RF Calibration & Test Mode Seminar

2002/04/04

Eric Song, Texas Instruments China

Production and RF Calibration

Production flow (simplified)

SMT → SW download / Initial Test / RF Calibration → Assembly → Final Test → Ship

Final Test → QA / QC

- Board Turn-on
- Basic Board Probing
- **Software Download** (if not using pre-programmed flash).
- **Initial test:** TX / RX current consumption, etc..
- **RF calibration**: VCTCXO, TX power, AGC, RSSI, ADC, etc..

- **Final Test**: Phase/Frequency-error, TX Power, TX template, Switching/Modulation-spectrum, BER, RX-level.
- Audio Tests: Speaker, Mic., Buzzer (Requires Advanced Fixture)
- Battery: Low Battery Indication, Charger Test.
- Display/Keypad (Requires Advanced Fixture)

Production and RF Calibration

Production flow - Where is TI involved?

•SW download stage → Bootloader → Flashloader

Bootloader		Flashloader
•Preprogrammed in Flash	→	Monitor / FLUID /Delta
•Download trough JTAG	→	Delta
•Calypso internal	→	FLUID / Delta

Download speed → Flashloader

- •Monitor 115.2Kbit/s
- •Delta 115.2Kbit/s up to 812.5Kbit/s
- •FLUID 115.2Kbit/s up to 921.6Kbit/s

Delta is a third party company that under NDA develops production test tools for TI.

Production and RF Calibration

- Initial Test
- RF Calibration
- Final Test

} RD33x RF Production Test and Calibration Specification

<u>Tools</u>

MS side TestMode and FlashFileSystem

TM provides direct access / control of L1 - HW

FFS makes it possible to store calibration values in the Flash

PC side PCTM.

<u>Test systems providers for TI reference designs</u>

Agilent (HP8960)
Rohde & Schwarz (CMU200)
Acterna (4400M)

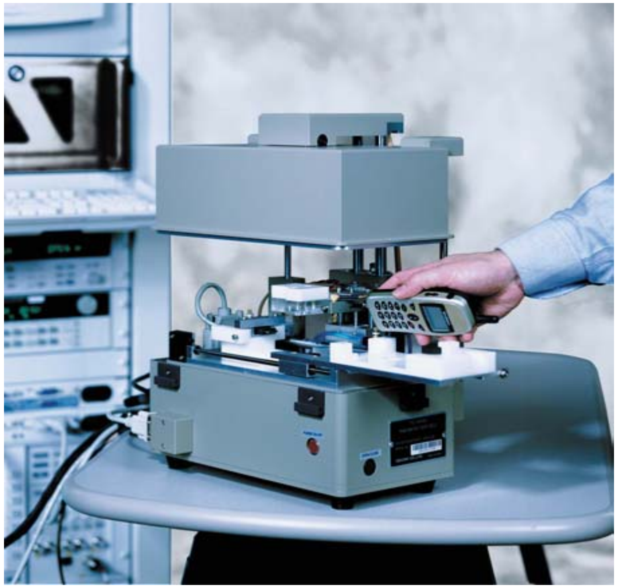
} Delivered in corporation with TI-Taipei, using tiAutoTM.DLL for communicating with TM

Delta (CMU200, HP8960)

Production and RF Calibration

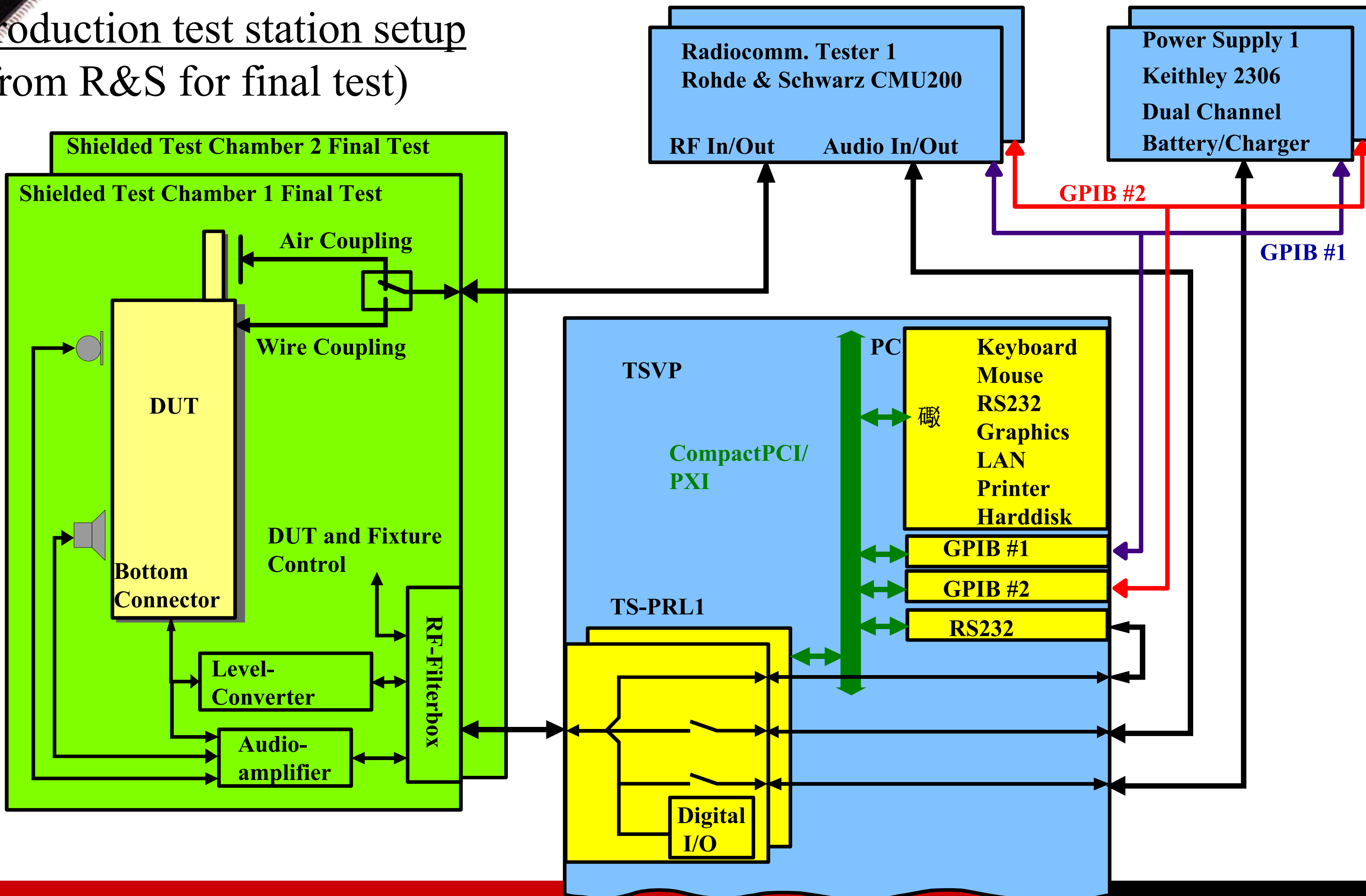
Production test station HW (from R&S)

Example of MS test fixtures



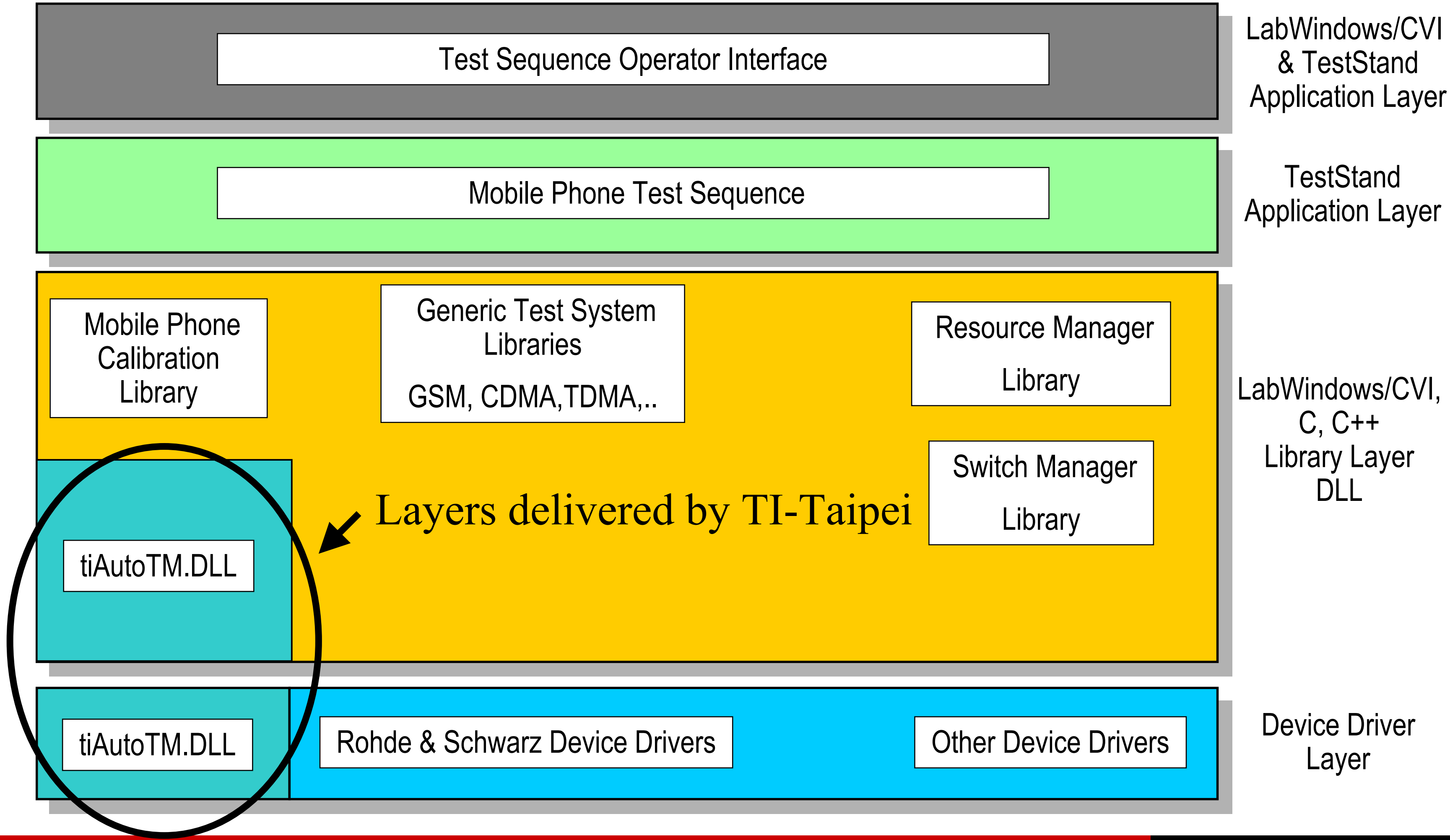
Production and RF Calibration

Production test station setup
(from R&S for final test)



Production and RF Calibration

Production test station SW overview



Production and RF Calibration

tiAutoTM.DLL overview (simplified)

Calculation function calls layer

Customized / generalized function calls layer (independent of TM version)

Primary TM Function calls layer (depending of TM version)

TI serial protocol handling layer

Serial driver (multi tread safe)

Production and RF Calibration

Example of TestMode commands used for doing BER test in non-signalling synchronised mode (on the CMU200)

General configuration

Synchronize frequency and timing vice

Setup TCH and loopback received data

Step	Equipment	Action	Comment
1	TM v. 3.7.0	TMS 1	Enter TestMode.
2	TM v. 3.7.0	RFPW 7 6 0	Set std to 6 (EGSM900/DCS1800) and band to 0 (EGSM900)
3	TM v. 3.7.0	RFPW 1 32	Set BCCH.
4	TM v. 3.7.0	RFPW 2 40	Set TCH, in this case CH 40.
5	TM v. 3.7.0	TXPW 1 5	Set Tx power level to 5.
6	TM v. 3.7.0	TXPW 11 0	Set TSC
7	TM v. 3.7.0	RXPW 2 3	Set timeslot
8	TM v. 3.7.0	TXPW 9 5	Enable TCH_LOOPBACK_A
9	TM v. 3.7.0	SCW 16 1	Set number of times to loop within RFE.
10	TM v. 3.7.0	SCW 17 1	Set number of loops before returning statistic results.
11	TM v. 3.7.0	SCW 18 1	Set number of loops between auto reset of statistics.
12	TM v. 3.7.0	RFE –S 13	Receive frequency burst type 0.
13	TM v. 3.7.0	RFE –S 12	Receive frequency burst type 1.
14	TM v. 3.7.0	RFE –S 11	Receive synchronization burst.
The MS should now be synchronized - press the *Call to MS* button on the CMU200 before proceeding.			
15	TM v. 3.7.0	SCW 16 0	Set number of times to loop within RFE to infinite.
16	TM v. 3.7.0	SCW 17 50	Set number of loops before returning statistic results.
17	TM v. 3.7.0	SCW 18 50	Set number of loops between auto reset of statistics.
18	TM v. 3.7.0	RFE 3	Do both RX and TX on TCH.

Production and RF Calibration

Open TestMode functions

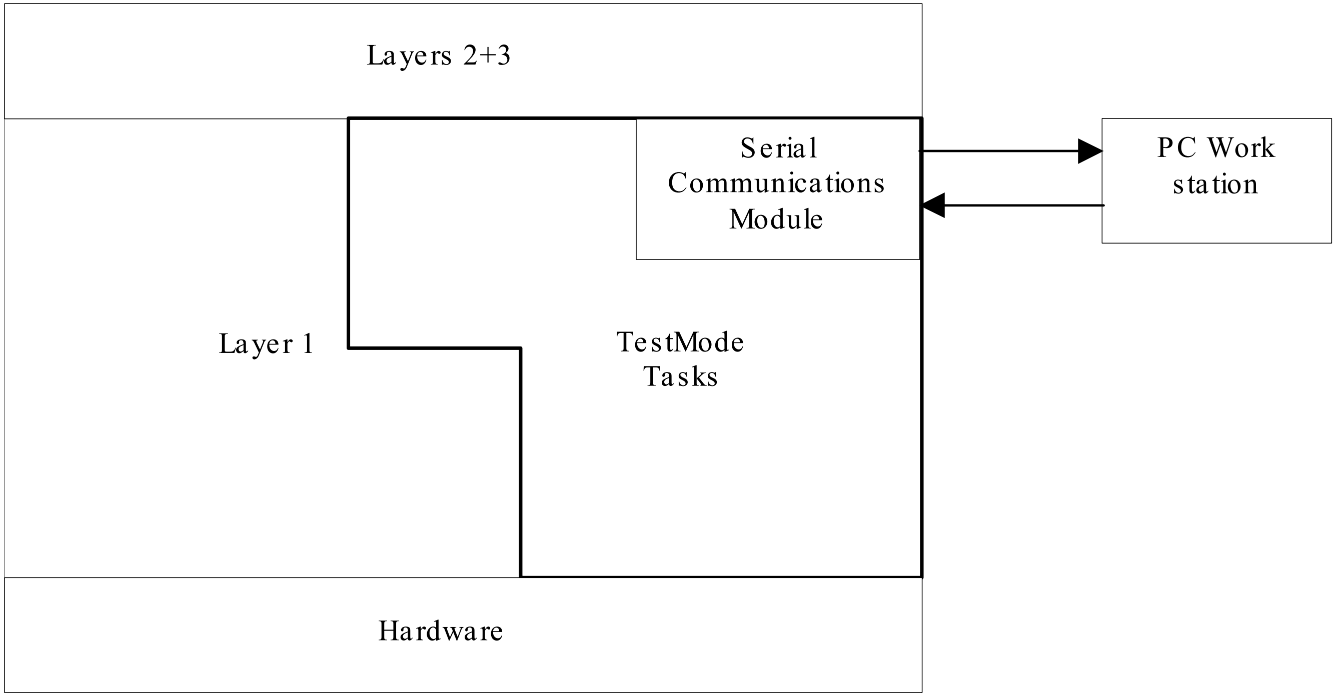
The SPW / R, STW / R, SE are open test mode functions exclusively for the customer to use.

IMEI Read	str 60
IMEI Write	stw 60 [8byte]
RTC Setting	stw 20 [7byte]
Serial NUM Write for IMEI	stw 61 [3byte]
Serial NUM read	str 61
Target Region Write	spw 100 number
7LED Color	spw 56 [0~7]
EEPROM Read	spw 55 address str 55
MIC BIAS ON/OFF	spw 72 1 / 0
Flash check Test	spr 61
Flash check Test	se 58
Speaker Test(gain setting)	spw 73 [1~255]
Speaker Test ON/OFF	spw 74 1 / 0
Main LCD Contrast Setting	spw 51 value / spr 51
Sub LCD Contrast Setting	spw 52 value / spr 52
	spw 53 value / spr 53
BackLight ON/OFF test	se 53 / se 54
Main LCD Check Test	se 50
Sub LCD Check Test	se 51
Vibrator Test	se 56
Melody Check Test	se 57
Key AutoTest	se 59

Agenda

- Test Mode Overview
- Sara RF Calibration

Test Mode Overview



- TestMode can be used in 2 ways:
  1) Manual operation (RF development, testing, calibration)
  2) It can be driven by customer-written software for the automatic production-line environment

Test Mode Overview

- **In pre-FTA:**
  - TestMode is used to check the perfomance of the MS:
    - drive the Transmitter and Receiver to make BER, TX Power, timing, etc., measurements in the lab
    - check the default RF parameters and compensation factors calculated during development

- **For FTA**:
  - TestMode is used to carefully calibrate the actual MS's which will be used for FTA
    - fine-tune the TX power levels, TX ramp templates, AGC gain tables, and various compensation factors

Test Mode Overview

- **For Production Testing:**
  - TestMode is driven by customer-written PC software to efficiently and quickly perform the various calibrations and tests
  - the serial protocol is optimized for speed
  - the calibration procedures are optimized for performance and speed
  - the MS's will be ready for Field Tests and release to market

Test Mode Overview

General RF Functions:

- Configure RF Parameters

1 BCCH
2 TCH ARFCN.
3 MON ARFC
8 AFC algorithm enable flag. 0 = disable, 1 = enable
9 AFC DAC value. The value is a signed integer in the range {–4096:4095}.
10 Initial value of AFC DAC. Value used when an initial FB read attempt is made.

- Transmitter and Receiver Enable Operations

0 stop all transmit and receive operations.
1 receive on TCH without network synchronization.
2 transmit on TCH without network synchronization.
3 simultaneous transmit and receive on TCH without network synchronization.

- Write RF table:

Global AGC parameters table, transmit temperature calibration table.
receiver RSSI temperature calibration table.

Test Mode Overview

- **RF Receiver Functions:**
  - enable/disable AGC algorithm
  - set AGC value
  - read/write AGC table
  - make a DSP power measurement
  - get RSSI report value
  - read/write RSSI compensation tables
  - read/write IL_2_AGC tables
- **RF Transmitter Functions:**
  - set TX power level
  - read/write TX ramp templates
  - set TX parameters (data to send in burst, tsc…)
  - read/write TX compensation tables

SARA RF Calibration

- VCTCXO Calibration
- Tx Power Calibration
- AGC Calibration
- Rx RSSI Channel Compensation
- Temperature Sensor Calibration
- Battery Sensor Calibration

1. VCTCXO calibration

The VCTCXO *"INI_DAC"* value need to be calibrated in order to have the frequency synthesis generating the LO signals accurately enough for the phone to do successful FB search.

2. TX power level calibration

- **Power Level Cal. done in production**
- **Channel Cal. done in development**
- **Temperature Cal. done in development**
- **Extreme Conditions Cal.(Voltage & Temp) done in development**

3. AGC calibration

For the receiver output power to be fixed at a well defined level, the software constant *GMagic* needs to be calibrated.

4. RX RSSI Calibrations

- Channel Calibration done in production
- Temperature Calibration done in development

5. Temperature Sensor Calibration

The ADC internal reference voltage is the largest contributor to measurement inaccuracy.

Measuring the ADC slope makes it possible to correct this in the SW.

6. Battery Sensor Calibration

The ADC internal reference voltage is the largest contributor to measurement inaccuracy.

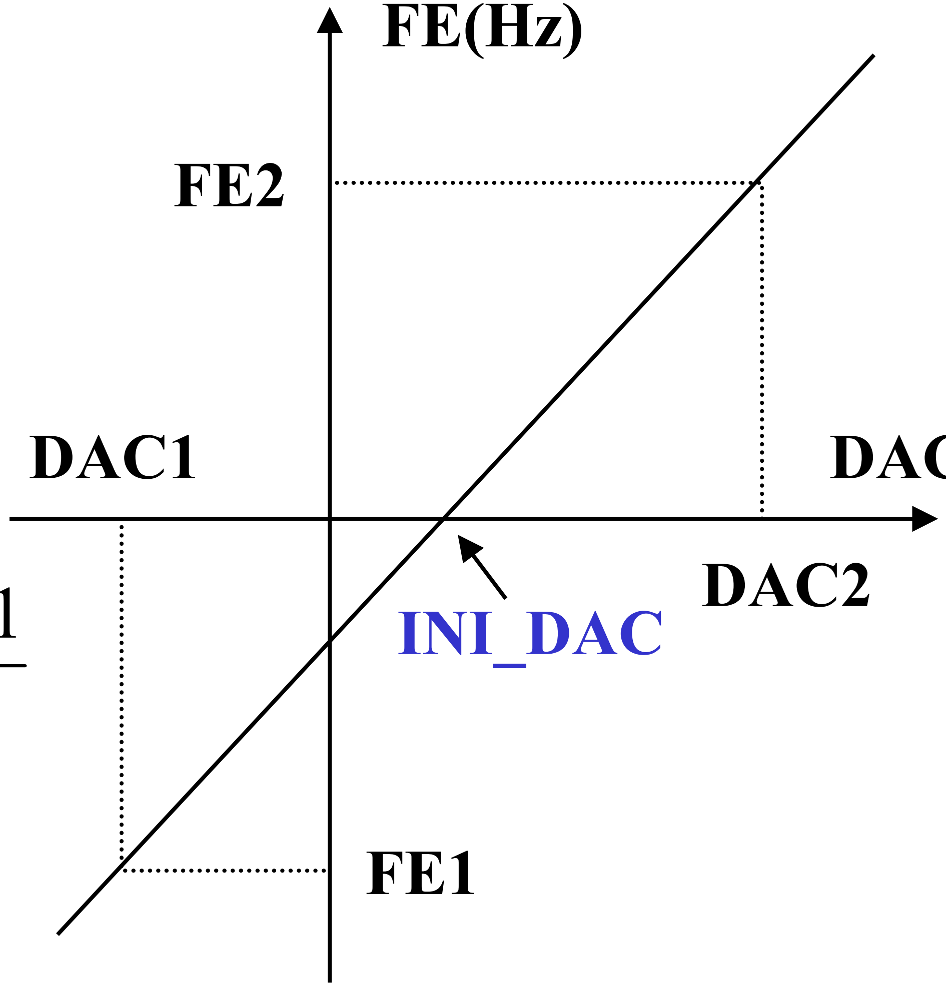
Measuring the ADC slope and offset makes it possible to correct this in the SW.

VCTCXO Calibration

VCTCXO Calibration (EXAMPLE)

$$K = \frac{FE\,2 - FE\,1}{DAC\,2 - DAC\,1}$$

$$INI\_DAC = DAC\,1 - \frac{FE\,1}{K}$$



Procedure

Step	Equipment	Action	Comment
1	TM v.3.0	TMS 1	Enter TestMode.
2	TM v.3.0	RFPW 2 40	Set TCH to 40.
3	TM v.3.0	RFPW 8 0	Disable AFC algorithm.
4	TM v.3.0	TXPW 1 12	Set TX power level to 12.
5	TM v.3.0	RFE 3	Do both RX and TX on TCH w/out network sync.
6	TM v.3.0	RFPW 9 –482	Set AFC *DAC1* value.
7	BSS	Measure the Frequency error.	Store the result in *FE1*.
8	TM v.3.0	RFPW 9 129	Set AFC *DAC2* value.
9	BSS	Measure the Frequency error.	Store the result in *FE2*.
10		Calculate *K* and *INI_AFC*	Using Equation (11.1) and (11.2).
11	TM v.3.0	RFPW 10 *INI_AFC*	Write calibrated *INI_AFC* value to MS.
12	TM v.3.0	RFPR 10	Check that *INI_AFC* value has been written to MS.
13	TM v.3.0	RFPW 9 *INI_AFC*	Write *INI_AFC* value to MS.
14	BSS	Measure FE	Check if within +/- 70Hz.
15	TM v.3.0	SE 102	Store *INI_AFC* in FFS.
16	TM v.3.0	RFPW 8 1	Enable AFC algorithm.

TX power level calibration

Test Steps

To calibrate the TX power levels the following steps have to be performed for both bands:

1. Setup the mobile to transmit on the channel specified in Table 10.2.
2. Setup up the power level that needs to be calibrated.
3. Calibrate the power level according to Table 10.2.
4. If output power is higher than specified in Table 10.2 then decrease the APC level.
5. If output power is lower than specified in Table 10.2 then increase the APC level.
6. Proceed with the steps above until all power levels both bands have been calibrated.

TX Power Standard Setting Value

Power level	EGSM900 @ channel 40 [dBm]	GSM1800 @ channel 700 [dBm]
0	-	28.8
1	-	27.5
2	-	26
3	-	24
4	-	22
5	31.8	20
6	30.5	18
7	29	16
8	27	14
9	25	12
10	23	10.5
11	21	9
12	19	7.5
13	17	6
14	15	4.5
15	13	3
16	11.5	-
17	10.5	-
18	9.5	-
19	8.5	-

Procedure

Step	Equipment	Action	Comment
1	TM v.3.0	TMS 1	Enter TestMode.
2	TM v.3.0	TXPW 14 0x0	Disable all TX calibrations.
3	TM v.3.0	RFPW 2 40	Set TCH to 40.
4	TM v.3.0	TXPW 1 5	Select power level 5 EGSM900
5	TM v.3.0	TXPR 4	Read the default *APC* value used on power level 5
6	TM v.3.0	RFE 3	Do both RX and TX.
7	BSS	Measure the output power	Trig on TSC 5.
8	TM v.3.0	TXPW 4 *APC*	Change the *APC* level so the output power corresponds to Table 11.4.
9	TM v.3.0	SE 104	Store *APC* levels in FFS.

Procedure for calibration of the TX power levels. This procedure has to be performed for both bands and all power levels.

Note that the TXPW (step 4) is for EGSM900 only. For GSM1800 the corresponding commands should be step 4 = [TXPW 1 100+power level].

RX AGC calibration

Purpose

For the receiver output power to be fixed at a well defined level
The software constant G_{Magic} needs to be calibrated.

Procedure

To calibrate G_{Magic} the following steps have to be performed for both bands:

1. Setup the mobile to receive on the ARFCN specified in Table 11.6.
2. Set the AGC in the receiver to the gain specified in Table 11.6.
3. Set the generator level to TL specified in Table 11.6.
4. Write INI_AFC value to MS.
5. Set test frequency as specified in Table 11.6 plus 67KHz.
6. Measure PM_1
7. Set test frequency as specified in Table 11.6 minus 67KHz.
8. Measure PM_2
9. Calculate $PM_{AV} = (PM_1+PM_2)/2$.
10. Calculate $G_{Magic} = (PM_{AV} – AGC – TL)x2$.
    TL is the test signal level in dBm.
    PM_{AV} is an average over the two power measurements in dBd made by the DSP.
    AGC is the IF gain in dB.
11. Download G_{Magic} to MS.

Note: Instead of step 5 to 8 you could also test only at the ARFCN center frequency modulated by a pseudo–random bit sequence (PRBS).
PCTM should be entered with the command line option "–a" for enabling asynchronous packet receive

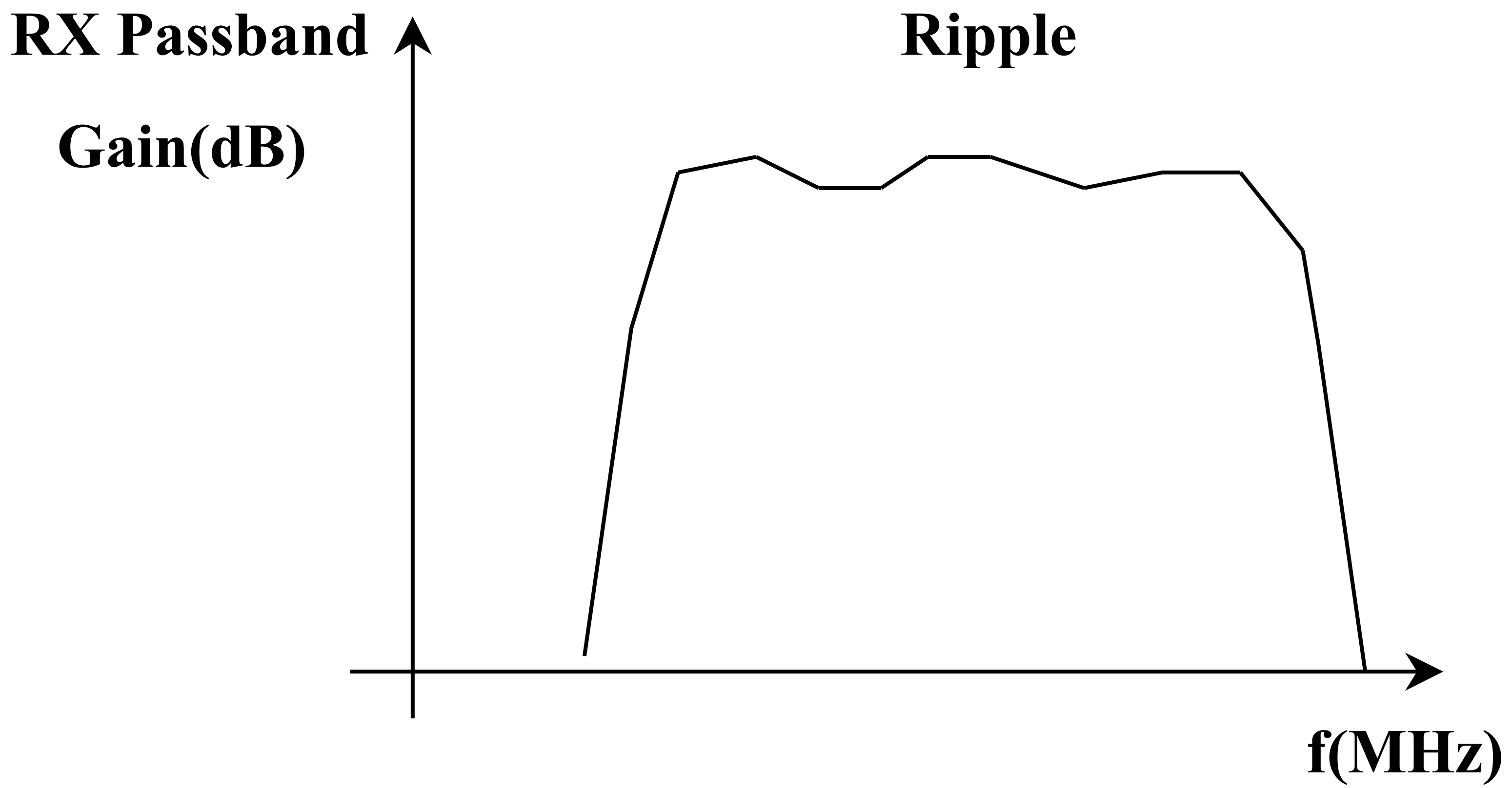
Procedure

Receive Band	Test ARFCN	*AGC* setting [dB]	*TL* [dBm]	Test frequency [MHz]
EGSM900	40	34	-74.5	943.0
GSM1800	700	34	-74.5	1842.8

Procedure

Step	Equipment	Action	Comment
1	TM v.3.0	TMS 1	Enter TestMode.
2	TM v.3.0	RFPW 2 *Test ARFCN*	Set TCH according to Table 11.6.
3	TM v.3.0	RXPW 14 0	Disable RX calibrations
4	TM v.3.0	RXPW 8 0	Disable AGC algorithm.
5	TM v.3.0	RXPW 1 34	Set AGC gain to 34 dB.
6	TM v.3.0	RFPW 8 0	Disable AFC algoritm.
7	TM v.3.0	RFPW 9 *INI_AFC*	Write *INI_AFC* value to MS.
8	TM v.3.0	SCW 17 50	Set number of loops before returning statistic results.
9	TM v.3.0	SCW 18 50	Set number of loops between auto reset of statistics.
10	TM v.3.0	SCW 25 0xF	Set statistic bitmask.
11	SG or BSS	Test frequency + 67KHz	Set test frequency according to Table 11.6.
12	SG or BSS	*TL* = -74.5 dBm	Set *TL* according to Table 11.6.
13	TM v.3.0	RFE 1	Receive on TCH without network synchronization.
14	TM v.3.0	Measure PM_1	Get PM_1 from the PCTM window and store it.
15	TM v.3.0	RFE 0	Stop RX.
16	SG or BSS	Test frequency - 67KHz	Set test frequency according to Table 11.6.
17	SG or BSS	*TL* = -74.5 dBm	Set *TL* according to Table 11.6.
18	TM v.3.0	RFE 1	Receive on TCH without network synchronization.
19	TM v.3.0	Measure PM_2	Get PM_2 from the PCTM window and store it.
20	TM v.3.0	RFE 0	Stop RX.
21		Calculate PM_{AV}	$PM_{AV} = (PM_1+PM_2)/2$
22		Calculate G_{Magic}	$G_{Magic} = (PM_{AV} – AGC – TL)x2$
23	TM v.3.0	RFTW 31 G_{Magic},40,0,39,40	Download G_{Magic} to MS.
24	TM v.3.0	RFTR 31	Check that G_{Magic} has been written to MS.
25	TM v.3.0	SE 106	Store G_{Magic} in FFS.
26	TM v.3.0	RXPW 8 1	Enable AGC algorithm.
27	TM v.3.0	RFE 1	Check that the RX level reported by MS corresponds to the used *TL* from the Signal Generator.

Rx RSSI Calibration


RX Passband
Gain(dB)
Ripple
f(MHz)

Test steps

1. Setup the mobile to receive on the ARFCN specified in followed Table
2. Set the *AGC* in the receiver to the gain specified in followed Table
3. Set the generator level to *TL* specified in followed Table
4. Write *INI_AFC* value to MS.
5. Set test frequency as specified in followed Table plus 67KHz.
6. Measure *PM*1.
7. Set test frequency as specified in followed Table minus 67KHz.
8. Measure *PM2* .
9. Calculate $PMAV = (PM1 + PM2)/2$.
10. Calculate $ChanCalX = (TL - PMAV + AGC + (GMagic/2)) \times 2$

TL is the test signal level in dBm.
PMAV is an average over the two power measurements in dBd made by the DSP.
AGC is the IF gain in dB.
GMagic is the AGC calibrated value

Test steps

ARFCN Interval		Test ARFCN	*AGC* setting [dB]	*TL* [dBm]	Test frequency [MHz]
EGSM900					
975	991	975	34	-74.5	925.2
992	1009	1000	34	-74.5	930.2
1010	1023	1017	34	-74.5	933.6
0	10	1	34	-74.5	935.2
11	30	20	34	-74.5	939.0
31	51	40	34	-74.5	943.0
52	71	62	34	-74.5	947.4
71	90	80	34	-74.5	951.0
91	112	100	34	-74.5	955.0
113	124	124	34	-74.5	959.8
GSM1800					
512	548	512	34	-74.5	1805.2
549	622	585	34	-74.5	1819.8
623	680	660	34	-74.5	1834.8
681	745	700	34	-74.5	1842.8
746	812	790	34	-74.5	1860.8
813	860	835	34	-74.5	1867.8
861	885	885	34	-74.5	1879.8

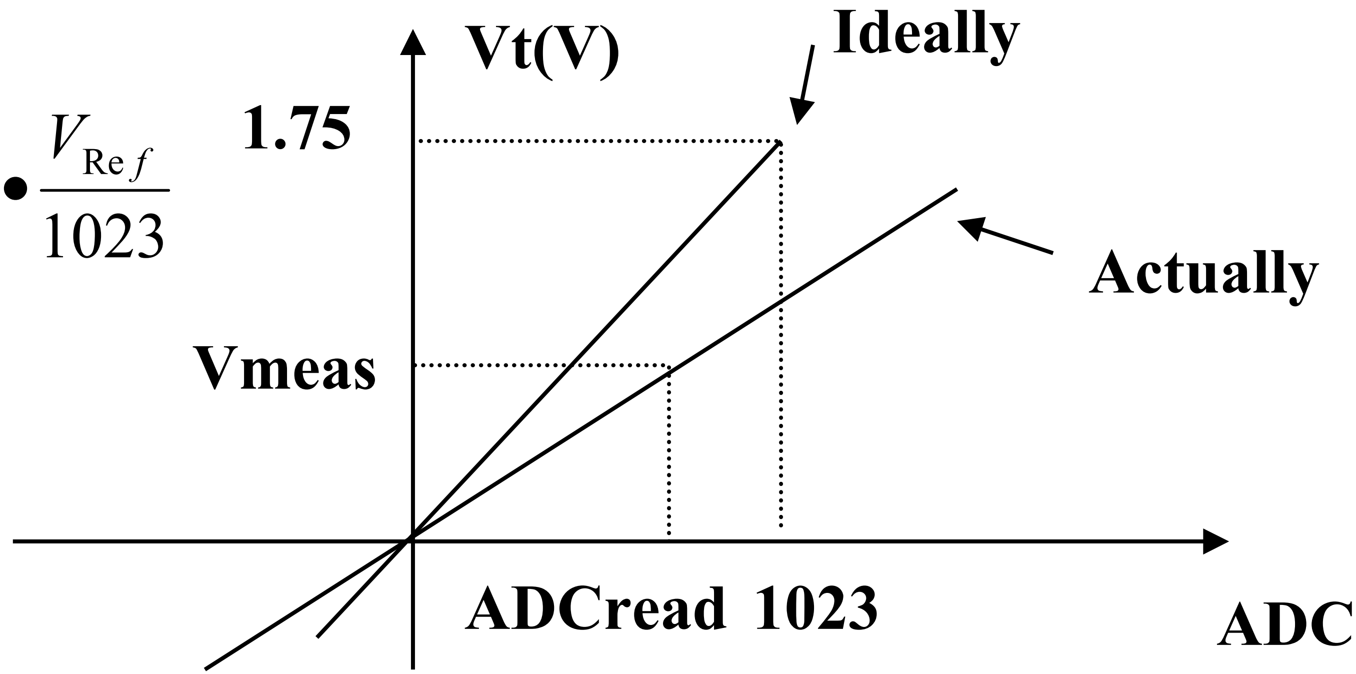
Procedure

Step	Equipment	Action	Comment
1	TM v.3.0	TMS 1	Enter TestMode.
2	TM v.3.0	RXPW 14 0	Disable RX calibrations
3	TM v.3.0	RXPW 8 0	Disable AGC algorithm.
4	TM v.3.0	RXPW 1 34	Set AGC gain to 34 dB.
5	TM v.3.0	RFPW 8 0	Disable AFC algoritm.
6	TM v.3.0	RFPW 9 *INI_AFC*	Write *INI_AFC* value to MS.
7	TM v.3.0	SCW 17 50	Set number of loops before returning statistic results.
8	TM v.3.0	SCW 18 50	Set number of loops between auto reset of statistics.
9	TM v.3.0	SCW 25 0xF	Set statistic bitmask.
10	TM v.3.0	RFPW 2 *Test ARFCN*	Set TCH according to Table 11.8.
11	SG or BSS	Test frequency + 67KHz	Set test frequency according to Table 11.8.
12	SG or BSS	*TL* = -74.5 dBm	Set *TL* according to Table 11.8.
13	TM v.3.0	RFE 1	Receive on TCH without network synchronization.
14	TM v.3.0	Measure PM_1	Get PM_1 from the PCTM window and store it.
15	TM v.3.0	RFE 0	Stop RX.
16	SG or BSS	Test frequency - 67KHz	Set test frequency according to Table 11.8.
17	SG or BSS	*TL* = -74.5 dBm	Set *TL* according to Table 11.8.
18	TM v.3.0	RFE 1	Receive on TCH without network synchronization.
19	TM v.3.0	Measure PM_2	Get PM_2 from the PCTM window and store it.
20	TM v.3.0	RFE 0	Stop RX.
21		Calculate PM_{AV}	$PM_{AV} = (PM_1+PM_2)/2$
22		Calculate *ChanCalX*	$ChanCalX = (TL - PM_{AV} + AGC + (G_{Magic}/2)x2$
Proceed with step 10 and forward until all channel in the EGSM900 band have been calibrated			
23	TM v.3.0	RFTW 25 10,*ChanCalX……1023,ChanCalX*	Download EGSM RX channel compensation values to MS.
24	TM v.3.0	RFTR 25	Check that RX channel compensation has been written to MS.
25	TM v.3.0	SE 106	Store *ChanCalX* in FFS.
26	TM v.3.0	RXPW 8 1	Enable AGC algorithm.
27	TM v.3.0	RFE 1	Check that the RX level reported by MS corresponds to the used *TL* from the Signal Generator o… channels.

Temperature Sensor Calibration

Principle

$$Vt = V_{ADC} \bullet \frac{V_{Ref}}{1023}$$



$$TempSenseCal = \mathrm{int}\left(\frac{1023 \times V_{Meas} \times 256}{ADC_{Read} \times 1750}\right)$$

Test Steps

1. Measure the voltage in TP with a voltmeter [mV].
2. At the same time take a reading from Ext. ADC number 3.
3. Calculate compensation factor *TempSenseCal* using equation
4. Download Calibration value.

$$TempSenseCal = \mathrm{int}\left(\frac{1023 \times V_{Meas} \times 256}{ADC_{\mathrm{Re}ad} \times 1750}\right)$$

Procedure

Step	Equipment	Action	Comment
1	TM v.3.0	TMS 1	Enter TestMode.
2	TM v.3.0	Set TEMP_SENSOR_EN	Activate Temperature Sensor
3	TM v.3.0	MPR 36	Read Ext. ADC 3.
4	Voltmeter	Measure V_{Meas} [mV]	TP822.
5		Calculate *TempSenseCal*	Using Equation (11.13).
6	TM v.3.0	MPW 56 *TempSenseCal*	Write *TempSenseCal* value to MS.
7	TM v.3.0	MPR 56	Check that *TempSenseCal* value has been written to MS.
8	TM v.3.0	SE 108	Store *TempSenseCal* in FFS.

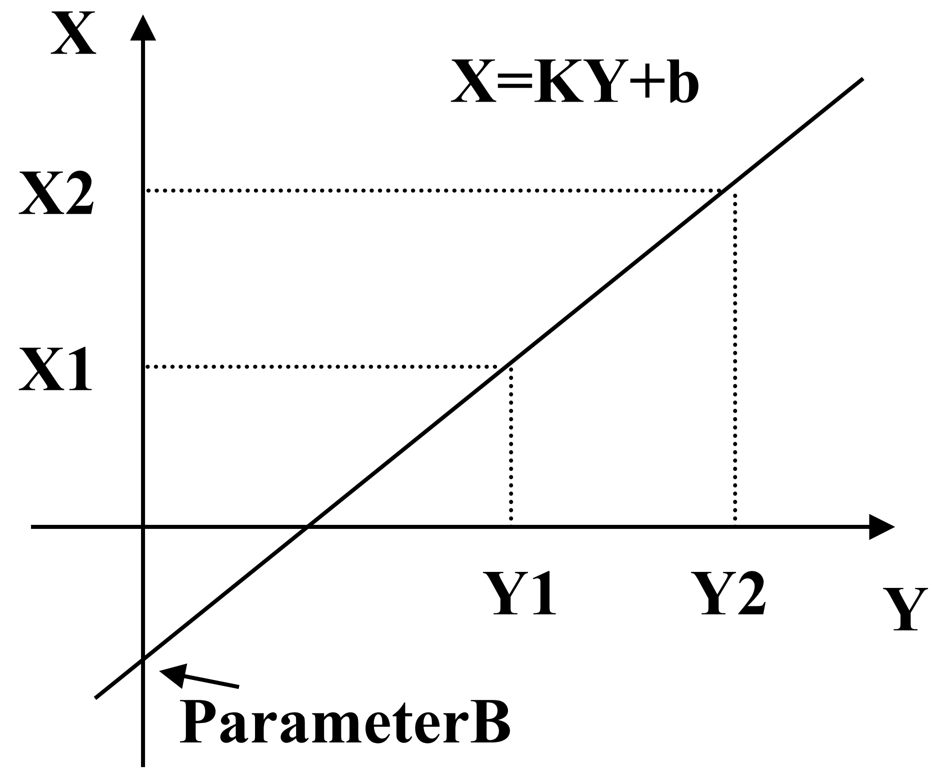
Battery Sensor Calibration

Principle

$$\begin{bmatrix} Parameter_A \\ Parameter_B \end{bmatrix} = \begin{bmatrix} Y_1 & 1 \\ Y_2 & 1 \end{bmatrix}^{-1} \times \begin{bmatrix} X_1 \\ X_2 \end{bmatrix}$$

$$\text{ParameterA} = \frac{X1 - X2}{Y1 - Y2} = K$$

$$\text{ParameterB} = \frac{X2Y1 - Y2X1}{Y1 - Y2} = b$$



Test Steps

1. Set the power supply voltage to 3200 mV = X1.
2. At the same time take a reading from Int. ADC number 0 =Y1.
3. Set the power supply voltage to 4200 mV = $X1$.
4. At the same time take a reading from Int. ADC number 0 = $Y2$.
5. Calculate *vbatcal_a* and *vbatcal_b* using equation

$$\begin{bmatrix} Parameter_A \\ Parameter_B \end{bmatrix} = \begin{bmatrix} Y_1 & 1 \\ Y_2 & 1 \end{bmatrix}^{-1} \times \begin{bmatrix} X_1 \\ X_2 \end{bmatrix}$$

ParameterA is multiplied with 1024 and rounded to an integer,

vbatcal_a = *int(ParameterA x1024)*

ParameterB is rounded to a signed integer

vbatcal_b = *int(ParameterB)*

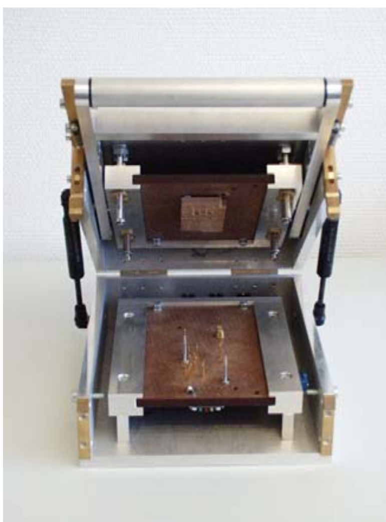
6. Download calibration value *vbatcal_a* and *vbatcal_b*

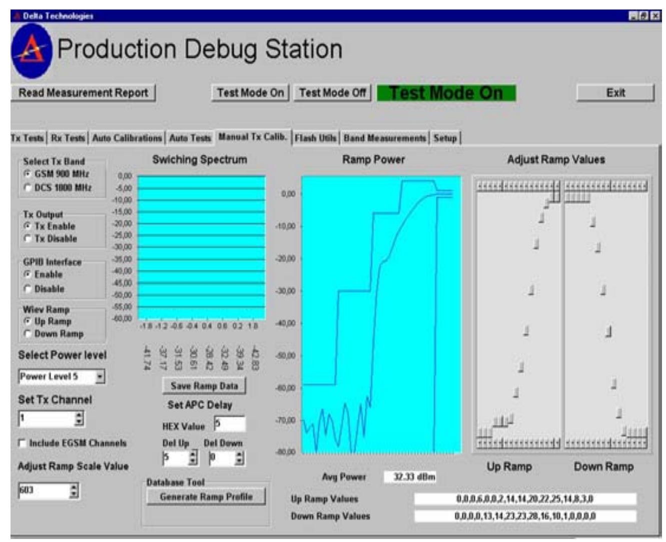
Procedure

Step	Equipment	Action	Comment
1	TM v.3.0	TMS 1	Enter TestMode.
2	Calibrated power supply	Set Vbat to 3200mV = X_1	
3	TM v.3.0	MPR 30	Read Int. ADC 0.
4		Save ADC value to Y_1	
5	Calibrated power supply	Set Vbat to 4200mV = X_2	
6	TM v.3.0	MPR 30	Read Int. ADC 0.
7		Save ADC value to Y_2	
8		Calculate *vbatcal_a* and *vbatcal_b*.	Using Equation (11.14).
9	TM v.3.0	MPW 50 *vbatcal_a*	Write *vbatcal_a value* to MS.
10	TM v.3.0	MPW 60 *vbatcal_b*	Write *vbatcal_b* value to MS.
11	TM v.3.0	MPR 50	Check that *vbatcal_a* value has been written to MS.
12	TM v.3.0	MPR 60	Check that *vbatcal_b* value has been written to MS.
13	TM v.3.0	SE 108	Store *vbatcal_a* and *vbatcal_b* in FFS.
14	TM v.3.0	MPR 20	Check that power supply voltage corresponds to converted value.

Debug Station

- TOOLS USED IN TI LAB ENVIRONMENT TO FASTEN TEST & CALIBRATION
- REAL TIME PA RAMP ADJUSTMENT
- AUTOMATIC COMPUTED VALUES STORED IN Flash File System
- COMPLIANT WITH TI TEST & CALIBRATION SPECIFICATION





Thank you

Q & A