Key Considerations and New Advances in High Volume Production for Millimeter-wave MMICs

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ABSTRACT

Millimeter-wave MMIC volumes are forecast to experience tremendous growth in the next decade. Current manufacturing strategies must be re-visited to achieve the cost-of-test required to remain competitive and enable these new commercial markets. Current manufacturing approaches and limitations for millimeter-wave MMICs will be reviewed.

Progress on new, high throughput manufacturing solutions will be presented. Factors in bringing new devices to production more quickly and achieving high throughput without sacrificing measurement performance, repeatability, and system usability will be covered. Test time benchmarks will be presented for example devices.

INTRODUCTION

Significant growth is forecast for millimeter-wave GaAs MMICs for the voice and data communications industry. Most of this growth, however, is heavily dependent on the manufacturer's ability to design and manufacture MMICs at a cost that will enable these markets. Manufacturing test strategies must be re-examined to help meet these cost goals.

1998 EVENTS AND MILESTONES

With the completion of spectrum auctions in March 1998, last year saw the beginning of rapid investment in Local Multi-point Distribution Service (LMDS) by device manufacturers and service providers. Various GaAs manufacturers introduced over 50 devices targeted at this market area alone in 1998. Service providers are scrambling to be first to deploy with several different kinds of services. Wireless SONET rings and multi-point business data services appear to be the leading entry applications. The large residential multi-point data services market will only be enabled by substantial reductions in the cost of the subscriber units.

Broadband data satellite services programs also progressed substantially. Teledesic and Celestri broadband data satellite programs merged with Motorola becoming the prime contractor. The European-led program, Skybridge, increased their constellation size in response to an increased subscriber forecast. Iridium services turn-on also occurred in fall of 1998, an important milestone for LEO satellite programs.

The basic point-to-point microwave radio market continues to experience good growth. Wireless voice communications saw the introduction and growing deployment of "pico-cell" base stations last year, many of which utilize millimeter-wave back-haul radios.

MARKET GROWTH

These market areas are driving an increasing need for higher volumes of microwave and millimeter-wave MMIC devices. Discrete designs are quickly giving way to MMICs to produce less labor-intensive and lower cost modules for use in phased-array antenna and microwave radios. Figure 1 summarizes the volume growth projected for GaAs MMICs over the next six years.

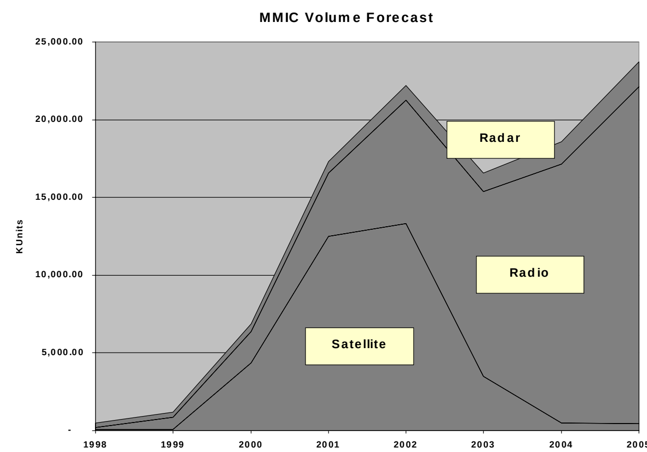

Figure 1. Forecasted Millimeter-wave MMIC Revenue Growth

This increase in volume is driving changes in the test strategies of GaAs manufacturers for high frequency MMICs. Time-to-market pressures will be intense as companies race to deploy infrastructure and generate service revenue as quickly as possible. Both the time to transition a new device into manufacturing as well as the actual time to test each device will be critical to meeting business goals.

REVIEW OF CURRENT MANUFACTURING STRATEGIES

Due to relatively low volumes in the past, simple test strategies, while labor intensive, have sufficed. The simplest approach is to manually connect various bench-top instruments to a single wafer prober to measure the desired parameters (Figure 2a). Another commonly used approach is to have several wafer probers dedicated to measurement equipment (Figure 2b). The third approach (Figure 2c) routes all the test equipment to the wafer prober through a switch matrix.

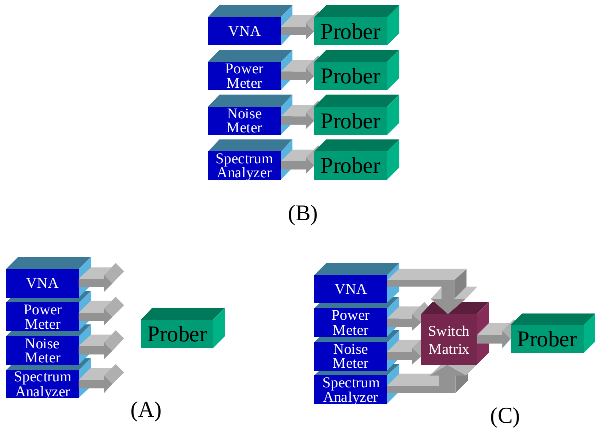

Figure 2. Current On-wafer Manufacturing Strategies

Limitations of Current Strategies

The first approach is the most time consuming due to manual re-configuration of the test equipment. This increases the risk of operator error, requiring a more highly skilled operator. For purposes of comparison between the different strategies, a 4-inch wafer of power amplifiers (approximately 1200 die) is used. Reported test times are 8 to 16 hours per wafer using this approach, depending on equipment set up time, calibration, and correcting configuration errors.

The second approach requires increased physical handling of the wafer between two or three semi-automatic wafer probers, increasing the risk of contamination and breakage. Both these approaches require re-probing the wafer several times, wasting time and increasing the risk of pad damage. Test equipment configuration errors are reduced or eliminated compared to the first strategy, reducing the risk of wafer re-test. Most of the test time improvement results from eliminating equipment set up (and correcting mistakes) and re-calibration. Reported test times using this approach range from 4 to 6 hours per wafer.

The third approach has the advantage of complete automated "one-touch" testing of the devices but is less often used due to the degradation (sometimes severe) in measurement performance and system stability caused by the switch matrix between the device and the test equipment and the increased complexity of measurement calibration. The automation of these types of systems is also much more complex and costly to implement, add new devices, and support. Measurement speed is also limited by bench-instrumentation speeds, particularly noise and power measurements. Reported test times range from 3 to 5 hours per wafer, depending on the sophistication of the test system software.

New Solutions

Hewlett-Packard Company is developing a production test system for the devices being introduced in these growing marketplaces. Building on the success of the HP 84000 RFIC test system, HP has extended the frequency coverage to 45 GHz by re-engineering the system with a high frequency millimeter-wave test head.

The system is designed specifically for production measurement of millimeter-wave MMICs. Figure 3 depicts the high-level block diagram of the hardware architecture. Using a high-speed tuned receiver to make *all* RF measurements rather than slower power and noise figure meters is essential to minimize test time. Noise sources and power sensors are used only during the calibration process. VXI-based resources are used with a MXI high-speed bus to optimize measurement throughput.

Reflectometers are placed very close to the DUT to provide extremely high calibration stability.

System capabilities can be expanded by adding optional high and low frequency test ports, DUT LO stimuli, analog and digital DUT control lines, and high power transmit and receive options.

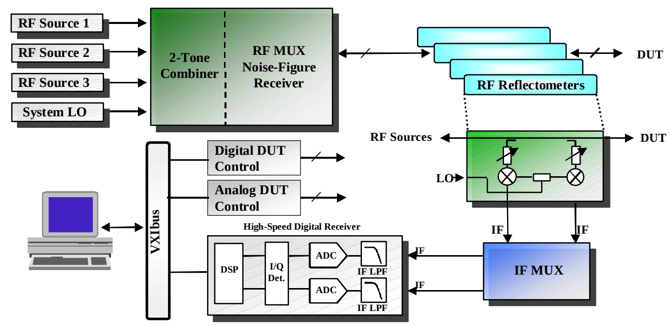

Figure 3. High-level System Block Diagram.

- S-parameters
  - Gain/loss, isolation, VSWR
  - vs. frequency
  - vs. control voltage or digital state
- Power (dBm)
  - output power
  - vs. bias voltage
  - Gain compression
- Efficiency (power added)
- Spurious signals (known)
- 2-tone inter-modulation
- Frequency, CW
- Harmonic distortion
- Supply currents
  - enabled, sleep mode
- Voltages
- Noise figure
- Mixer conversion gain or loss
  - Mixer leakage
  - LO->RF, LO->IF, carrier feed-through
  - VSWR

Table 1. Needed System Measurement Capabilities.

Table 1 summarizes the device measurements currently available with the system at first shipment. Additional measurement capabilities are planned for subsequent product releases[1].

For the example power amplifier, test times of 90 minutes[2] or less per wafer can be achieved using this system.

[1] Upgrade paths will be provided to facilitate capability expansion.

[2] All test time comparisons assume a 0.5 second wafer prober index time between die.

Increased Test Yields

Significant improvements in the cost of test result from improved test yields as well as from lower device test times.

Test yield is impacted by the guard bands that must be applied to measured device data to compensate for system measurement accuracy and stability. Measurement data guard bands that are

devices (Type 1 error) and passed bad devices (Type 2 error). Guard bands are normally not symmetric around the spec limits due to the higher costs associated with shipping a bad device.

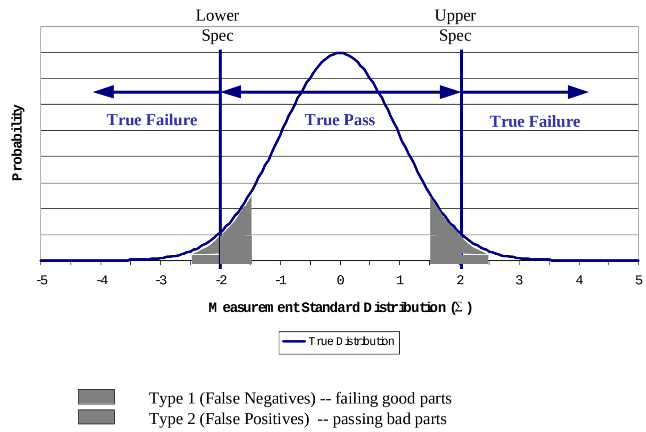

Figure 4. Insufficient guard bands result in Type 1 and Type 2 errors.

Better system measurement accuracy and stability allow these guard bands to be tightened, minimizing Type 1 and Type 2 errors. This can substantially increase test yield and avoid an unhappy customer and the down-line expenses associated with shipping bad devices.

As an example, examine the impact of improved guard bands on a $10 device with yearly production volumes of one million devices. An improvement from 2% to 1% in Type 1 errors (failed good parts) results in an annual revenue increase of $100,000. The financial impact of shipping bad parts (Type 2) is difficult to quantify. As an approximation, assume that the down-line financial impact is ten times the price of the device. Improving Type 2 errors from 0.2% to 0.1% reduces this financial impact from $200,000 to $100,000, a savings of $100,000 annually. In this example, the ability to narrow measurement guard bands using a more accurate and stable test system results in $200,000 of either increased revenues or lower product warranty expense.

Additional savings are realized due to less required floor space and fewer and lower skilled operators. The operator software interface is intentionally designed to be simple to minimize operator errors and training requirements.

Fast Test Plan Development

Test plan development time is minimized through a graphical forms-based user interface which allows test plans to be defined and/or modified efficiently either on- or off-line from the manufacturing test system. Test developers have a wide choice of "canned" stimuli and measurements that are quickly added to the test plan using the graphical interface. The availability of standardized test plan elements also ensures consistency in test plan development between production engineers.

Examples of additional development tools include loops, test variables, conditional branching, and math blocks. Measurement results can be combined and expressed in different math blocks. De-embedding transforms, test limits, and wafer mapping are all available to the developer.

Test plans can then be optimized to reduce test time using built-in optimization tools. No "code writing" is required to define or revise a test plan, providing flexibility and lowers the required software engineering skills to bring a new device into production.

Summary

The millimeter-wave MMIC market is on the verge of substantial volume growth. Current manufacturing strategies will not provide the cost of test required to produce devices at prices that will enable the consumer growth in these new markets. Hewlett-Packard is developing a millimeter-wave production test system to address these more demanding manufacturing needs.

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