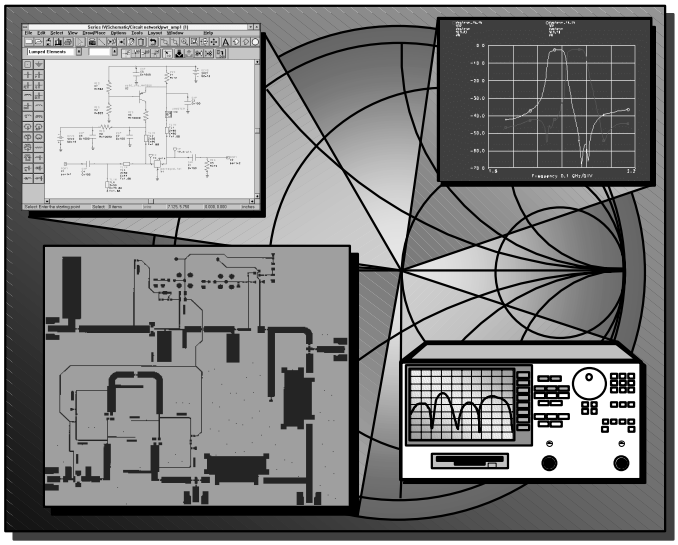
RF Design and Measurement Seminar

Slide #1

HP RF Design and Measurement Seminar



HEWLETT PACKARD

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David Ballo
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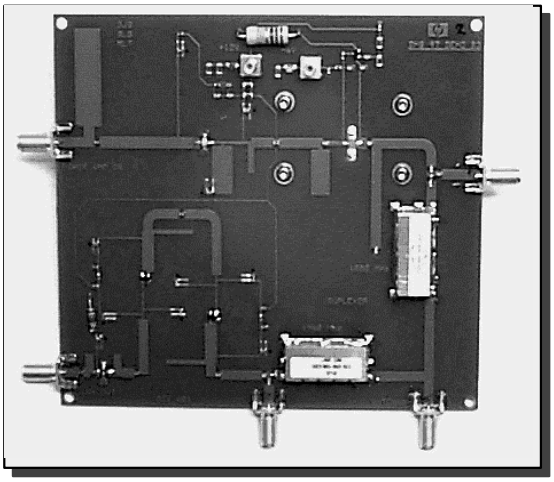
Slide #2

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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Welcome to Hewlett-Packard's RF Design and Measurement Seminar. The purpose of this seminar is to document the modern predictive RF design process. Hopefully, this will give new RF design engineers good preparation for their first circuit designs. We will focus on design methodology, not on specific mouse or button pushing to operate the tools. In other words, this seminar will not be a step by step description of how to use electronic-design automation software (like circuit and system simulators) or how to operate a network analyzer. We will talk in general terms about which tools to use and when and how to use them. We will also provide some practical design tips based on our case study of a PCS-band transceiver.

If you are interested in learning about the operation of the instruments or EDA software used for today's seminar, there is training information available on the web at http://www.hp.com/go/tmeducation.

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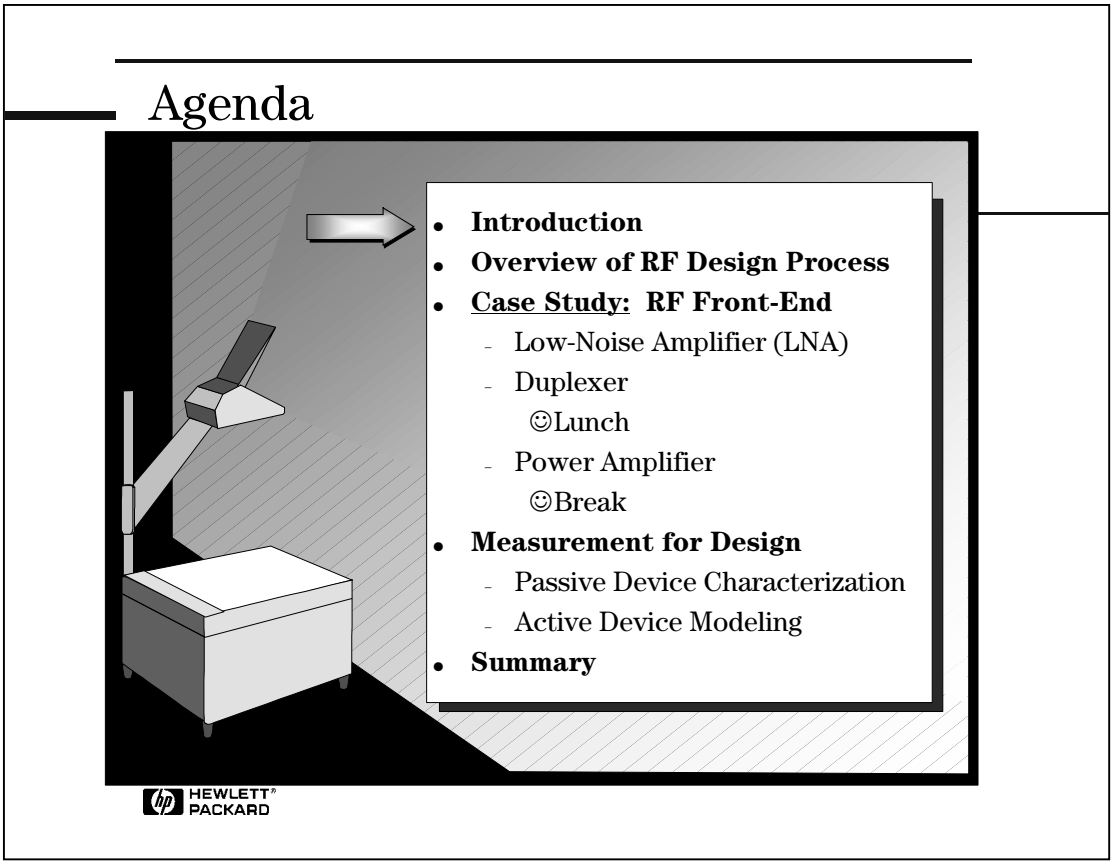

This is what we'll do today. First, we will provide an overview of the RF design process. Then we will begin our case study of an RF front-end wireless transceiver. This includes the design of an LNA, duplexer and power amplifier. Lastly, we will talk about obtaining models in the Measurement for Design section.

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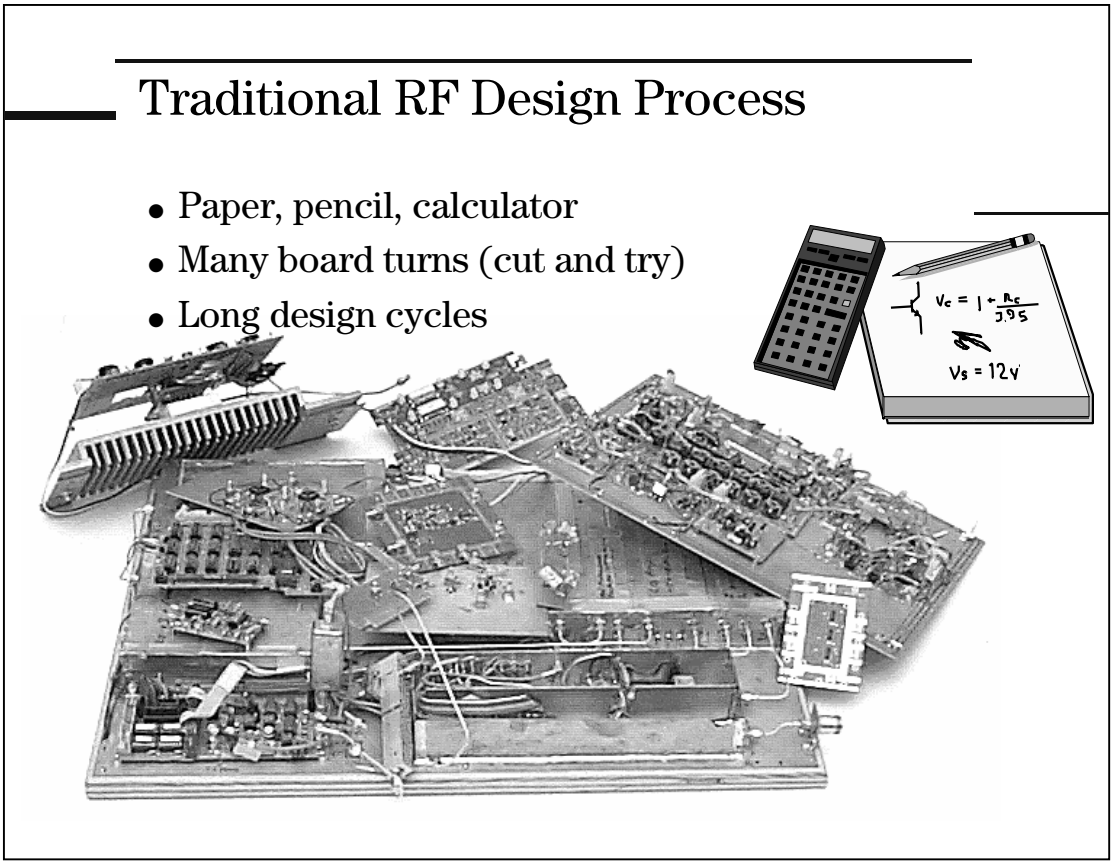

The traditional approach to RF design begins with a pad of paper, a pencil and a calculator (or slide rule for old-timers). Most of the critical aspects of the RF design are worked out with physical prototyping. The prototypes start out simple and then get more complicated as more circuits are added. At some point, the entire system is tested by connecting together the various circuits. This non-predictive process results in numerous board turns, which are time-consuming and expensive.

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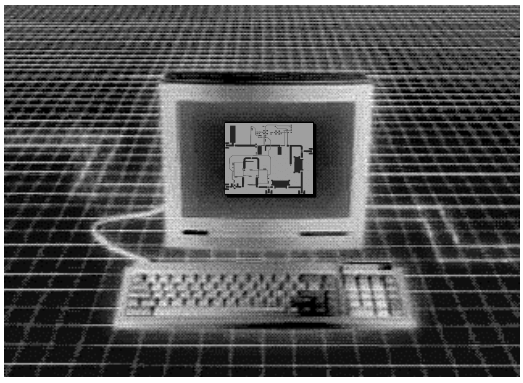
Modern, Predictive RF Design Process

- 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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The modern RF design process combines electronic-design automation (EDA) software and measurement equipment (such as network and signal analyzers) for an efficient and productive process.

There will still be multiple design iterations, but most of them will be performed in the computer, and not with physical breadboards. This faster design process improves time to market, letting you introduce your products ahead of your competitors.

And finally, the manufacturability of the board is greatly increased through the use of yield analysis and optimization.

In the Appendix in the back of this seminar book is a review of RF terms and principles. This section covers transmission lines, the Smith chart, measurement terminology for reflection and transmission measurements, S-parameters, and nonlinear measurements. We're going to assume that you are familiar with these terms and concepts either from previous experience or another HP seminar.

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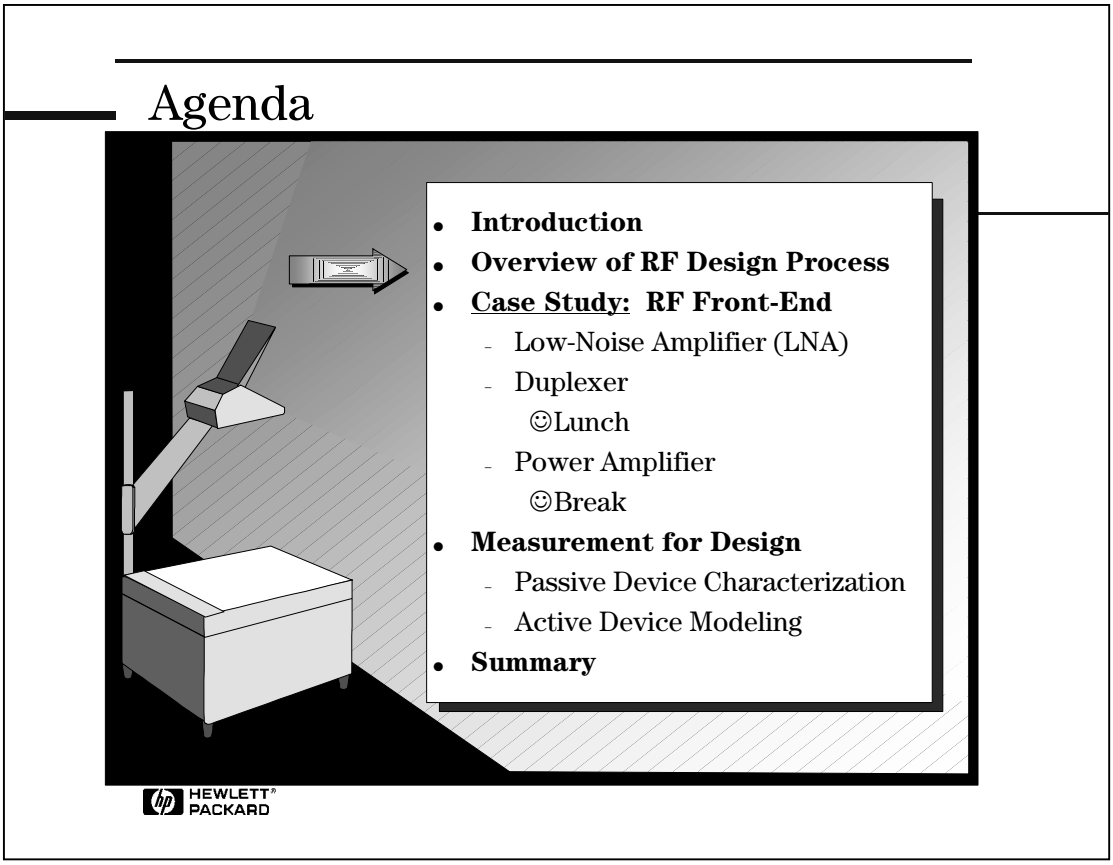

Let's begin with the RF Design Process, why a good process is important, what the elements of a well-constructed RF design process are, how many companies and engineers approach implementing this process (traditional or non-predictive design process) and finally, we'll talk about why we're here today, how to implement a modern, predictive RF design process.

At the end of this section, we'll provide a brief overview of the products and solutions offered by HP that help you solve RF design problems.

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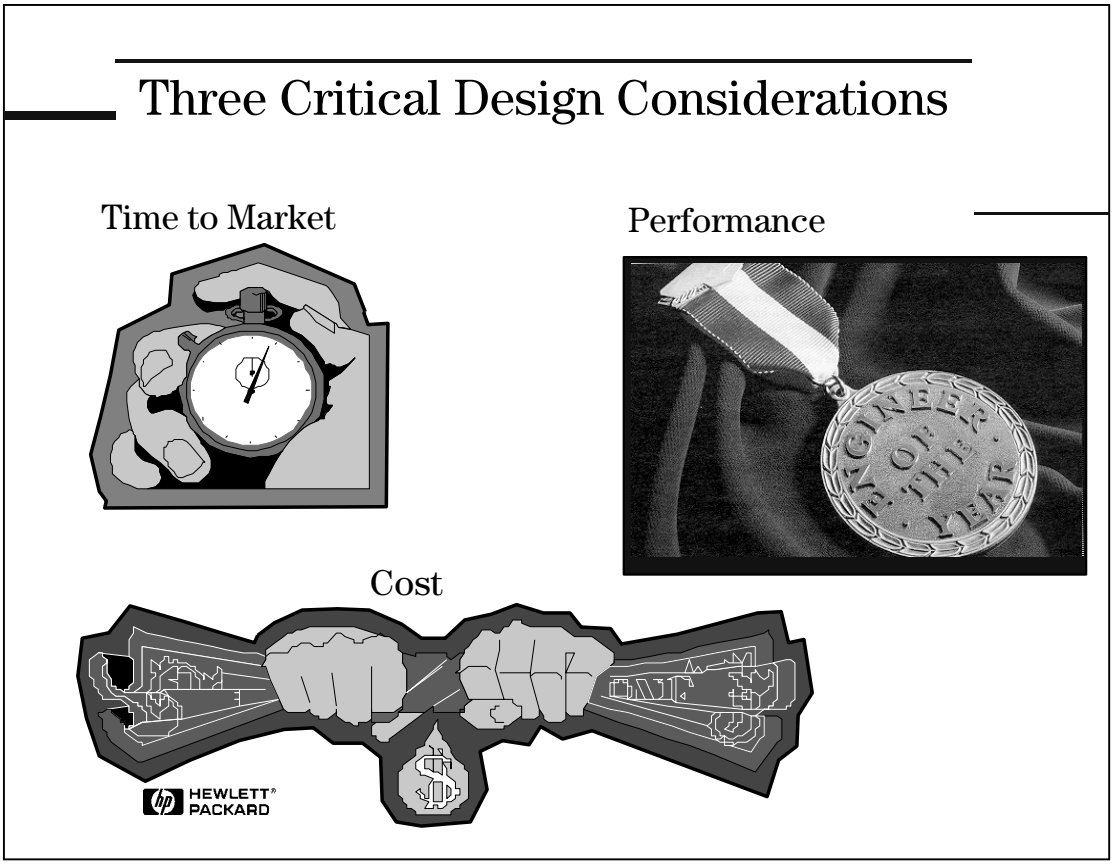

The continual introduction of new, improved products is the foundation of any company's future growth and success. In general, the three critical design considerations of new products are performance, cost, and time to market. These new products must meet the customer's needs better than the competition, be completed on budget, and be available when the customer needs them. It is usually not possible to optimize all three criteria. In creating an acceptable balance, designers will choose to optimize for one, do what they can for another, and simply accept the outcome of the third.

For example, in the defense/aerospace industry, performance is typically the most important factor, for the wireless industry it's time-to-market, and for a relatively mature industry like pagers, continually reducing cost is the primary goal.

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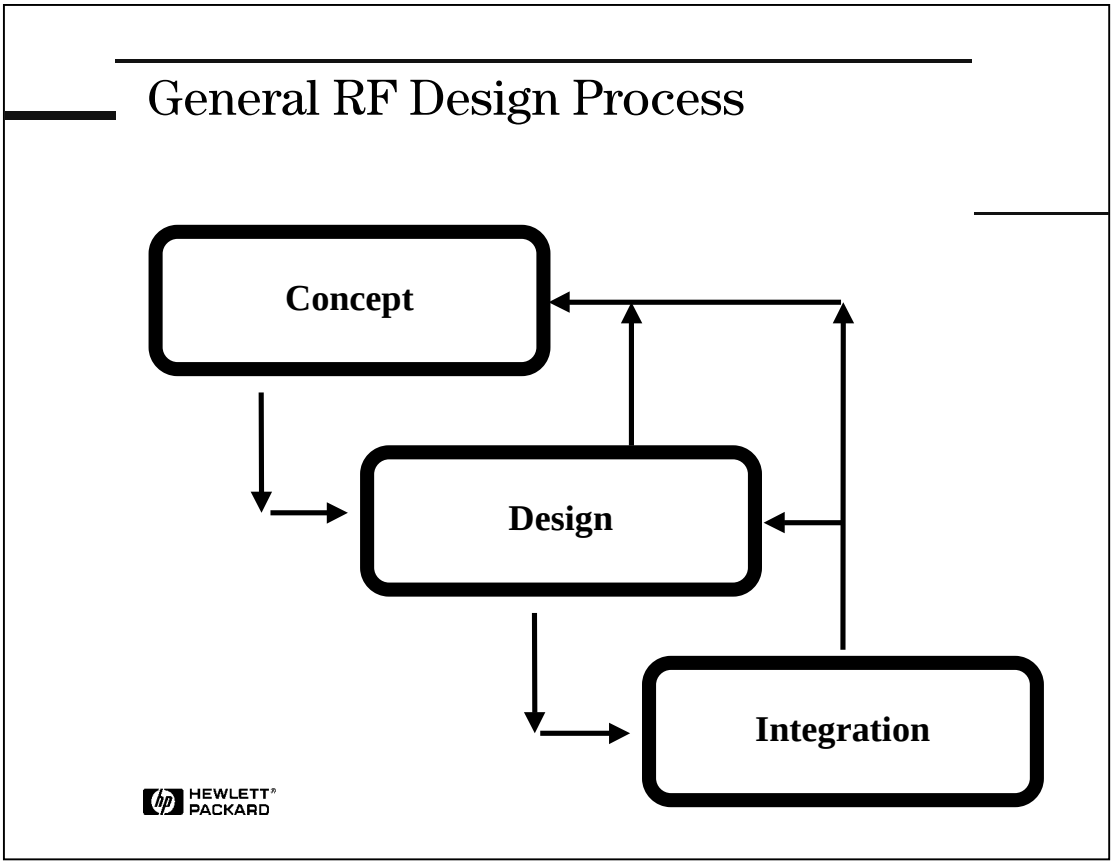

Let's begin by looking at the stages of an RF design process.

The first stage, Concept, is where the project goals are defined, functional block diagrams are created and overall system-level topologies are investigated.

Once the project is defined and the initial system configuration set, the Design of individual circuits begins. When the Design Stage is completed the individual circuit designs should function, but until this point they have been isolated from the rest of the system. Now we need to find out how the designs work together.

At the Integration Stage, the individual isolated circuits are interconnected, the physical layout is created, the board is loaded and the entire system is tested.

The design process is not a simple path from one stage to the next. All of the stages are interconnected and the results of one stage directly influence each preceding stage.

Let's go into each of these stages in more detail.

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Concept:
System Design\Analysis\Partition

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

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In the Concept Stage, the system-level design decisions are made. Inputs to this stage include pertinent information such as market definition, customer profile, and risk assessment. The three most important inputs to this stage are time-to-market, cost, and performance. These three factors are prioritized in this stage. Which one of these three priorities is the most important and which one is the least? What trade-offs are we willing to make?

For example, if time-to-market is the highest priority, you may chose to modify a similar already functioning system/circuit design. Or if performance is the highest priority, you may choose a triple conversion receiver over a single or dual conversion design.

Once the goals are assessed and priorities are set, the designer can experiment with various system configurations. Once one has settled upon the system design, it is then partitioned into its sub-blocks and initial specifications are allocated to the individual circuits making up the system.

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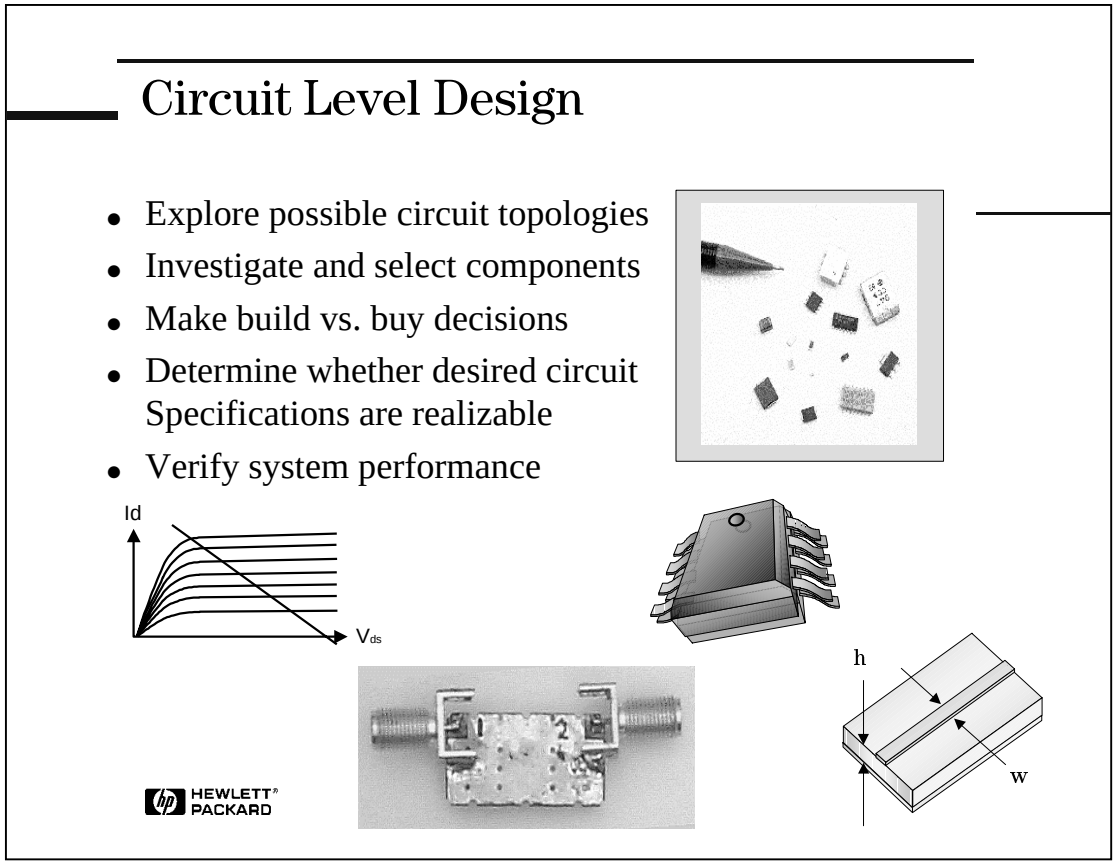

The next stage is the design of the individual circuits. Like the system design, circuit design starts off with brainstorming to explore possible circuit configurations. By looking at the required specifications of the circuit and the project requirements, the designer can decide to build or buy parts of the circuit. Other investigation tasks include the selection of components based on vendor's specifications, reliability, and other practical factors. At this stage, the designer will also need to determine if the circuit specifications are realizable. If they are not, this information is fed back to the Concept Stage where the system-level configuration may need to be modified.

This is where all of the hard work creating, debugging, and modifying the circuit design is performed. The goal is to meet the specifications set by the system design in the Concept Stage.

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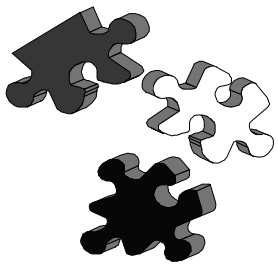
Integration

- 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



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At the Integration Stage, the individual circuits are combined and their combined performance is measured. If the performance is less than acceptable, which is almost always the case, troubleshooting follows.

Troubleshooting may involve circuit redesign. It may involve system reconfiguration and circuit re-allocation. Modification of the system specifications or even a change to the project definition are the possible results of this stage. One design can (and usually does) directly affect the others.

While information is flowing back and forth between the design stages, other forces from the outside world are also at work. The market definition, target customer, customer needs and wants are very likely to change during this time. All this information will reflect what the final system will need to be.

The best design process is one in which the discoveries at one stage are used to modify the earlier stages, easily and efficiently.

Next, we will contrast the differences between the non-predictive traditional design process with the modern, predictive approach. You will see that one of the main differences between these two approaches is their ability to handle changes much more easily, thus enabling you to meet your objective.

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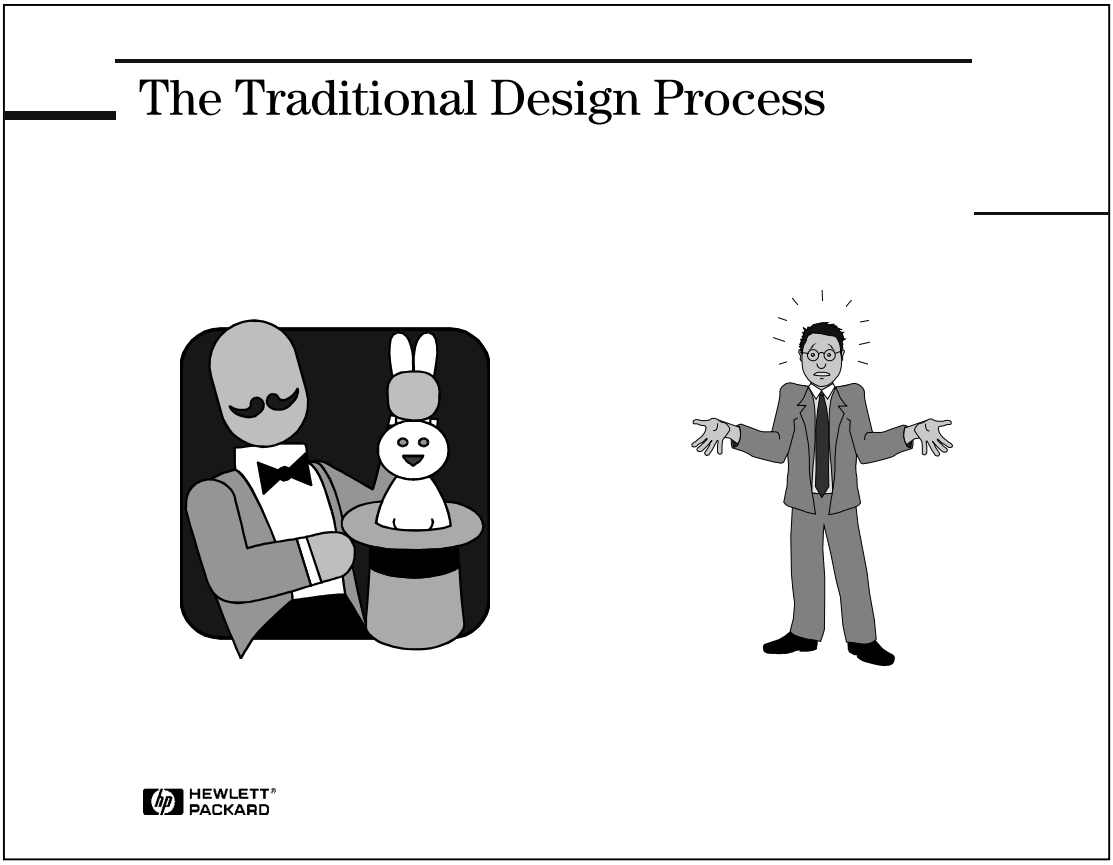

When it comes to RF circuit design, it seems like every company has the gurus who are magically able to get RF designs to work. Unfortunately, all of that knowledge is in their heads and only gained through years of experience.

In the meantime, you need to work on your design without the knowledge and experience of the guru. You can ask the guru for help occasionally, but for the most part, you need to figure it out on your own and begin the apprenticeship of becoming a guru yourself.

Without any other alternative, you begin the way that the guru did, the traditional approach to RF design.

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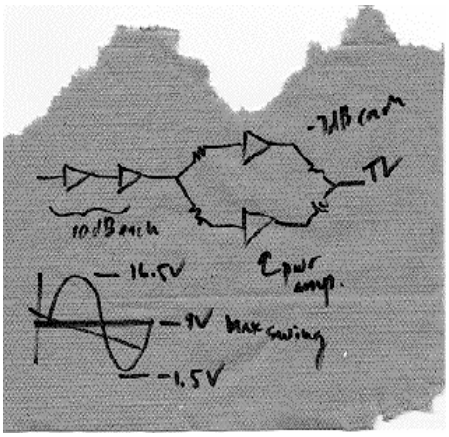
Concept:
System Design/Analysis/Partition



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

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Let's begin with a look at the traditional approach to design. The design is mostly done on paper. As shown here, sometimes the documentation lacks a professional look and feel. Paper calculations are easily prone to math errors. The system analyses are sometimes crude since it's difficult to analyze circuit interactions. This can result in serious system-level failures.

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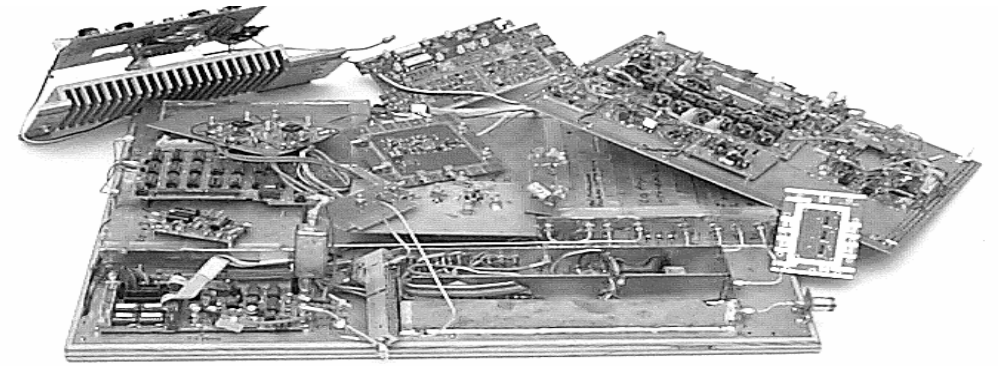
Circuit Level Design

- 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!!!



In the traditional circuit design stage, you typically go from paper analysis straight to a physical prototype to verify your design. Often, you experiment by cycling through several physical prototypes before you reach a successful one. This process of refining physical prototypes is more of a trial-and-error refinement, which is not very conducive to learning or understanding why your design does not work. Multiple physical prototypes are very time-consuming and expensive. But you rely on this process, because without it you'd be lost.

Also, with the traditional approach it is difficult to predict manufacturing yield.

Lastly, system integration presents other problems. . . .

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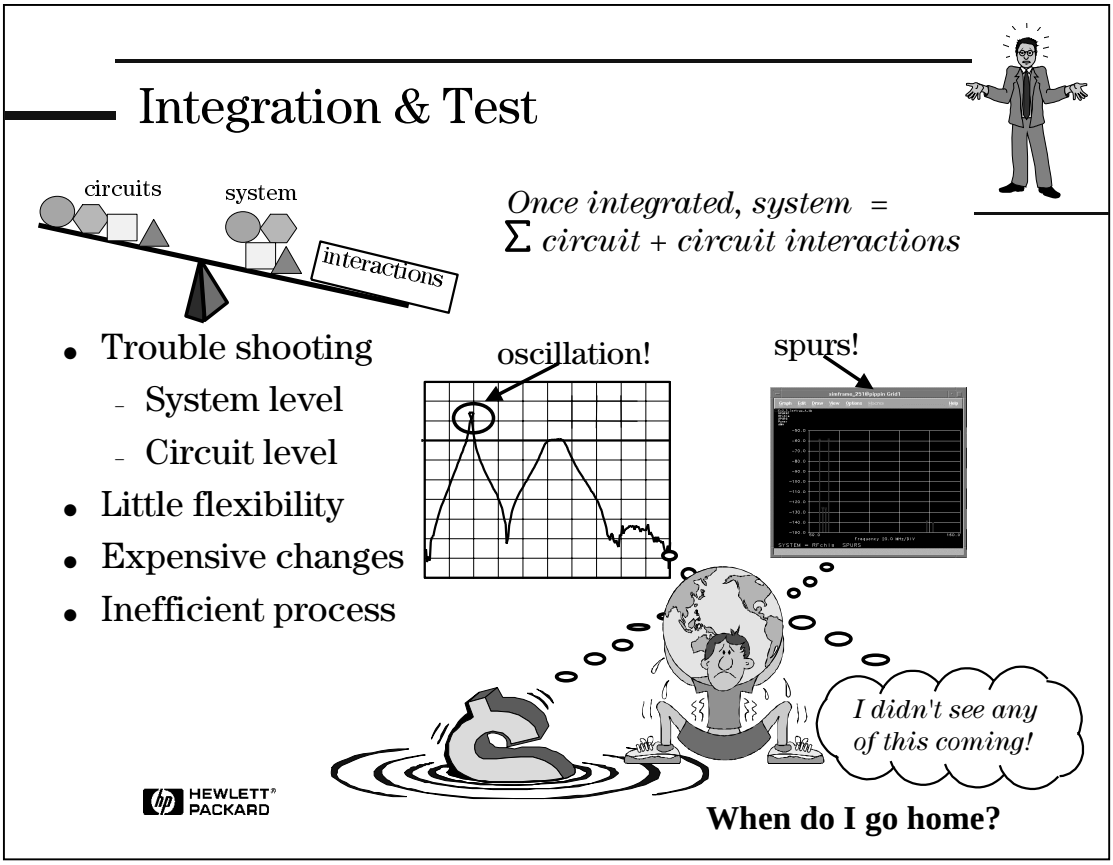

Once all the individual designs are completed, we integrate them to view the overall system performance. At this point, we typically notice that the system performance differs significantly from expected results. Even though all the individual circuits meet specifications when isolated, the circuit, when connected and overall system, does not.

In the traditional approach, it is difficult to analyze which circuit interactions are the most likely culprits. Troubleshooting at this level is time-consuming and expensive.

You have an entire system to troubleshoot. Where do you start? This is where project deadlines slip and you begin working late hours feeling you have to bear the weight of the whole world on your shoulders.

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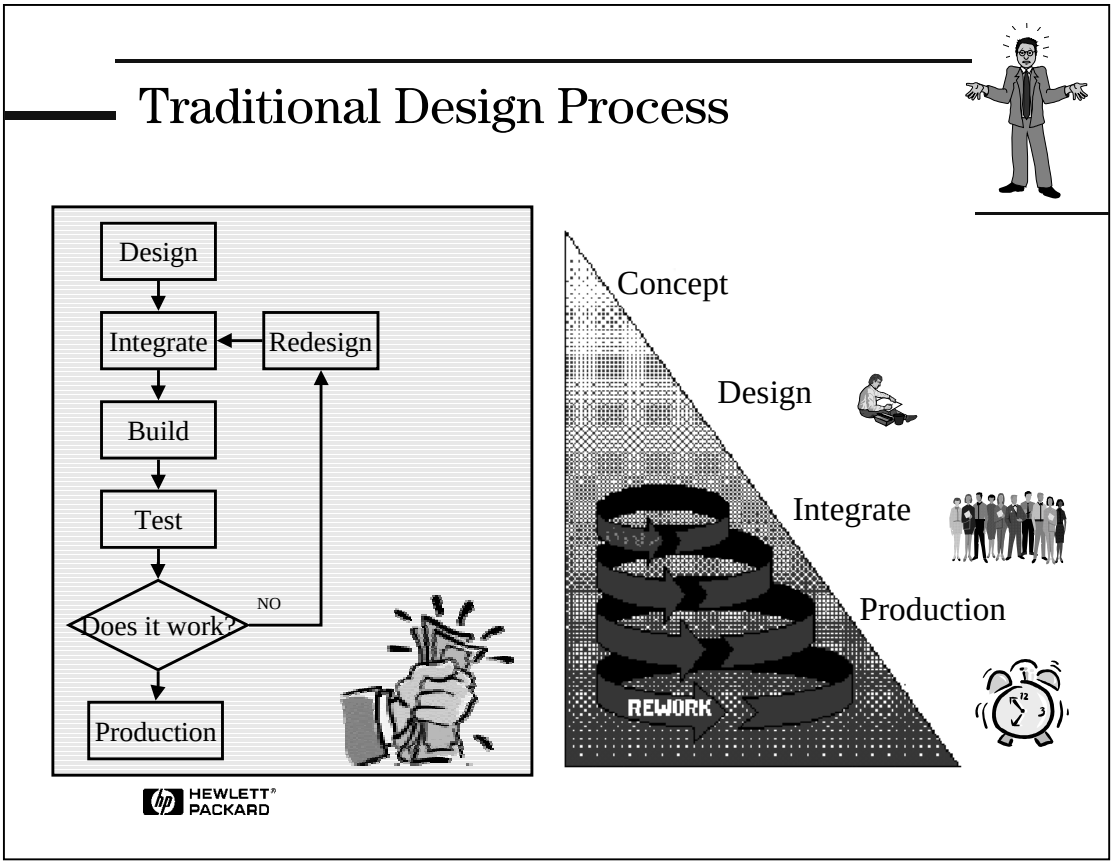

The problem is that this process is non-predictive. You hope that your design works, but in case it doesn't, you run multiple physical prototype boards varying some of the components hoping that one works. When it doesn't, you fall into "cut and try" mode, hoping each change you make fixes the problem, but you don't know that it will.

Time passes. The pressure to fix the design increases but unfortunately, as the designs get integrated into higher levels of the system and when the manufacturing yields are too low, the problem gets worse, requiring more and more re-work.

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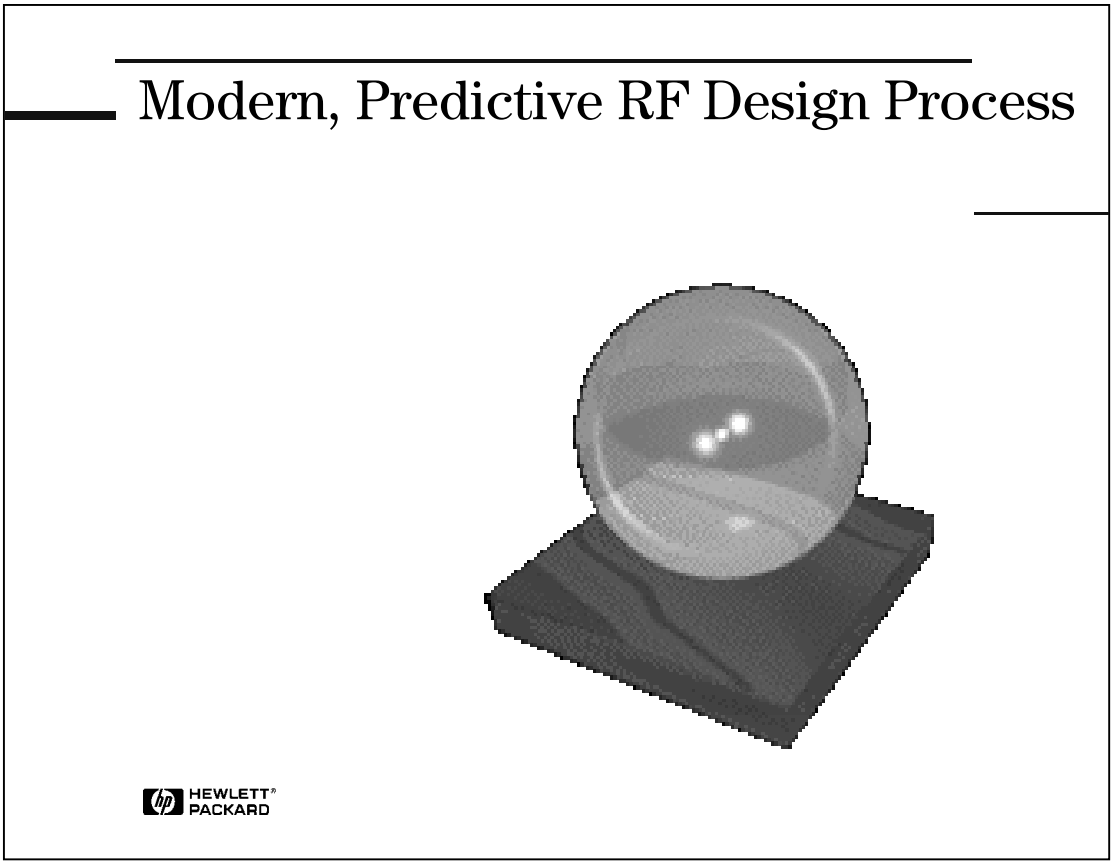

The Modern, Predictive RF Design Process allows you to know with a greater certainty how your design will work and, more importantly, how it will work when connected to the system.

You now have a crystal ball.

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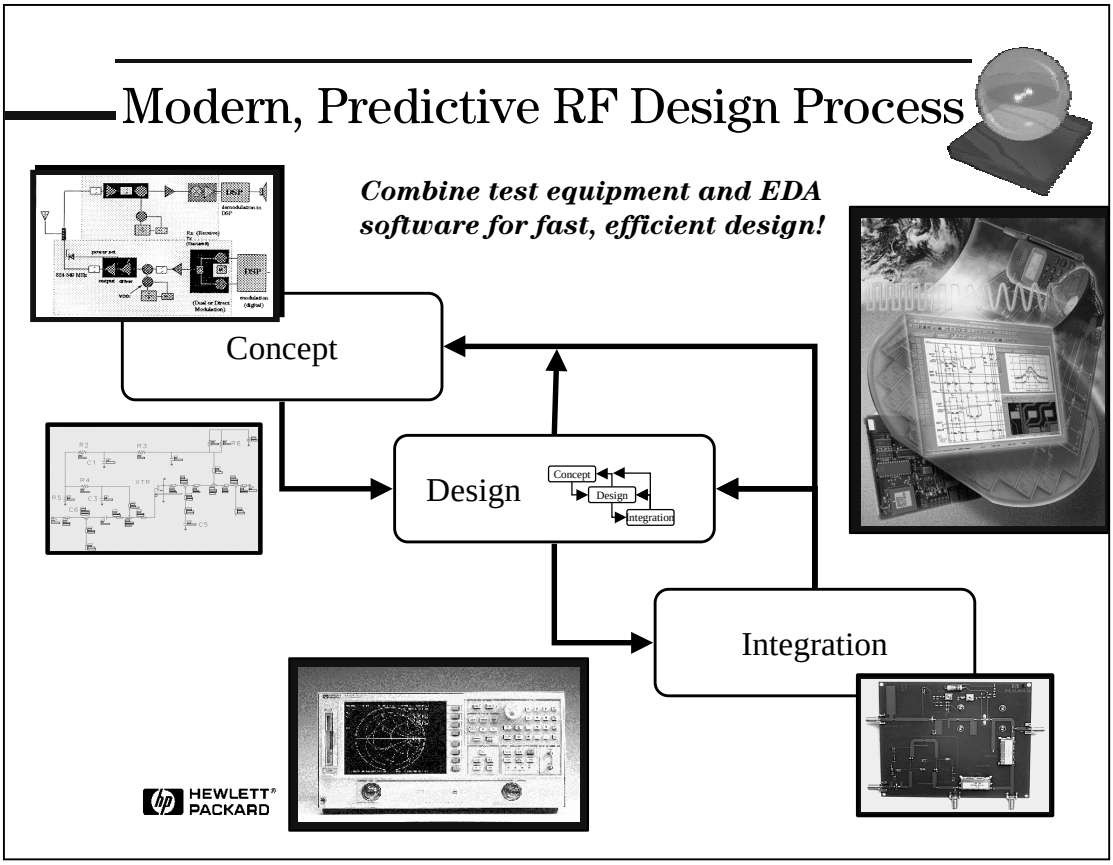

Let's now look at the modern, predictive approach to RF design.

The modern process follows the same stages as the traditional approach, but because EDA software and test instrumentation are used, the process is more predictive and less reliant upon physical prototyping saving time and money.

There is now a much closer link between the stages. Changes in the circuit design can be easily evaluated at the system level. Measurements made after integration are used to improve designs and models for use at the Concept and Design stages.

Before we go into each of these stages in more detail, let's talk a little about the foundation of a predictive RF design process: Models.

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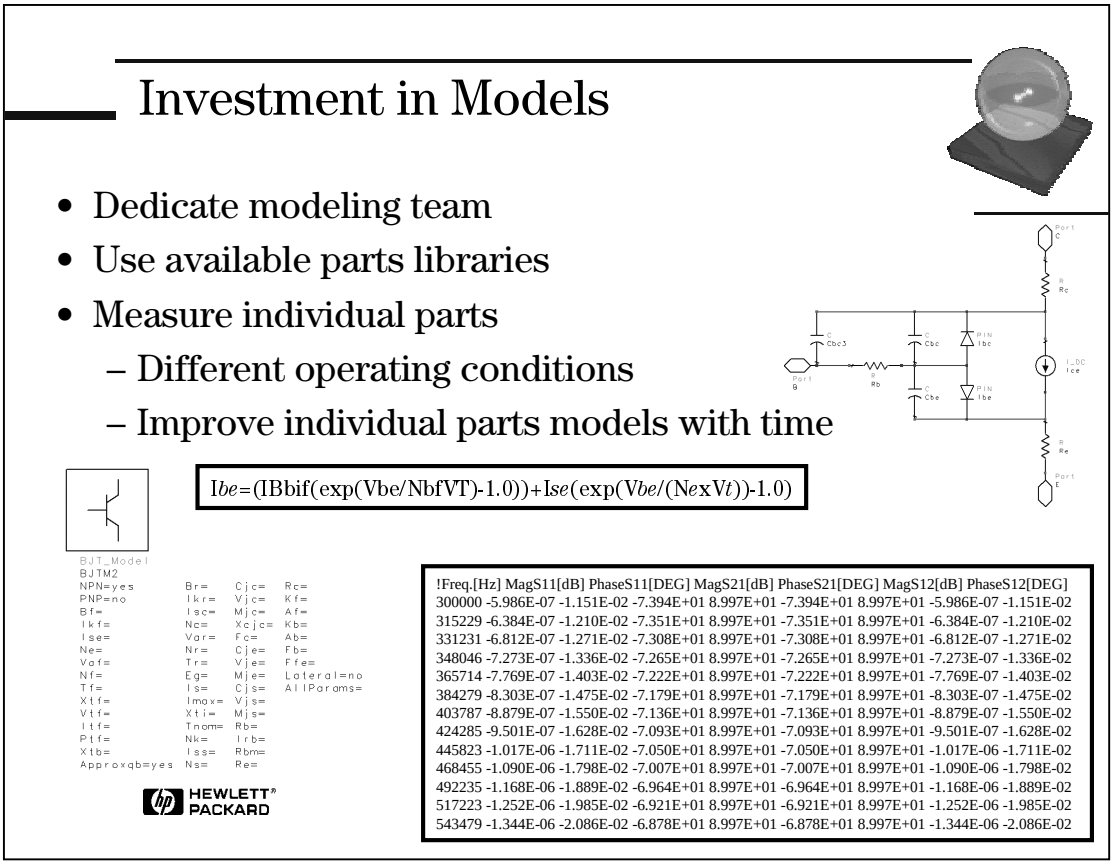

Probably the most important part of beginning a predictive RF design process involves an investment. In much the same way that you would invest in your education for use in a future career, investing in models for your RF design work will provide a strong foundation for a productive design future.

Models are mathematical representations of the individual components you use for your design. It's these models that the EDA software uses to allow you to design predictively. Some companies have decided that models are so critical to their success that they have dedicated modeling teams. It's their sole responsibility to create models for the parts used by their designers. But not all of us are so lucky, this is why HP provides model libraries for many commonly used active and passive parts.

You may be using a part that HP does not have a model for, so you can always measure the parts that you use and develop your own personal model library. And just as importantly, as you build and test designs, you'll want to improve your models to accurately reflect your manufacturing process and unique design needs.

At the end of the seminar we will talk about creating models by measuring your own devices.

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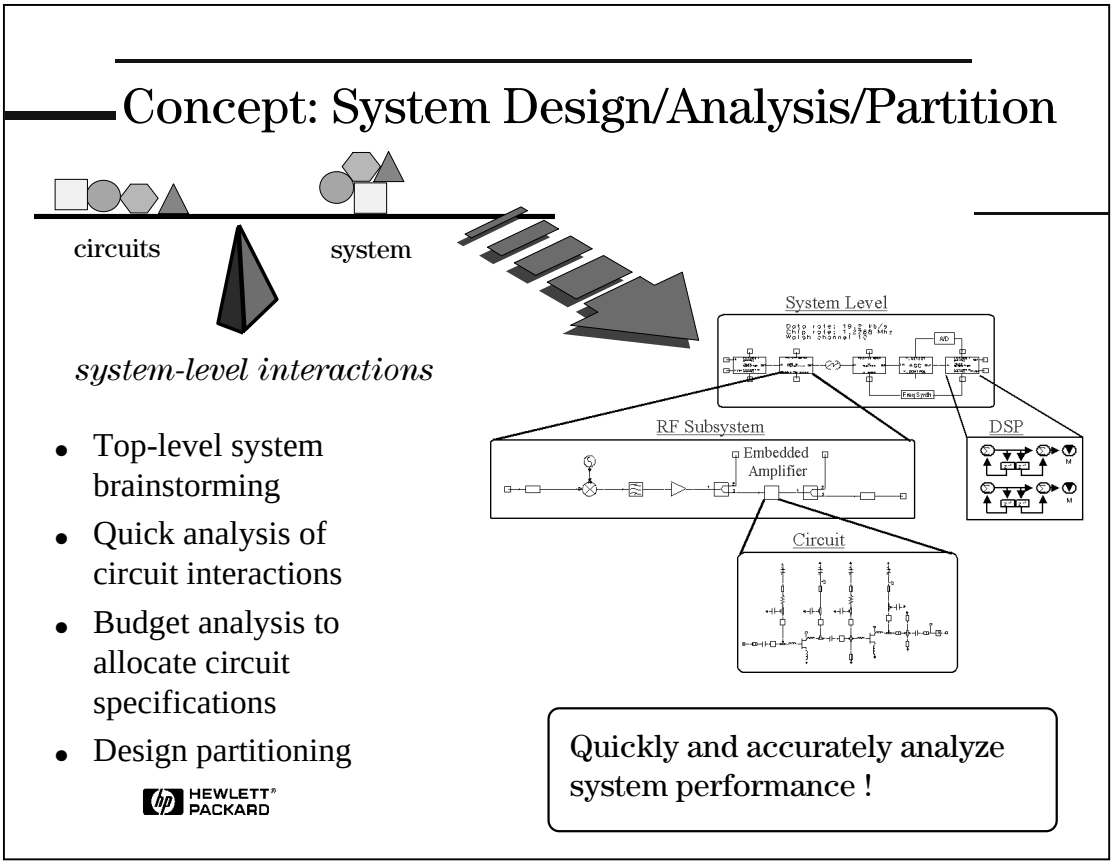

In the Modern Predictive Concept stage, EDA software facilitates exploring various system configurations. For each of the functional blocks in the system, individual behavioral models are used to analyze the overall system performance. Block and level budget analysis aids in design partitioning and circuit specification allocation. And as individual circuit design blocks are completed their effect on system performance is easily determined.

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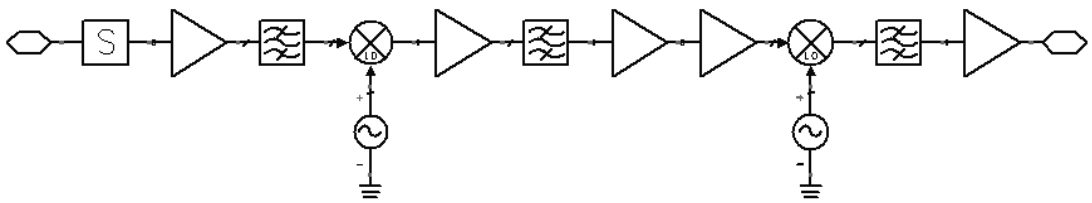
Block & Level System Budget Analysis



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

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The system designer needs to make tradeoffs between the functional blocks of the design. Design partitioning and budget analysis are easily performed, allowing the analysis of all system-level parameters including gain, noise, and intermod measurements.

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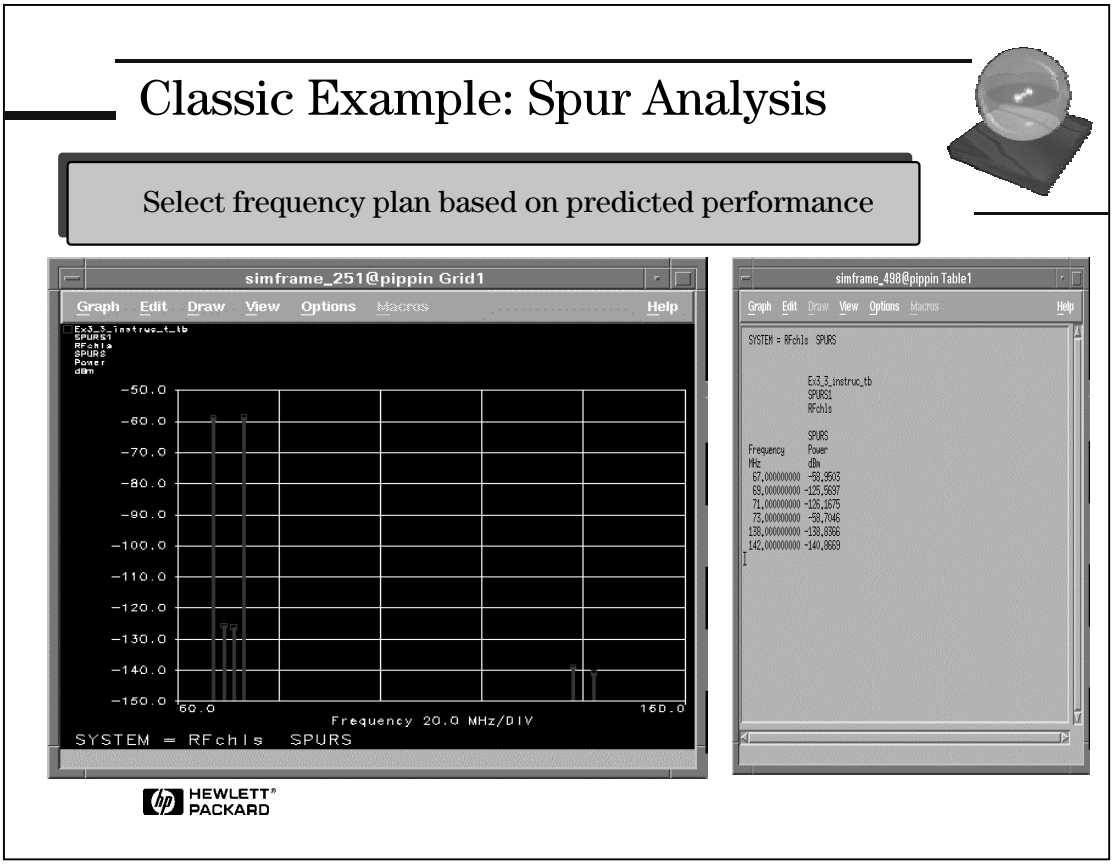

A classic example of a system-level design problem is spur analysis. Spurs from nonlinear devices such as mixers, diodes, and power amplifiers are another common problem for the system designer. In addition to predicting the frequency and level of spurs, spur analysis allows you to determine the best frequency plan (selection of IF frequencies) based on simulated results, making it easier to keep track of multiple spurs for complex subsystems, such as dual downconverters.

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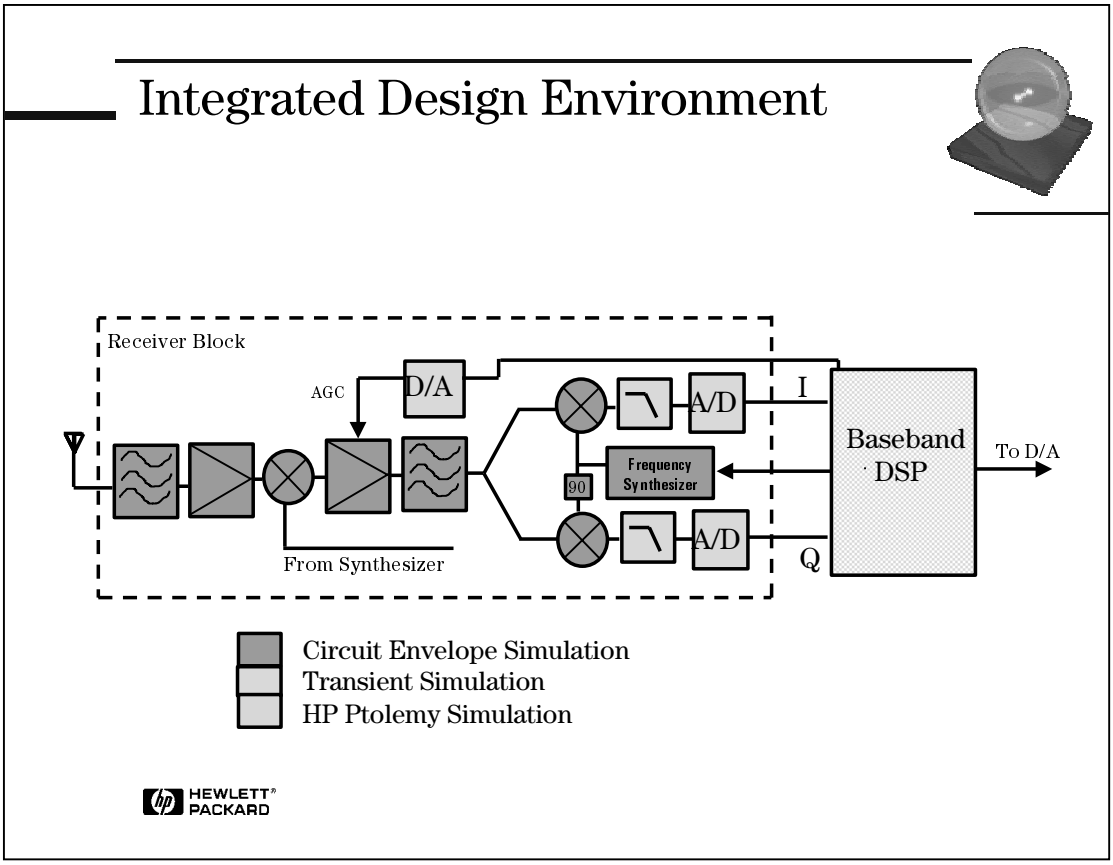

Today's mixed signal communications designs combine RF, analog, and digital circuitry. These individual designs are partitioned by the system-level designer early in the design process and are developed in isolation. It's only when they are integrated that the interactions between the DSP and RF circuitry are uncovered. Between 40% and 75% of the design effort at some companies is spent at the integration stage.

Modern Predictive Design Process now provides the means to uncover these interactions throughout the entire design process, not just at the end.

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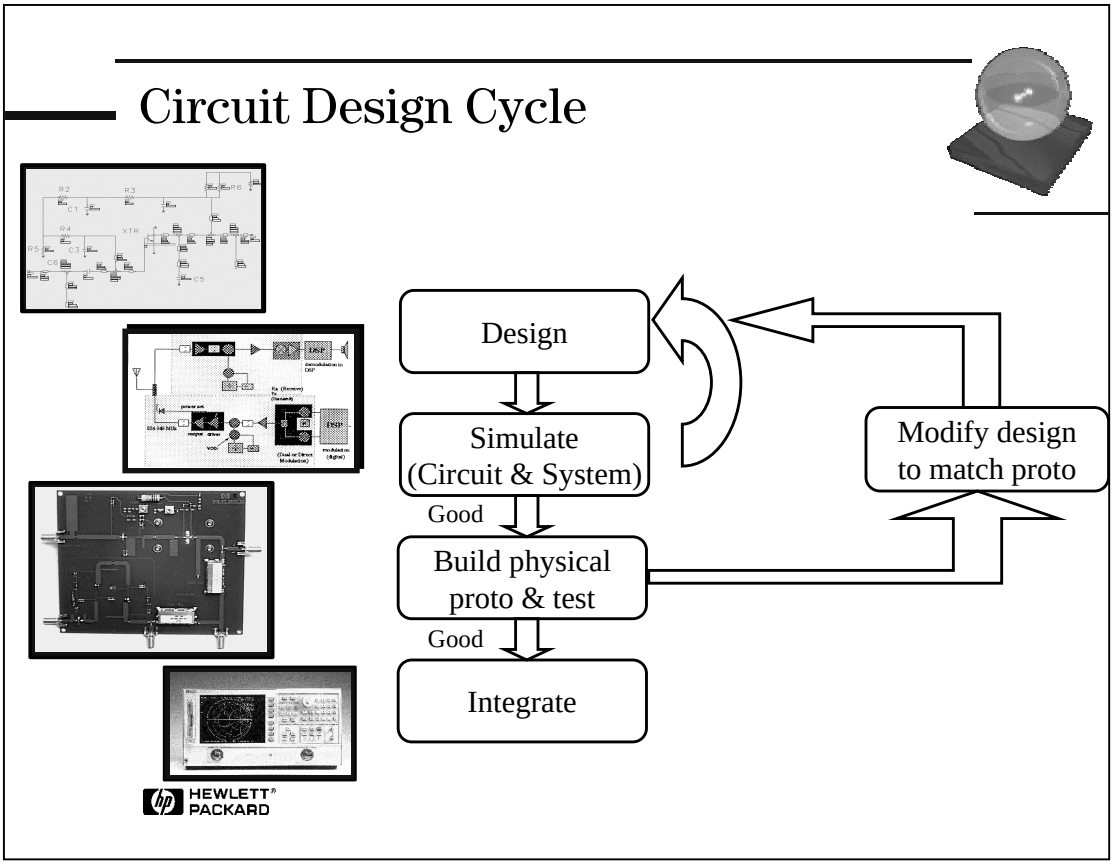

Now, you begin the circuit design process.

While you create the design with the intention of it working the first time, this is unlikely. You design the circuit using EDA software until you get the performance you require before building a prototype.

Then you will compare your simulated results to your measured ones. At this point, you will want to modify the circuit design to accurately reflect the measured results.

Then you redesign to meet specifications and continue this iterative process until your goal is met. Now your design is ready for integration.

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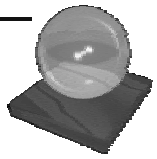
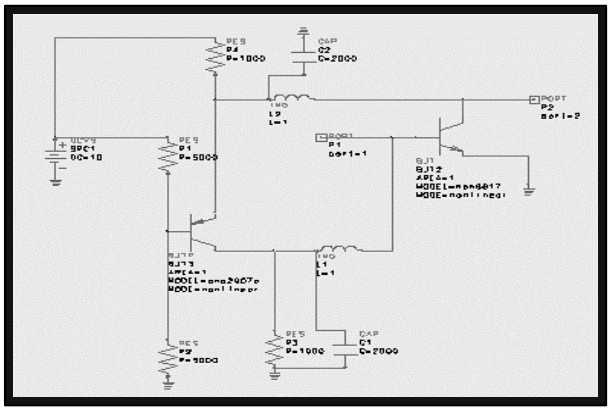
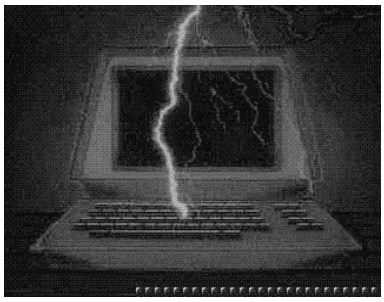
Circuit Design
Brainstorm







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

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Through the aid of simulation software, you can quickly and conveniently brainstorm all the various possibilities, experiment with different biasing configurations, explore multiple circuit configurations, and conduct a quick analysis of the configurations and examine the trade-offs of each. This stage is when ideas are explored and with speedy automated analysis, you can quickly determine which ideas are feasible.

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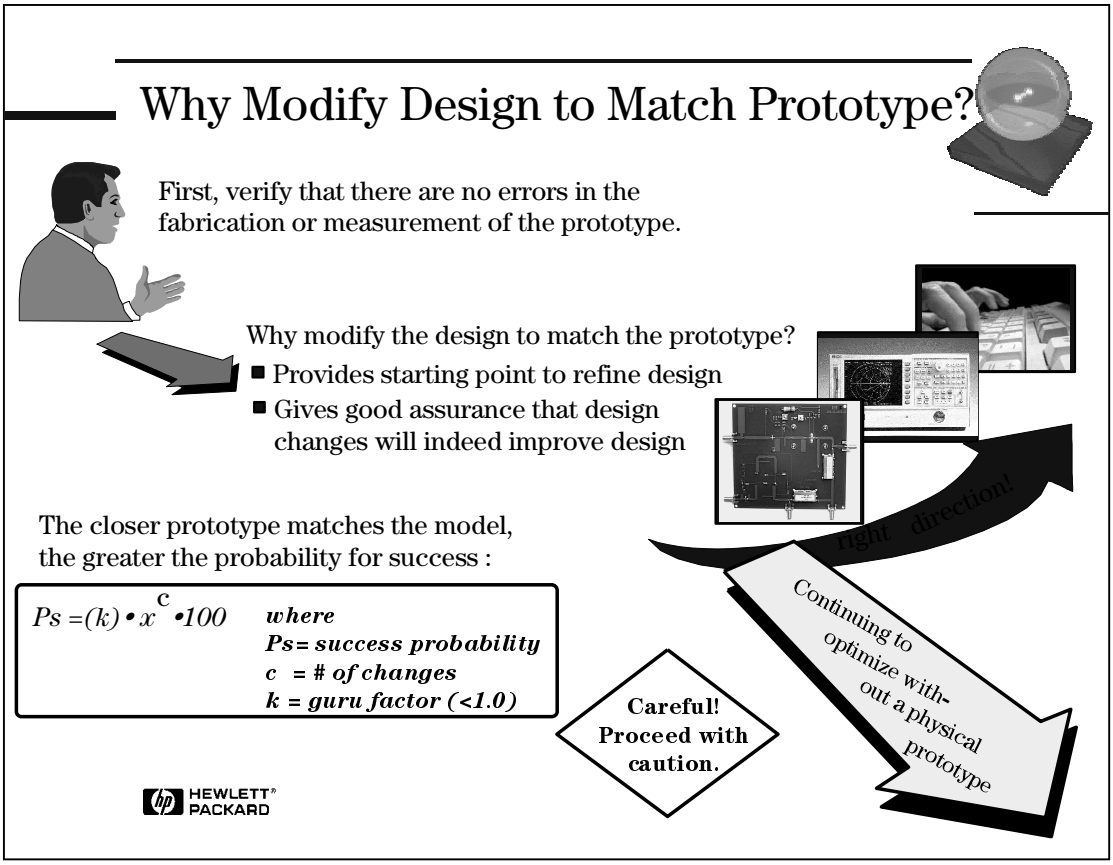

If the prototype performance differs from expectations, you need to do an initial check to verify that all the components, transmission line dimensions, connections, etc. are as specified. Once you are confident that the discrepancy does not lie in the fabrication of the prototype, the next step is to modify the design to match the behavior of the prototype.

The reason for matching the design to the prototype is to create a starting point from which to refine your design. This gives you good assurance that further design changes will accurately reflect the measured performance of the circuit. Once the design is accurately modified, you can now redesign and simulate.

Regardless of the prototype's performance, the information is still useful for refining elements of your circuit design. However, the closer the prototype's performance matches what's modeled, the greater will be the success probability of your next prototype. The equation above shows that as more changes are made to the model, the probability for success decreases. The probability for success is dependent upon the number and extent of the changes made and the experience of the designer.

RF Design and Measurement Seminar

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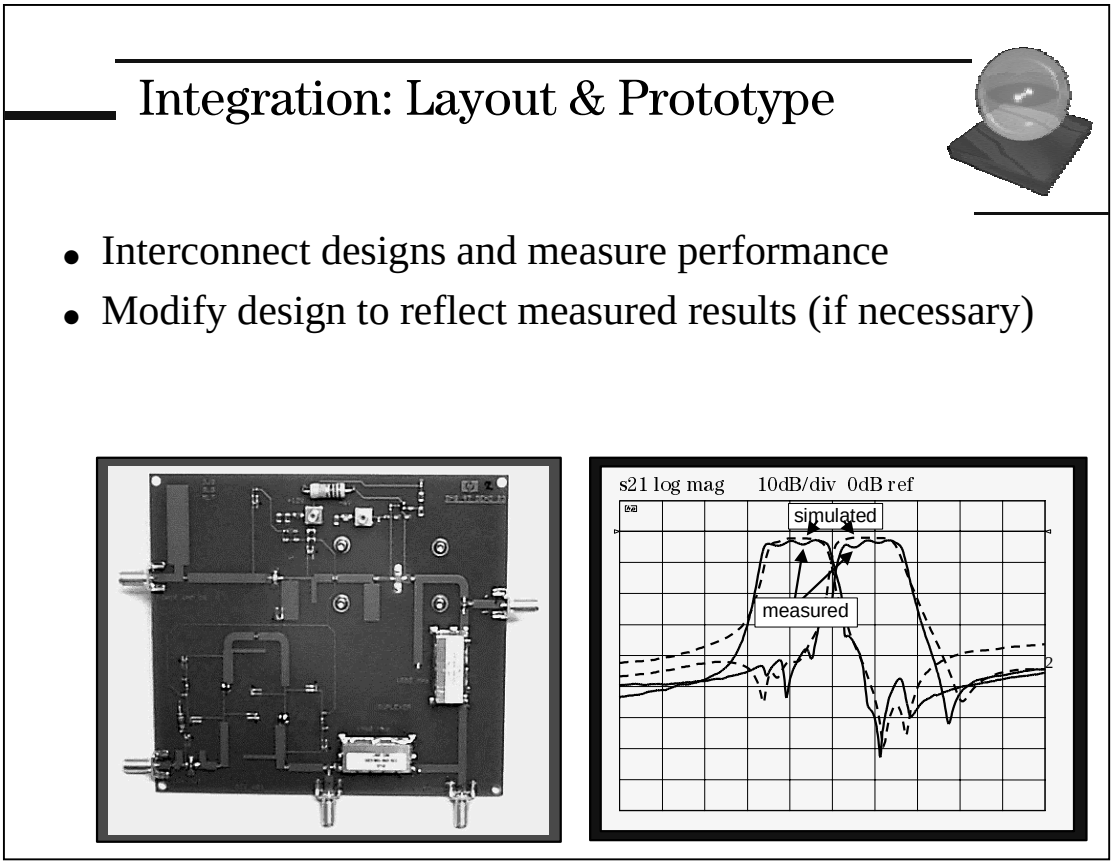

Now that the individual, isolated circuits perform well and simulate well when connected, it's time to build the integrated design and measure interconnected system performance.

Quite often, it's here that you'll uncover unexpected (and unmodeled) interactions between your individual designs. Hopefully, most of these were discovered during your system simulations, but depending on the density of your design, there may be coupling or other proximity effects appearing.

Similar to the Design Stage, the system measurements are used to update the design as necessary and to verify performance of your completed design. But because you are using a predictive design process, the number of physical design iterations will be fewer and the problems easier to resolve.

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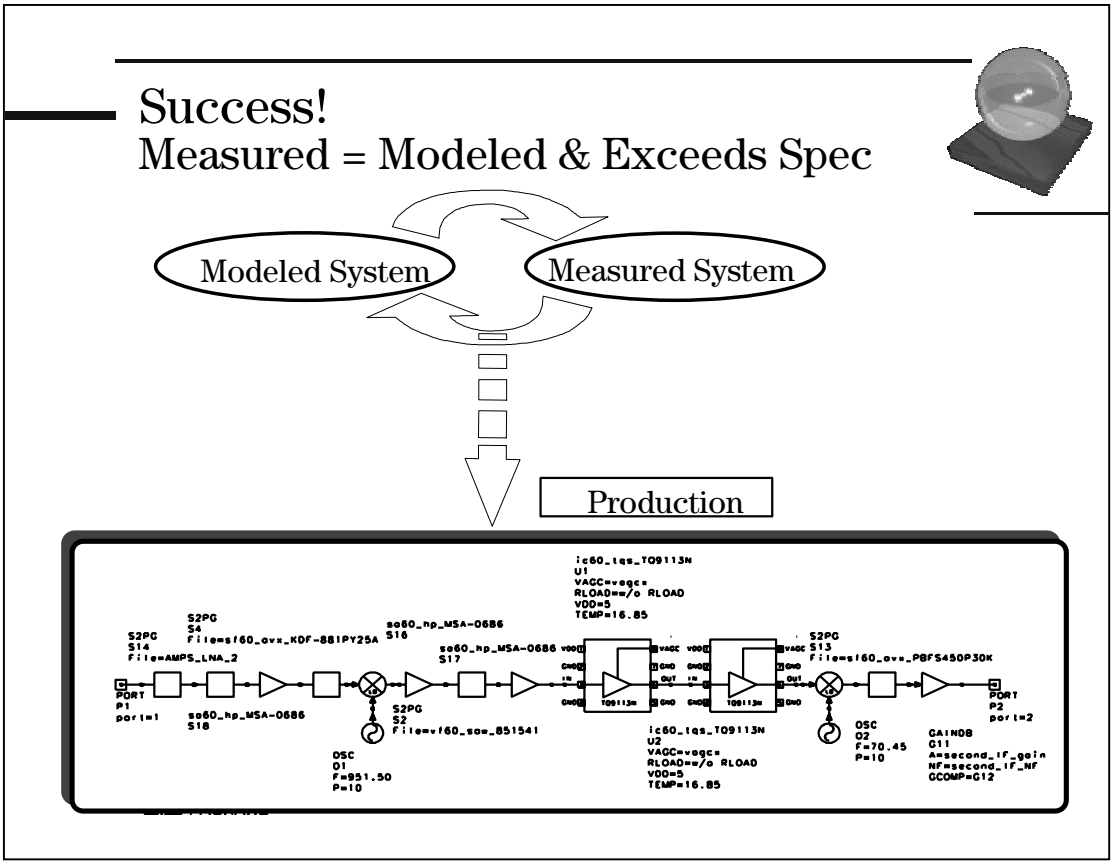

Finally, success is achieved when measured equals modeled and the design meets performance as well as manufacturing specifications.

Unlike the traditional final physical prototype, this final model is available for design re-use with full functioning schematic and layout ready for modification or use as necessary, saving time and money for the next project.

Finally, documentation is easier with the modern method since the schematics and test results are readily available in professional, electronic form.

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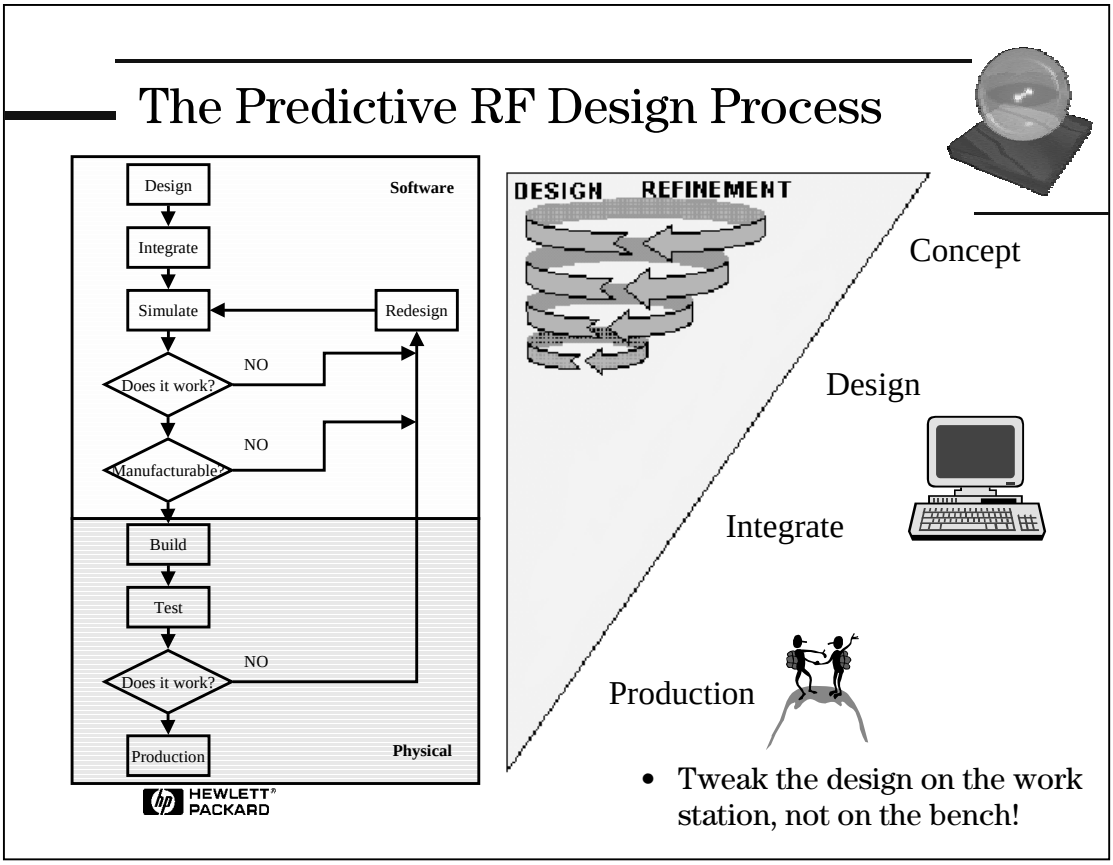

The key to success is the use of EDA software with accurate models early in the development process. The more design refinement that is performed in EDA software the fewer physical prototypes you'll need.

It's like climbing a mountain. Most of the time and effort is on the front end. There is no substitute for proper training, planning, conditioning, and having the proper equipment. And having all of that makes the actual climb easier, achievable, and predictable.

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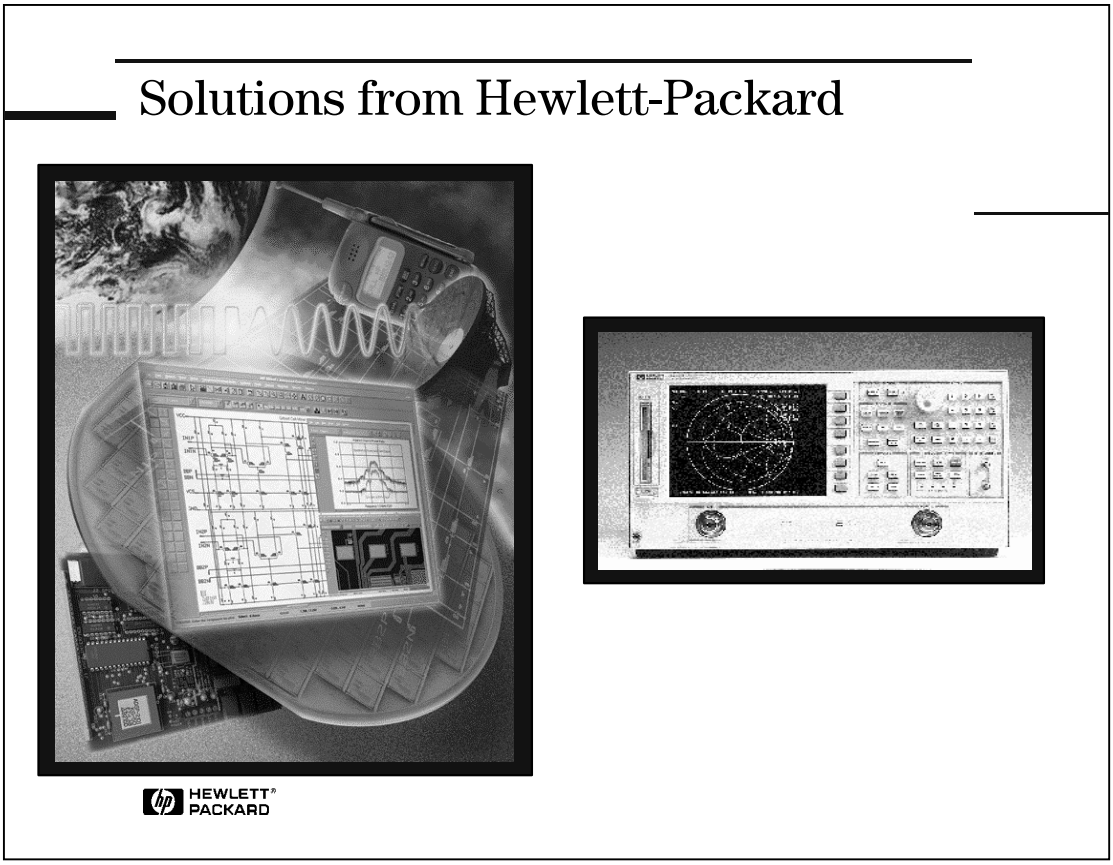

Hewlett-Packard supplies comprehensive solutions, EDA software and test instrumentation, to assist you in creating RF designs using the modern predictive design methodology.

Here we'll briefly mention these products.

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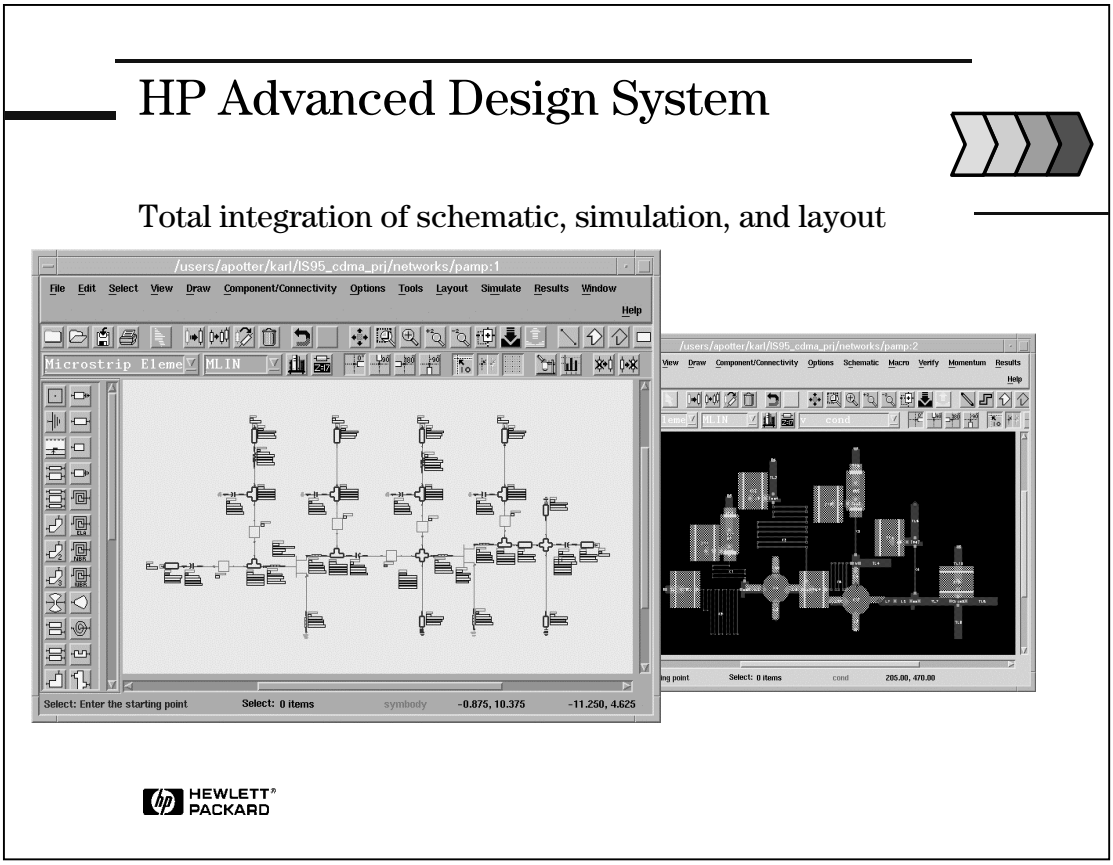

Modern, Predictive RF Design is made possible with **HP Advanced Design System**.

HP Advanced Design System was specifically created to address Communication Signal Path Design. This includes DSP, System, Layout, EM as well as Circuit Design provided in an integrated environment.

HP Advanced Design System offers design suites targeted for:

- System design
- Microwave circuit (MMIC & hybrid) design
- RFIC design
- RF board design
- DSP design
- EM design

In today's seminar, we will be using HP Advanced Design System to demonstrate the use of EDA software in the Modern Predictive Design Process.

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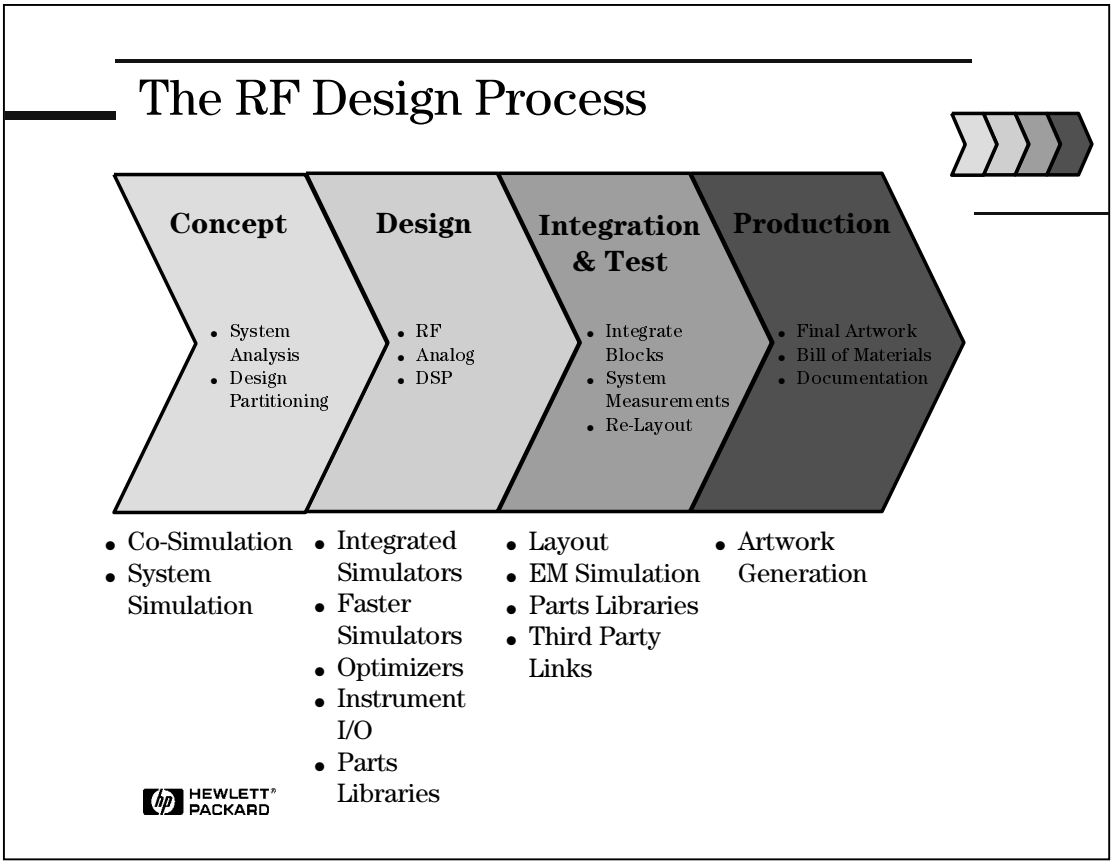

Specifically, HP Advanced Design System helps solve design problems at every stage of the design process.

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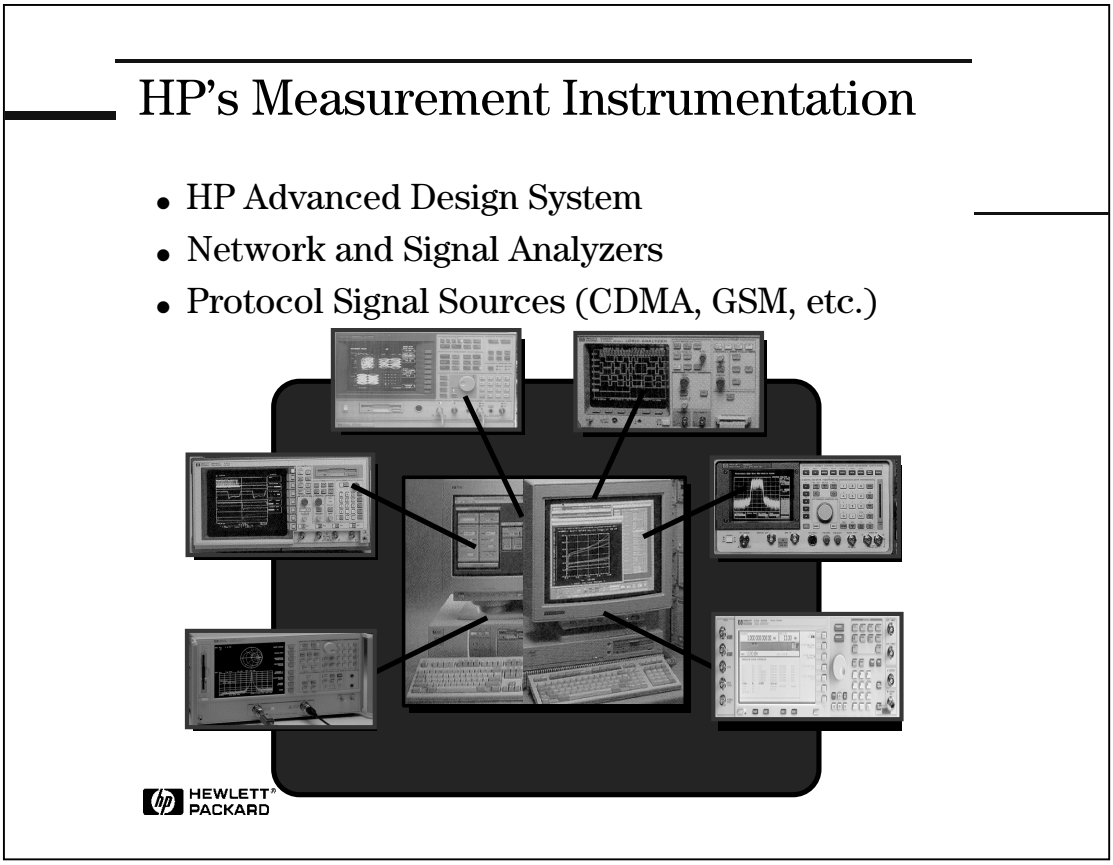

And HP Advanced Design System links directly to HP test instrumentation, including HP analyzers and sources. These links are useful when measuring parts to generate models and to verify performance when the designs have been built.