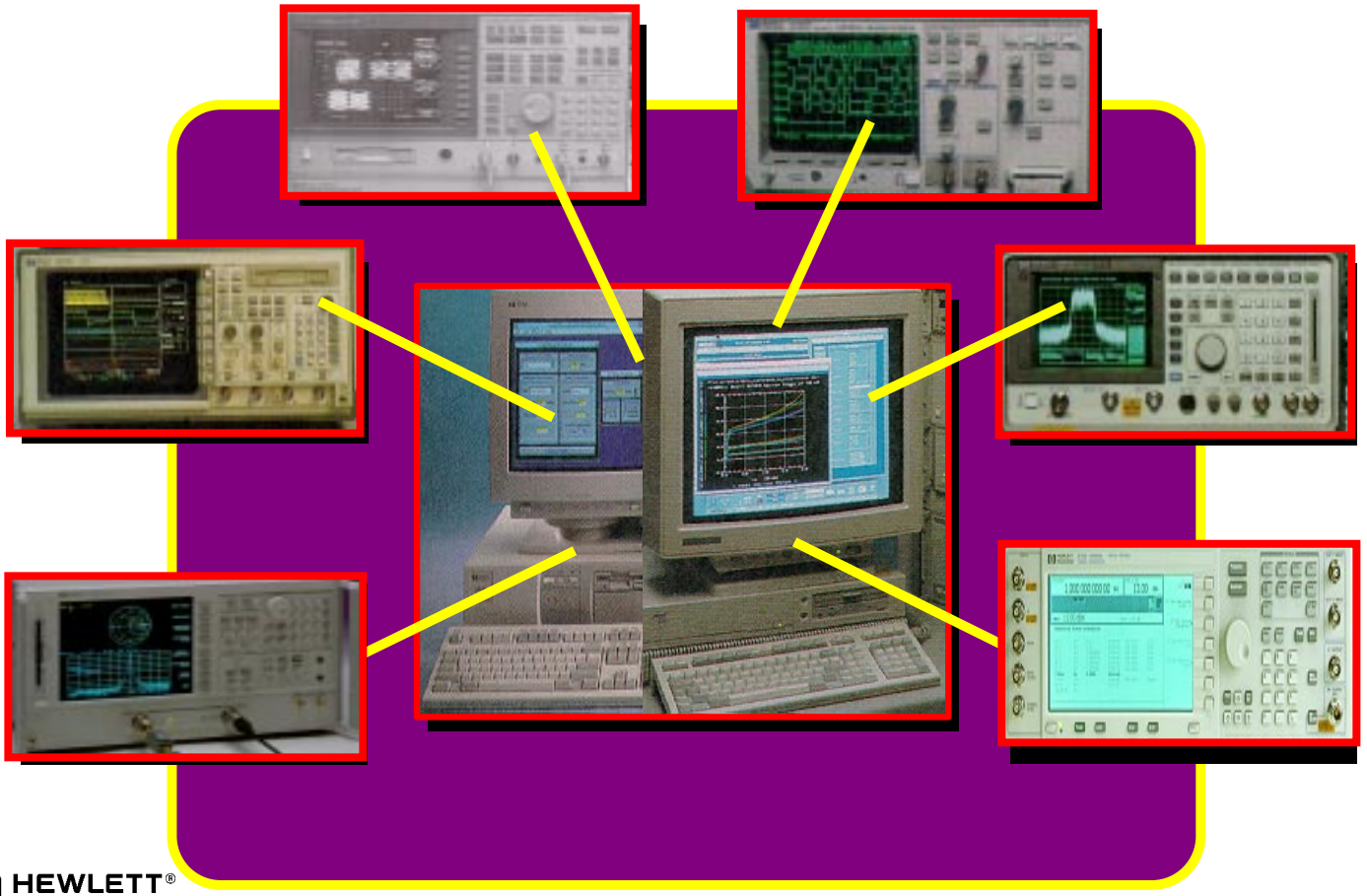
HP's Measurement Instrumentation

- HP Advanced Design System
- Network and Signal Analyzers
- Protocol Signal Sources (CDMA, GSM, etc.)



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