

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

Technical Description: T610 Radio on the Tranceiver Board

Contents:

1	GENERAL.....	2
1.1	CROSS REFERENCES	2
1.1.1	Names.....	2
1.1.2	Abbreviations.....	3
2	OVERVIEW	4
2.1	THE TX PATH	4
2.2	THE RX PATH	5
3	FREQUENCY PLAN	6
4	THE RADIO BLOCKS	7
4.1	THE ANTENNA SWITCH.....	7
4.2	THE RECEIVER.....	8
4.2.1	RF filter and balun.....	8
4.2.2	Receiver front-end.....	8
4.2.3	VCO.....	9
4.2.4	Sigma delta A/D Converter	10
4.2.5	Digital filter.....	10
4.3	THE TRANSMITTER.....	11
4.3.1	Frequency synthesis and modulation.....	11
4.3.2	Direct modulation and frequency synthesis.....	12
4.3.3	Phase detector	12
4.3.4	Prescaler.....	12
4.3.5	Charge pump and pulse skip detector.....	13
4.3.6	Loop filter	13
4.4	POWER AMPLIFIER & POWER CONTROL BLOCK:.....	14
4.5	THE VOLTAGE CONTROLLED X-TAL OSCILLATOR (VCXO):	15
4.6	POWER MANAGEMENT	15
4.7	BLUETOOTH.....	15
5	PRINTED CIRCUIT BOARD	16

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

1 GENERAL

This document describes radio solution, which is part of the transceiver board mounted in the GSM pocket phones.

The other part of the transceiver board that carries the base band part is described in the corresponding document 2/1551-ROA 128 0351/2.

The primary purpose of the radio part is to transfer the information to and from the base stations without distortion, and to handle the large dynamic range of the signals that occur during normal use.

- Section 2 is the data flow through the phone described in both TX and RX direction.
- In section 4, several of the electrical functions and circuits are described in more detail.
- In section 5 the layer structure of the PCB is briefly described.

1.1 CROSS REFERENCES

1.1.1 Names

In most cases the different components in the phone are given names which are used during the development phase. These names are also used in this description.

The following list shows the used component names and the corresponding position numbers used in the schematics.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

Ingela	N201
Victoria 2+	N800
Power amplifier	N340
13MHz xtal	B201
Antenna switch	N100
GSM SAW filter	Z103
DCS SAW filter	Z101
PCS SAW filter	Z102
Voltage regulator	N250
Martha	D600
Herta	N660
Ran – Bluetooth RF Module	N900

1.1.2

Abbreviations

Some common abbreviations are used in the text. These are explained below.

A/D	Analogue/Digital
HW	Hardware
MS	Mobile Station
PCB	Printed Circuit Board
RF	Radio Frequency
RSSI	Received Signal Strength Indicator
RX	Receive
TAE	Terminal Adapter Equipment
TX	Transmit

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

2 OVERVIEW

A general block diagram that describes the GSM phone is shown in the figure below. It shows the signal flow through the phone, and indicates the different hardware parts involved in the transmission and reception.

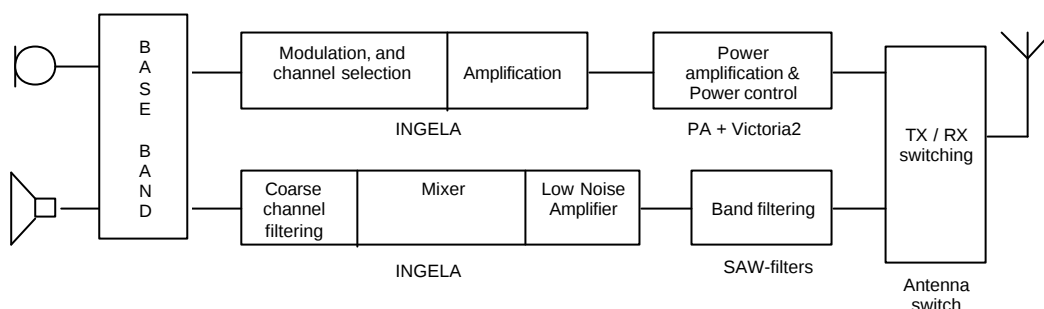


Figure 2.1 Block diagram for GSM phone.

All names below the boxes in figure correspond to the project names of the component that performs the indicated operation.

The component that controls the data flow has the project name MARTHA and is located in the baseband block. It acts as the Central Processing Unit containing an AVR microprocessor, DSP, internal RAM and the interfaces to external components and units as the external memories and the radio. It also performs the signal processing not done in the other parts.

2.1 THE TX PATH

The speech signal from the microphone is amplified and digitized to a 16 bit-PCM signal in HERTA. It is then sliced into 20 ms pieces and thereafter speech coded in DSP to reduce the bit rate. Further data processing is carried out in MARTHA that includes channel coding, interleaving, ciphering and burst formatting. The data is then put through a wave form generator (IQ signal) before it is fed to the radio.

The RF-ASIC INGELA is the heart of the radio. It has an integrated direct modulation transmitter where the channel selection and modulation is applied in one stage via a fractional-N type of synthesizer. The information is added via the divider ratio of the synthesizer. INGELA also amplifies the signal and buffers it before it is sent to the power amplifier. The buffer amplifier can be turn on & off, and it is used to secure pre burs output power. The power amplifier and VICTORIA 2+ are connected in a control loop that makes the power ramping, and controls the output power.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

2.2 THE RX PATH

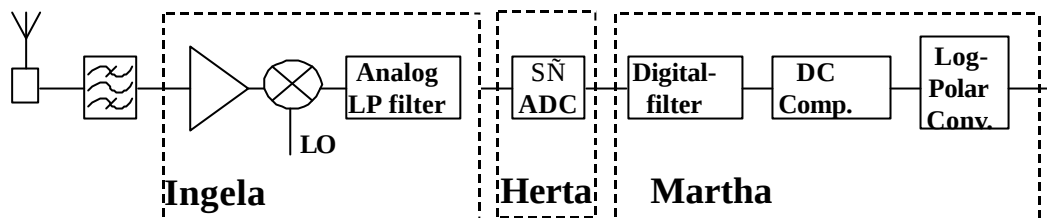


Figure 2.2: Receiver block diagram.

The signal received by the antenna is fed through a band pass filter and directly into Ingela. The RX part in Ingela contains a direct conversion receiver and the RF signal is mixed down to base band in one step. Except for the RF filter, all filtering except for the anti-aliasing filtering is done in baseband domain. The main part of channel filtering is in other words done in the digital domain.

The signals IRA, IRB, QRA and QRB from the radio are hard limited phase modulated and differential signals that contain all the data received. A fast phase digitizer in HERTA, demodulates these signals and the phase information is then fed to MARTHA.

The handling of the DC-level is a big difference compared to the super heterodyne receiver. (The received signal is mixed with the same frequency that will give a DC-signal and the signal information) The DC component has to be removed before detection otherwise the ADC could be saturated, which would completely destroy the information.

The first step in MARTHA is an equalizer that uses a Viterbi algorithm to create a model of the channel. Then the received bursts are further processed to decipher the information. After the de-interleaved (collection and reassembling all eight "half bursts" into a 456 bit message), the sequence is decoded to detect and correct errors during the transmission. The decoder uses soft information (probability that a bit is true) from the equalizer to improve error correction.

Finally the bit stream is speech decoded in the DSP and then transformed back into analogue speech in HERTA.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

3 Frequency plan

The PLL in INGELA will be used for both RX and TX operation. Direct conversion will be used for RX and TX. In TX mode, the PLL will work directly on the transmitted frequency, whereas the RX VCOs will operate at the double received frequency. The LO will then be divided by two just before entering the mixer.

	TX-band	RX-band
EGSM	880.2-914.8 MHz	925.2-959.8 MHz
DCS	1710.2-1784.8 MHz	1805.2-1879.8 MHz
PCS	1850.2-1909.8 MHz	1930.2-1989.8 MHz

The frequencies that correspond to the channel numbers (ARFCN) for the different bands are

	TX-band (MHz)	Channel numbers	RX-band (MHz)
EGSM	$890 + 0.2 \cdot n$ $890 + 0.2 \cdot (n-1024)$	$0 \leq n \leq 124$ $975 \leq n \leq 1023$	TX-band(n) + 45
DCS	$1710.2 + 0.2 \cdot (n-512)$	$512 \leq n \leq 885$	TX-band(n) + 95
PCS	$1850.2 + 0.2 \cdot (n-512)$	$512 \leq n \leq 810$	TX-band(n) + 80

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

4 The radio blocks

4.1 The antenna switch

The antenna switch is the block that combines the signals from the power amplifier (one for EGSM and one for DCS & PCS) going towards the antenna, with the three signal paths leading towards the RF ASIC INGELA. It is solved with a PIN diode switch solution in a multilayer module.

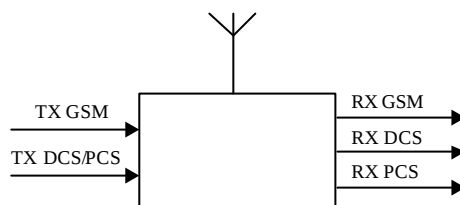


Figure 4.1: Antenna switch PIN diode module.

In transmit mode the main function is to lead the signals from the PA module to the antenna with as small insertion loss as possible, and in the same time attenuate power trying to leak between the TX paths and the RX paths.

In receive mode the main function is to lead the small signal picked up by the antenna with as small insertion loss as possible to the RF filters and then further towards the low noise amplifiers in INGELA.

The antenna switch module is also contributing to the suppression of harmonics generated in the PA module, and slightly helping in the attenuation of high out of band blocking interfering signals that might be picked up by the antenna since the bandwidth is naturally not infinite.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

4.2 The Receiver

4.2.1 RF filter and balun

An unwanted out-of-band signal might limit the front-end thereby making it impossible to detect the wanted signal. Possible out of band interfering signals must therefore be attenuated to the same levels as the in band blocking requirements for which the front-end circuitry is designed.

Simplified calculations show the maximum allowable attenuation (including losses in the PCB, mismatch etc) from antenna to LNA input to achieve a nominal sensitivity of -105 dBm (which is stated in the generic design specification, the GSM specification states -102dBm):

- E-GSM: 6.4 dB DCS: 6.4 dB PCS: 6.4dB

We have chosen the following specification for balanced SAW filters.

- Insertion loss (dB): Typ: 3.0 Max: 4.0
- Ripple (dB): Typ: 0.5 Max: 1.0

For the antenna switch we have chosen to specify:

- Insertion loss EGSM (dB): Max: 1.2
- Insertion loss DCS (dB): Max: 1.5
- Insertion loss PCS (dB): Max: 1.5

4.2.2 Receiver front-end

The RF signal is amplified and then directly converted to a base band signal. The conversion is done by dividing the signal into I and Q base band signals, $f_{LO} = f_{RF}$ and the LO signal is 0° in phase at the I channel and in +90° with the Q channel. The down converted spectrum will be folded around DC. The base band signals are amplified to a level that is suitable for the ADC.

The primary task of the base band filtering in Ingela is to prevent aliasing in the ADC. The sample frequency of the $\Sigma\Delta$ A/D converter is 13 MHz. Interfering signals and noise with frequencies close to 13 MHz offset (and multiples of f_s) will be folded around $f_{s/2}$ into the base band. This base band filter will also reduce the power from adjacent and *blocking* signals. Limitation of the noise bandwidth and adjacent channel power is mostly done in the digital filter chain in Martha.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

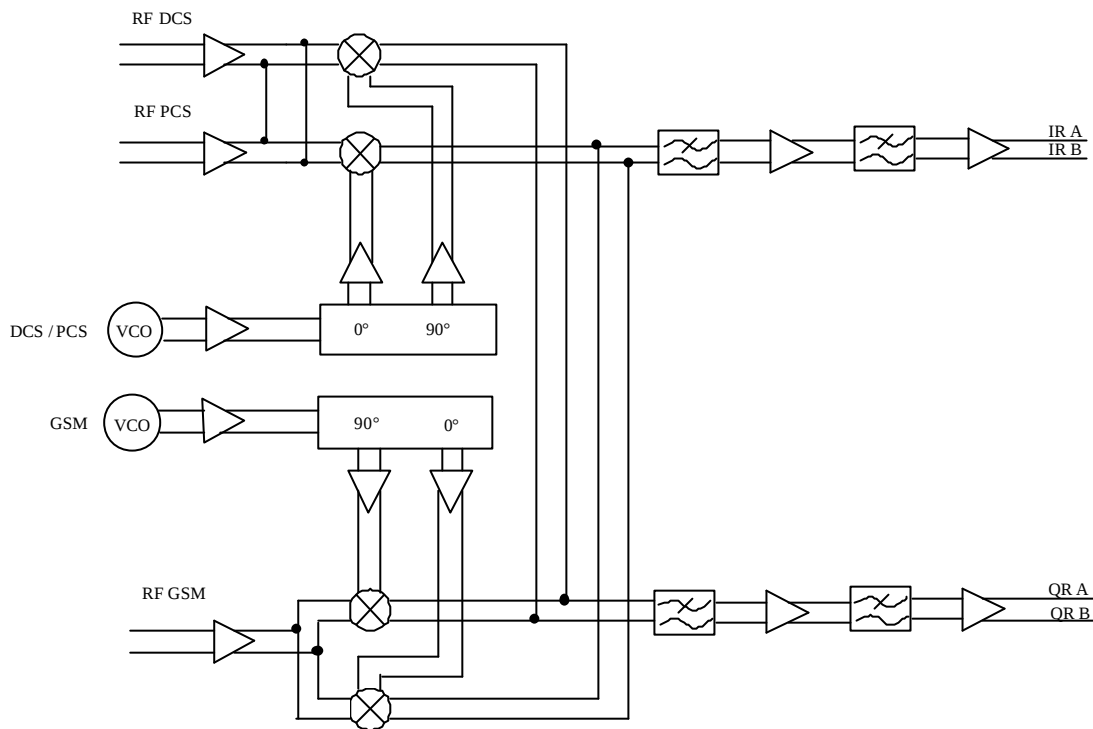


Figure 4.2: Receiver front-end.

4.2.3

VCO

The VCOs are on chip. To meet the demands on LO phase noise we need a high Q-value in the resonator circuit.

High Q coil resonators make it possible to fulfill the requirement on phase noise, -140 dBc/Hz at 3 MHz offset from the carrier, and at the same time achieve as large tuning range as possible.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

4.2.4 Sigma delta A/D Converter

The base band signals are digitized with a dual $\Sigma\Delta$ A/D converter. Each output is a 13 MHz bit stream. The conversion generates high frequency quantization noise that must be attenuated in the digital filter.

MCLK input level:	> 0.4 Vpp, and < 1.2 Vpp.
Dynamic range:	70 dB (20*log(1.54/0.487E-3)).
Min SNR:	12 dB
Input level range:	487 μ Vpp-1.54 Vpp (differential)

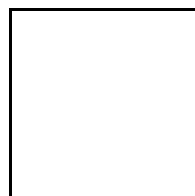


Figure 4.3: Sigma delta A/D converter in Herta.

4.2.5 Digital filter

Almost all of the channel- and adjacent channel filtering is done in digital filters.

I and Q data are serially sent from the ADC. The first filter has to reduce the noise from the $\Sigma\Delta$ to avoid noise being folded down to base band.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

4.3 The transmitter

4.3.1 Frequency synthesis and modulation

The “frequency synthesis and modulation” block is almost completely integrated in the RF ASIC Ingela. The loop filter is external and the modulation parts are integrated in the base band ASIC Martha.

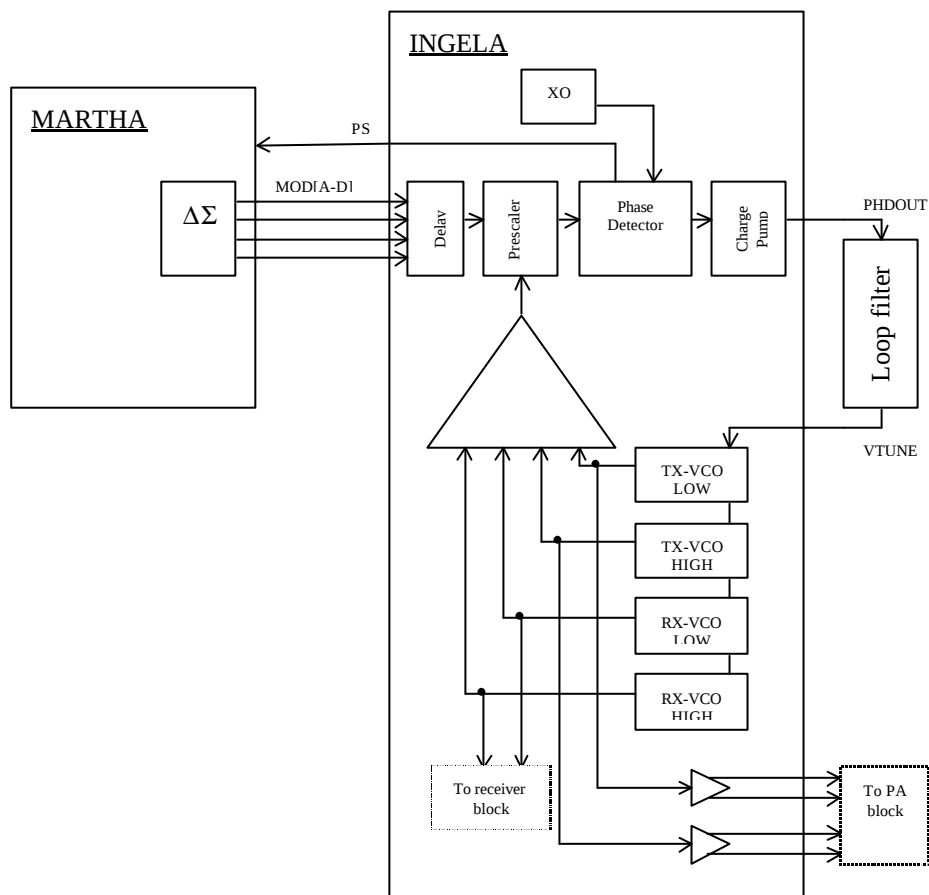


Figure 4.4: Block schematic of the frequency synthesis and modulation.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

4.3.2 Direct modulation and frequency synthesis

The main component for the frequency synthesis and up-conversion is Ingela. The direct modulation concept will be used and the base-band chip Martha has, together with Ingela, all the required functions for direct modulation. The use of direct modulation means that we will not have any intermediate frequency (IF) in the transmitter chain.

To be able to keep the VCO gain at a reasonable level, four different VCOs are implemented: High band/RX, High band/TX, Low band/RX and Low band/TX. These VCOs are totally integrated in Ingela. The logic signals RXON, TXON and BSEL are used to determine which VCO should be used.

The modulation and (partly) the channel selection is performed in a $\Sigma\Delta$ modulator in Martha, which controls the divide ratio in a fractional-N PLL in Ingela via four parallel 26 MHz leads.

Other information that needs to be sent to Ingela, such as charge pump current setting and divide ratio offset, is transferred via the serial bus, SYNCLK, SYNDAT, SYNSTR.

Figure 4.4 shows a block schematic for the frequency and modulation block.

4.3.3 Phase detector

The reference frequency from the crystal oscillator (XO) is 13MHz and is not divided down before entering the phase detector. The phase detector is implemented to be able to trig on both up going and down going flanks, so the comparison frequency is twice the reference frequency, i.e. 26MHz.

4.3.4 Prescaler

The prescaler divides the VCO signal down to 26MHz, which is the comparison frequency in the phase detector. An offset value, N_0 , is sent to the prescaler via the Ingela F-word on the serial bus. N_0 is programmable in integers between 16 and 95, which means the frequency can be chosen in steps of 26MHz by only using N_0 . To be able to select channels with 200kHz spacing, the prescaler divide ratio, N , can be varied by MOD[A-D] from the output of the $\Sigma\Delta$ in Martha. MOD[A-D] are parallel logic signals that can change state at the rate of 26MHz. If we call the contribution from MOD[A-D] N_{mod} , the actual instant divide ratio, N , is given by

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

$$N = N_0 + N_{\text{mod}}, \quad N_0 \in [16, \dots, 95], \quad N_{\text{mod}} \in [0, \dots, 15]$$

Since the loop will be chosen to be much slower than the frequency of changing N , the effect will be that a stable carrier is generated at a frequency that corresponds to the average value of N . In our implementation, N_{mod} is limited to the range $[0, \dots, 12]$.

The channel selection is performed by first choosing an appropriate value of N_0 and then controlling C , the input value to the $\Sigma\Delta$ modulator. The generated (un-modulated) carrier is described by the equation

$$f_0 = (N_0 + 6) \cdot 26 \cdot 10^6 + C \cdot 5 \cdot 10^3 \text{ Hz}$$

where C is an integer in the range $[-8840, \dots, 8840]$.

The modulation is up-sampled several times and filtered in the waveform generator (WFG) before coming in to the $\Sigma\Delta$ modulator. Thus, the output from the $\Sigma\Delta$, N_{mod} , consists of information from both channel selection and modulation. The loop bandwidth has to be chosen so wide ($\approx 200\text{kHz}$) that the modulation information passes through.

4.3.5 Charge pump and pulse skip detector

The charge pump current is programmable with I_{phd} in the Ingela F-word. This makes it possible to tune the loop bandwidth, which is desirable especially due to the matching that needs to be made between the pre filtering of the information, that is performed in the waveform generator (WFG), and the loop. Since the VCO gain will vary over the frequency band, with different units and over temperature, this matching has to be made by calibration in production and a temperature compensation table.

4.3.6 Loop filter

The loop filter is the only thing in the PLL that is implemented with discrete components. Since the $\Sigma\Delta$ modulator is of the order three, we need a fourth order loop filter to get a frequency roll off that is good enough.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

4.4 Power amplifier & Power control block:

The block consists of the power control and power management ASIC Victoria 2+ and one power amplifier from Skyworks which include an amplifier for the GSM band and one for the combined DCS/PCS band. The output power is controlled by adjusting the power amplifier current, which is measured via a $0.051\ \Omega$ resistor. The RF output power from Ingela consists of two balanced signals, TXOLA and TXOLB TXOH for GSM and TXOHA and TXOHB for DCS/PCS. These balanced signals are converted to single ended signals in two baluns and fed to two PI-network attenuators before they are fed to the power amplifiers.

To change band, two twin transistor switches are used to switch the Vapc signal to either the GSM or DCS/PCS PA. As control signal for these transistors, BSEL0 is used.

For maximum freedom an additional low pass filter is inserted between Victoria2 and the power amplifiers in the PAREG node.

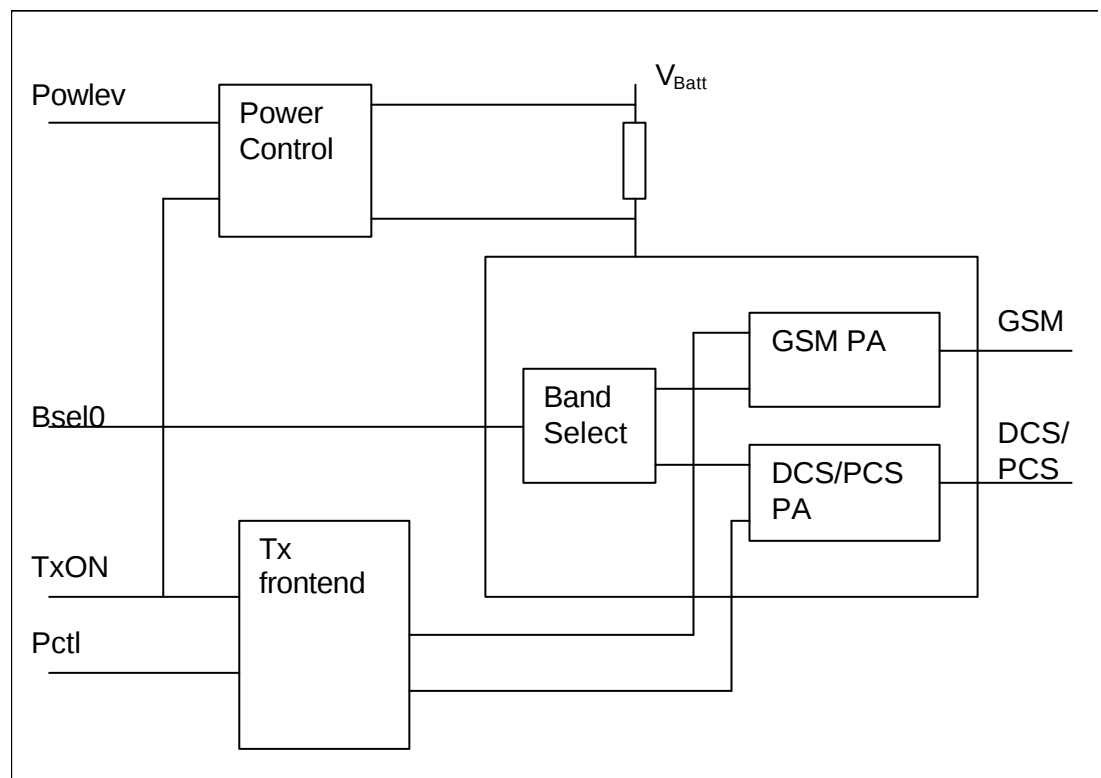


Figure 4.5. Overview of the PA and PA-control block.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

4.5 The Voltage Controlled X-tal Oscillator (VCXO):

The voltage controlled crystal (xtal) oscillator (VCXO) is an oscillator consists of two main components: an active device that acts as an amplifier and a feedback network to provide positive feedback in the system. The feedback network is frequency sensitive and includes some types of resonators to set the operating frequency. In addition some type of variable reactance element must be present for control the frequency. Normally the variable reactance is controlled by a dc voltage, hence the term voltage – controlled oscillator .The typical design emphasis is on low noise stability bandwidth, linear and wideband tunability, reliability and low cost.

The solution is an internal Pierce oscillator in Ingela using an external crystal. The 13 MHz signal is the reference for the different frequency generator in the radio and also the clock signal for the logic circuits. This requires a very frequency stable 13 MHz generator. That is the reason for using crystal oscillator.

4.6 Power Management

The radio is supplied using an external low-noise voltage regulator in order to have a very clean voltage supply that is necessary to avoid noise or interference especially for the VCOs integrated in Ingela.

4.7 Bluetooth

The Bluetooth function of the phone is implemented in the baseband ASIC Irma B and the RF Bluetooth module Ran. All of the Bluetooth radio is inside the module except for a filter that is placed between the module and the antenna. The reason to include this filter is to improve the isolation between the GSM bands and the Bluetooth band to not have degraded sensitivity in Bluetooth while transmitting in the other bands.

Prepared (also subject responsible if other)

SEM/GUR/BRR Pontus Nelderup

Approved

SEM/GUR/BRR Mikael Nilsson

Checked

DESCRIPTION

No.

1/1551 - ROA 128 0351/2

Date

2003-02-28

Rev

B

Reference

5 PRINTED CIRCUIT BOARD

The printed circuit board is an 8-layer board. Five layers (layer 1, 2, 3, 7 & 8) carry all the connections between component terminals. Two layers (layer 4 & 6) are used as ground planes, and both these planes cover the whole board. The layer between the ground planes (layer 5) is made to carry sensitive signals and strip lines.

The layer structure is listed below:

Layer 1	Components, radio signals (Primary side)
Layer 2	Radio and base band signals
Layer 3	Radio and base band signals
Layer 4	Ground plane
Layer 5	Radio strip line layer
Layer 6	Ground plane
Layer 7	Base band and Bluetooth signals
Layer 8	Components, base band and Bluetooth signals (Secondary side)