Design for Manufacture: Consumer Wireless Devices

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Abstract:

Today most of us carry a Personal Communicator - maybe a 'simple' mobile phone or, perhaps, a more complex 'always-connected' organizer. Whatever we call it a cellular telephone terminal has to be designed to meet exacting standards defined in the system specifications and policed by the regulatory authorities.

However, some parameters defined within the specifications cannot be economically achieved just by stringent design of the terminal equipment. Classically 'quality cannot be tested into a product' but in reality equipment can meet the requirements only through calibration of the hardware. In mobile telephone manufacturing the processes of 'test' and 'calibration' become inextricably linked. In this paper the author draws from his theoretical knowledge and practical experience in the design of test systems to discuss some aspects of terminal test technologies and how these affect the economics of device manufacturing.

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Agilent spun out from Hewlett-Packard in 1999.

Introduction

In little more than twenty years the mobile telephone has revolutionised the way we work, rest and play. Here in the UK there are more than 70 million registered (active or potentially active) mobile telephones in use. World wide there are approximately 3 billion mobiles in use. By almost any measure the mobile telephone has been one of the most outstandingly successful inventions of all time. The development of the mobile telephone has powered a significant economy, generated thousands of patents and stimulated any amount of creative thinking.

The mobile telephone is no longer just a telephone that works without wires; it is a personal communicator, a timepiece, a camera, a broadband wireless modem. It may also be an entertainment centre, a personal organizer and a pocket computer system. In 2005 the total number of mobile telephones manufactured was said to be about 800 million units. This year it will exceed 1.2 billion.

Somewhere in the world a new mobile phone pops off a production line every 10 milliseconds. Every one of those phones needs to be tested! As handset volumes rise there is significant pressure to streamline the manufacturing process to minimise manufacturing cost. This paper looks at some aspects of handset design, focussing on test processes to see how these too can be streamlined.

Manufacturing and Test Challenges

Mobile telephone handsets are manufactured using similar techniques to those of almost any high volume electronic product. Multilayer panels of circuit boards are machine-loaded with components and soldered using high-speed automated assembly systems. Individual boards are separated and assembled; other sub-assemblies are added and the phone ‘chassis’ is built. A basic mobile phone will have something like 60 – 80 components loaded on a single circuit board, whereas a multi-band, multi-format business phone may have several hundred parts.

At the end of the production line ideally 100% of handsets would be defect free. However, in the real world this just does not happen. But with production volumes measured in tens or even hundreds of thousands of units per day even a small fraction of units that are faulty will result in a large number of units that need re-work and repair, so careful control of the manufacturing process is essential. Problems due to component quality or manufacturing process control just cannot be tolerated or the production line will soon be swamped by a rapidly growing ‘bone pile’ of units that need to be reworked or repaired.

The purpose of testing a mobile handset satisfies the need to prevent a number of potential problems. The obvious reason is to confirm that the manufacturing processes are correctly being implemented. A proper test regime should ensure that the product works properly when it reaches its consumer. But the most important function of the ‘test process’ is to perform RF alignment and adjustment so that every phone manufactured meets the exacting standards defined by the mobile telephone specifications. This is an absolute requirement of the regulatory authorities, and is essential to ensure proper operation of the cellular telephone system.

Testing is not implemented in a single stage. Typically subassemblies such as the major circuit boards, keypad and display and will be checked before they are assembled into a finished handset. The diagram in fig.1 shows a typical but simplified production and test flow.

Handset manufacturing test

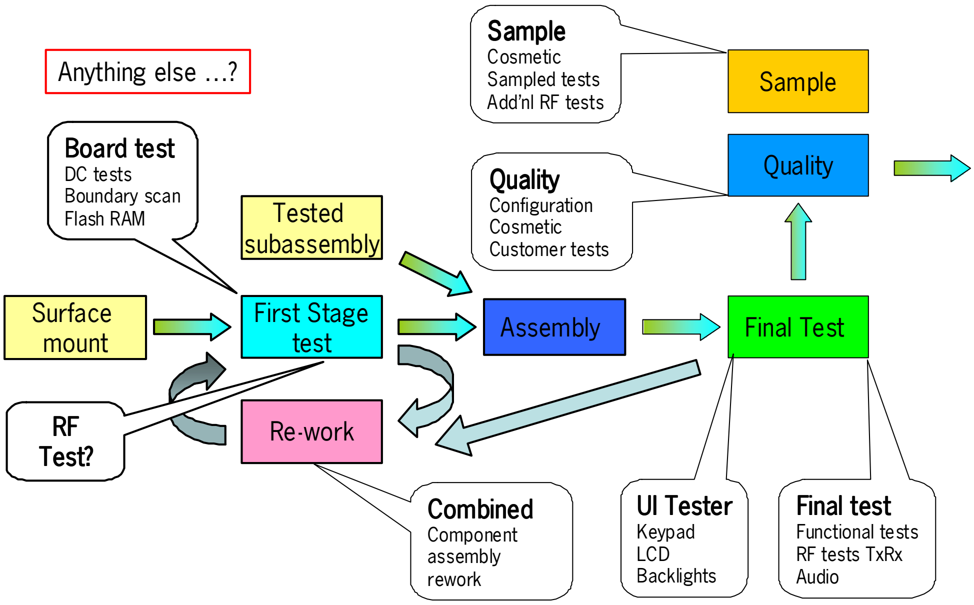

Fig 1. Handset manufacturing test

The inherent complexity of the mobile phone standards cannot be ignored in the manufacturing test process. We cannot pretend that there are no limitations to the capability of RF technology. The fact is, of course, that the mobile telephone is a complex radio transceiver operating on multiple bands using a variety of complex modulation and signalling formats. Also it needs to share airspace with maybe hundreds of other units, all using the nearest network base station. To do this successfully it must operate correctly, within a fairly fine range of operating tolerances.

RF alignment is important because the cellular phone systems are designed to give adequate performance to the largest number of users. The network controls the handset power to ensure that there is adequate signal at the base-station; handsets close to the base-station transmit lower power levels, those at greater distances transmit higher power. The control algorithms attempt to balance the power from all users to maximise performance for all users. However, a handset that transmits too much power will tend to generate more interference, and a handset that transmits too little power will tend to have poor coverage in fringe areas.

The design of a handset balances material cost against manufacturing cost. Quite probably we could design a handset that would test and align itself. In fact some self test and adjustment does go on inside a phone but most designs need some calibration during the manufacturing process.

ITEM	PARAMETERS
TX Power	Maximum power, power steps, power control linearity, flatness
RSSI	Receiver signal strength indicator level, linearity, flatness
Crystal	Frequency reference 'free run' f_o

Table 1. Calibration items

The simplified diagram figure 1 shows where tests are performed in the manufacturing flow. Power calibration generally requires a direct connection to the handset and most handsets today do not have an antenna connection accessible once the handset has been assembled.

The transmit power calibration is performed to adjust the transmit power and the power control steps. This needs to be done for each of the transmit bands (defined by the number of power amplifier blocks) supported by the handset. Today a 2G GSM handset may operate on three or more frequency bands and a 3G handset on considerably more. The cellular networks have spilled out from the 900 and 1800 MHz bands and in different regions may occupy allocations in the 400/450, 700, 800, 900 1500 1700, 1800 1900 and 2100 MHz bands. The world has shrunk and many users expect their handsets to roam anywhere and connect everywhere.

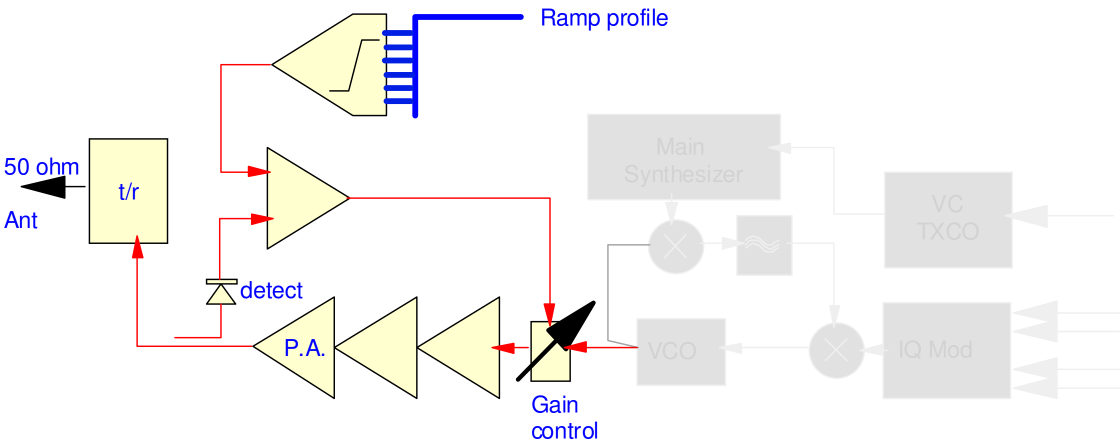

Fig 2 Transmit Power Control

Fig 2 shows typical power output stage for typical single-band GSM handset. In a dual-band phone there are two power amplifiers, one for each band, but the modulator and up-converter sections (greyed in this diagram) are common to both bands.

The output power is set by a control loop which also controls the power profile using a gain control element. A portion of the output power is sampled and detected by a diode detector. The detected voltage is compared to the ramp profile generated in a DAC from data sent by the base-band processor. The difference voltage drives the power control element.

The overall approach to calibration is simple. Firstly, a set of default data is loaded into a calibration table. This data is used to control the power prior to the calibration procedure. In the calibration procedure each power level is measured and the difference between the measured power level and the required power level is recorded. From this difference, together with knowledge of the behaviour of the design, new control values are calculated and the calibration table loaded with these values.

Measuring and adjusting each power level in turn is more-or-less feasible for a GSM handset with fifteen or 16 power levels. 3G designs use range switching amplifiers to allow power control over a much greater range of output levels. The spec requires 1dB gain steps from the maximum output power down to levels below -50dBm. This requires 70 - 80 distinct output levels and measuring these individually becomes too slow to consider for high volume manufacturing.

As well as the Transmitter calibration there is a need to calibrate the receive signal strength indicator ("RSSI") detector circuits. The RSSI is used to measure the signal level of the cellular network received by the handset. Signal levels of the serving cell and neighbour cell are telemetered to the network base station controller (in a GSM network) or the RAN-C (in a 3G network) where this information is used to make decisions on when to hand-over the handset from one cell to another.

RSSI measurements are calculated from intermediate frequency samples passed to the receiver baseband processor. Calibration compensates for differences in RF/IF gain and typically needs to be performed on three or more channels across each of the receiver bands implemented in the handset. In this context the band can be taken to mean combinations of a receiver band filters and low noise amplifier. A typical 2G/3G handset may implement two, three or more bands defined in this way.

Reducing the Cost of Test

Over recent years manufacturers have looked to designers to reduce the manufacturing overhead due to calibration and test. It is a fairly easy task to estimate the cost saving that can be achieved by reducing manufacturing cycle time.

A basic GSM handset typically will have a relatively simple microprocessor system which can power-on and boot-up in a couple of seconds and be ready to make a phone call in less than ten seconds. Handsets have become more complex and subsequently the start-up times have increased. Today, a typical smart-phone can boot only a little faster than a PC. The smart-phone probably will implement a greater number of bands so the radio subsystem has much more work to do before it is ready to make a call.

To test the transceiver in a mobile phone it is, of course, necessary to get it to transmit. Until fairly recently the approach adopted by most handset manufacturers, was to use a 'Cellular Telephone Test Set' such as the Agilent E5515C RF Communications Test Set to put the handset into a 'test call' using the same over-the-air signalling protocols used to control the handset. .

Once the call is set-up then the over-the-air signalling protocols can be used to force a 'handover' or 'reassignment' to change channel frequency or transmit power level. In the 3G world 'closed loop' power control is embedded into the physical layer of the OTA protocol and this can be used to rapidly change power from one end of the power control scale to the other. On a GSM channel the power control is supported by higher layers and the protocol includes a mechanism in which the output power steps through all the intermediate levels between the current power level and a final power level, the dwell time for each level being approximately half a second. This mechanism has become the basis of a fairly time-efficient transmit power calibration scheme.

Many handset suppliers have assumed the use of call control protocols in manufacturing as an essential element of the test process. Probably this was an ideal approach with first generation ('analogue' radio format) and also for early second generation (IS45 and GSM) handsets where specific circuitry supported generation and decoding of the OTA protocols. In today's handsets there is a high level of integration within the chipsets and so this is no longer a valid assumption.

An alternative approach to using call procedures is to implement a set of physical test modes and to use these to control the device under test (DUT). Test modes allow direct control of transceiver functions from a test system with less processing overhead. This enables reduced test times to be achieved. Also, not only is the test overhead reduced but the rules for the design of test systems can be changed. For instance a test mode can support a simplified transmit calibration using just PC/computer to control the DUT though a serial or USB connection and a Measurement Receiver or Power Meter to make the measurements. Similarly, the only test equipment needed for receive calibration would be a modulated Signal Generator. Furthermore these separate calibration functions can be engineered to be performed concurrently.

With a conventional Mobile Telephone Test Set measurement procedures normally use signal vectors that mimic accurately the signal formats defined in the cellular standards. For all intents and purposes the handset is operating as if on a live network, maybe with some additional functionality such as the ability to support defined channel configurations and test loopback. Naturally this approach is appealing to the test engineer because it provides a direct link between results measured on the manufacturing test system to conformance test measurements mandated to validate the basic design of the phone.

Removing this constraint from a manufacturing system enables very short calibration and test cycles to be achieved. Test firmware loaded into the handset can be designed to drive the handset through a cadence of channels and transmit power levels and with *a priori* knowledge of the test pattern the test system can rapidly take a full set of measurements from which the calibration data may be calculated. This approach is now successfully deployed by many manufacturers, reducing calibration times from tens of seconds per band down to just a few seconds.

The development of new radio technologies, such as WiMAX and 3GPP-LTE, bring new levels of complexity to the radio environment. Test methods, based on physical test procedures, provide a way to ensure devices can be manufactured as readily as those using the current standards.

Conclusion

Test time is a significant factor in the manufacturing cost of a mobile phone and hence a contributor to the selling price on the high street. With production volumes of over a billion mobile phones per year the ability to control and reduce manufacturing cost can be achieved by the development of advanced test techniques and this can be a key differentiator between the leading and also-ran suppliers.

References

Agilent E5515C Wireless Communications Test Set
Test Application E1968A for GSM/GPRS/EGPRS handset testing
Agilent publication reference 5988-9684EN

GSM/GPRS/EGPRS Calibration Application.for the E6601A Wireless Communications Test Set Technical Data Sheet. Agilent Publication reference 5989-5293EN

W-CDMA Dynamic PowerAnalysis Using the
Agilent 8960 Wireless Communications Test Set
Agilent publication reference 5989-2573EN

Fast Device Tune Measurement Solution for Calibrating W-CDMA Mobile Phones with the Agilent E6601A ireless Communications Test Set.
Agilent Application Note publication reference 5989-6500EN

Mobile WiMAX™ Manufacturing Test with the N8300A
Agilent publication number 5989-8348EN