Information on TEA5991 stereo FM radio with enhanced RDS

AN3003

Application Notes

Abstract

This document provides information on the TEA5991 stereo FM-radio with enhanced RDS.

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1 About this document

1.1 Purpose

This document provides information on TEA5991 stereo FM radio.

1.2 Scope

This document provides a detailed description of the features and usage of the TEA5991 FM stereo and RDS radio in mobile applications.

1.3 Revision information

Table 1 Revision history

Date	**Rev.**	**Comments**
2009-07-07	1	Initial release.

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2 Introduction

2.1 TEA5991 block diagram

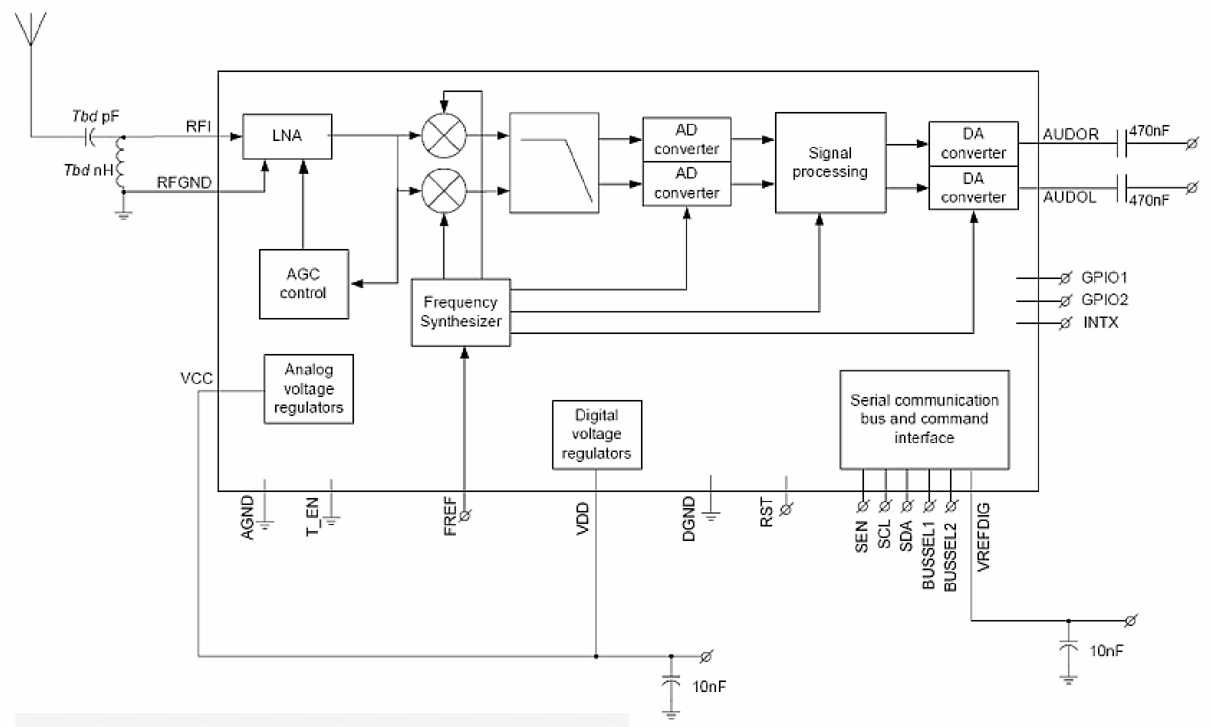

Figure 1 A typical application diagram

2.2 Functional description

The TEA5991 is part of a new generation FM-radio ICs, with a flexible concept.

The TEA5991 is a stereo FM-radio plus RDS. It features internal voltage regulators for both analog and digital circuits.

The TEA5991 is a small, low-cost IC with a low power consumption which includes no external component except for the supply decoupling capacitors. This all makes it very suitable for the mobile phone market.

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3 Functions and features

3.1 RF

3.1.1 Antenna input, matching and sensitivity

The TEA5991's single ended RF-input has an input impedance of 200 ohm with 2pF parallel typical. This input has been designed to work directly with an earphone-wire as FM antenna without any external components. This gives the simplest and cheapest configuration with a good performance and can be found on the demo boards.

Besides this direct connection, the TEA5991 can be connected in three other ways:

- Matching to 50 ohm with resistive network. This configuration can be used in a measurement set-up to match the TEA5991 input to the 50 ohm source impedance of the measurement equipment (losses should be taken in account).
- Matching to 50 ohm by means of a 1:4 impedance transformer. This gives the best performance with regard to sensitivity.
- Matching to 50 ohm and offering pre-selection with L-C networks. These configurations can be used to improve the performance with a wire antenna.

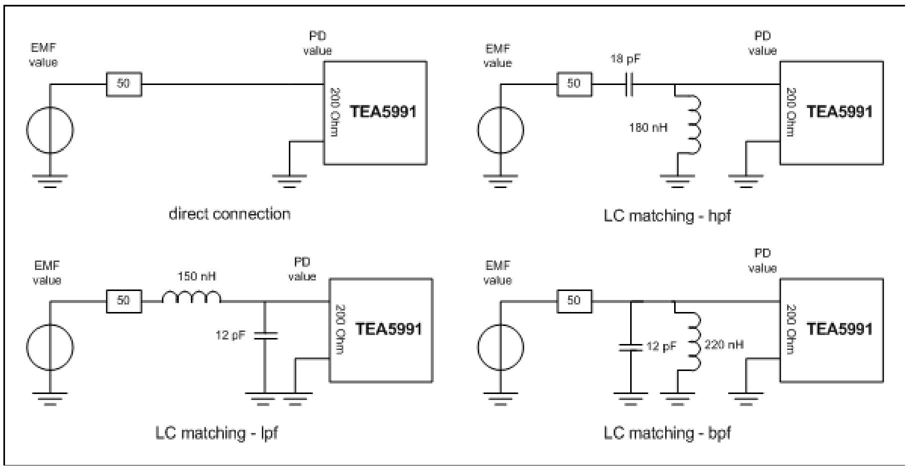

Figure 2 Examples of connections and matching for the Eu/US FM-band

The way the TEA5991 is connected has influence on the measured sensitivity performance expressed in EMF voltage. The EMF voltage is voltage read-out from the measurement equipment which is assumed to have a 50 ohm source impedance.

In the datasheet the sensitivity is expressed in PD voltage, which is the voltage across the input pin of the TEA5991. This is the real performance of the device not influenced by matching. However this voltage is usually not measured.

Table 1 shows the measured performance of the TEA5991 with various matching networks and the corresponding PD voltages. The measured performance is typical for these given matching networks.

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Table 1 Measured sensitivity performance with various matching networks

	PD voltage (µV)	**EMF voltage (µV)**			
		Direct connection	**Resistive matching**	**L-C lpf / hpf**	**L-C bpf**
Typ. FM sensitivity(@ 26 dB SNR)	1.0	1.25	2.0	1.1	1.25
Typ. RDS sensitivity (@ 95% BQR)	10	12.5	20.0	11.0	12.5

The given L-C matching filters have been designed for the European/US FM-band (87.5 – 108 MHz). The response of the LPF L-C matching filter is indicated in Figure 3: at the European-band edges the loss is approximately 0.2dB with regard to the centre frequency (~96 MHz) response.

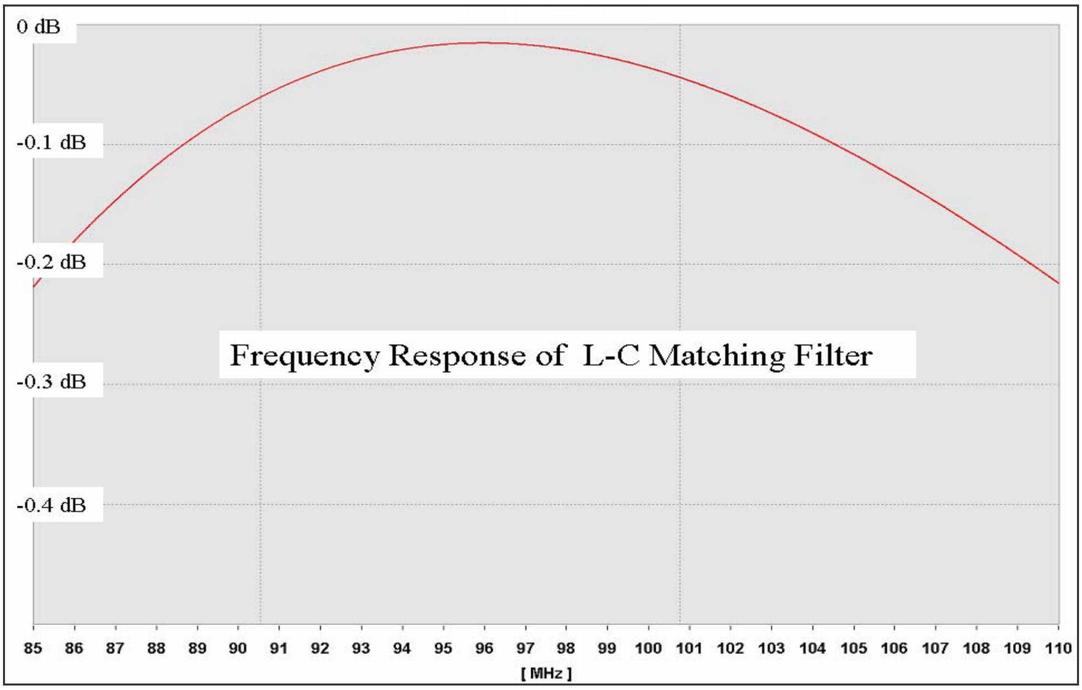

Figure 3 L-C lpf matching circuit connected to RF-input frequency response

3.1.2 LNA, RF AGC and RSSI

As mentioned before, the LNA has an input impedance of 200 ohm // 2pF.

The LNA's gain is set to +20dB. Its RF-AGC has a total control range of typically more than 50 dB, to guarantee that the LNA and the mixer are always in their linear operating range for the specified RF-input level range.

The third order input intermodulation figure (IP3i) is 98dBµVemf typical.

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The RSSI indication reads a hexadecimal value for the received signal strength in the range from 0x000 to 0x7FFF, converted to decimal this is 0 to 32768. Full scale is reached at a typical FM-signal level of 1400µVrms at the TEA5991's FM-input.

This means that every RSSI step corresponds to 43nV at the TEA5991's input. See Figure 4.

The read RSSI value is a hexadecimal value, but can easily be transformed to µV or dBµV by following equations:

RF-input level [µV] = RSSI-value (decimal) * 0.043µV.
RF-input level [dBµV] = 20 * Log (RF-level [µV]).

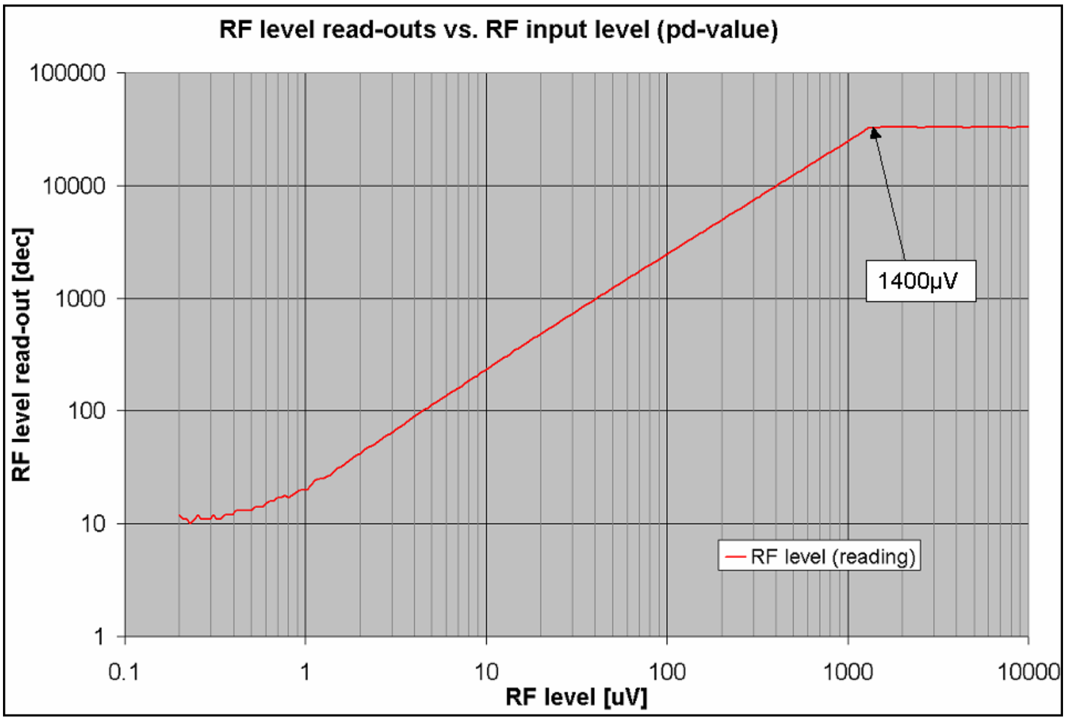

Figure 4 RSSI curve: FS at ~1400µVpd, each RSSI step corresponds to 43nV

3.1.3 RF mixer

The RF-mixer is a quadrature I/Q mixer, which converts the wanted FM-frequency to an intermediate frequency (IF) of approximately 200 kHz by mixing it with the local oscillator (LO) signal. The actual IF-frequency depends on the RF-frequency. The complex I/Q mixer provides at least 40 dB image rejection.

The mixer is followed by a simple low-pass filter, only passing the wanted IF-frequency. Necessary channel filtering, i.e. selectivity and adjacent channel rejection, is realized in the DSP implemented IF-filter.

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3.2 IF

3.2.1 IF filter

For anti-aliasing reasons a 1st order 1 MHz LPF filter is placed just in front of the ADC. The TEA5991's channel filter is implemented in the DSP, its center frequency varies between 160 kHz and 240 kHz, depending on the actual oscillator frequency and injection side. The IF-filter center frequency is adjusted accordingly (all clocks are coupled to the DCO frequency). Selectivity of this filter is typically 60 dB at 200 kHz distance. Its bandwidth varies dynamically, depending on signal strength and presence of adjacent channels. The maximum IF-bandwidth is approx. 225 kHz (-3dB).

3.2.2 Demodulator

The FM-demodulator function is realized in the DSP, its demodulation characteristic is based on the quadrature demodulator.

3.3 Reference clock

3.3.1 External reference clock input

A 32.768 kHz clock signal must be connected to pin Fref of the TEA5991 in order to let the FM-radio work.

This clock signal should have the amplitude of 1.80 V peak-to-peaks, the duty-cycle is not critical. Further clock requirements are described in the TEA5991 datasheet.

In case the TEA5991 is used in a system that cannot deliver the exact 32.768 kHz reference clock (e.g. a micro-controller), but instead e.g. a 32.623 kHz clock is available, the TEA5991 can be given a frequency offset with values between –1024 Hz and +1024 Hz (-32.768 ppm to +32.767 ppm), or 215 ÷ 210 = 25 equals 32 ppm/Hz offset. In above-mentioned example the offset given to the TEA5991 would be –4640 ppm or 0xEDE0. The value is negative because the reference clock is too slow. During standby, this setting is memorized and restored when powered up. After power down, this reference frequency offset must be set again.

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3.3.2 Software

The command for the reference frequency offset is as follows:

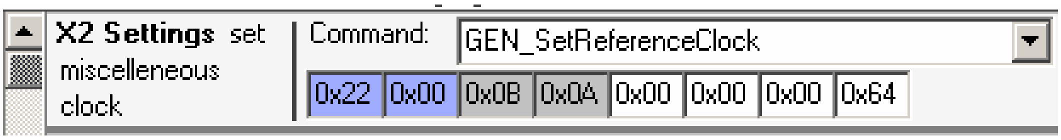

Figure 5 Command for reference frequency offset

The corresponding GUI input (Other / Generic window): example for +3.1 Hz offset.

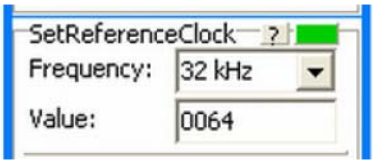

Figure 6 Corresponding GUI input

3.3.3 Tips and tricks

In most cases the 32.768 kHz reference clock can be taken from the host or PMU, but be sure it is jitter-free and has 1.8 Vpp amplitude.

3.4 Audio DAC and audio outputs

3.4.1 Left / right audio out

The audio outputs give 80mVrms typical for FM-signals with 22.5 kHz deviation at maximum volume setting. Volume can be controlled, independently for Left- and Right-channel, from maximum (0x7FFF) to zero (0x0000). The typical volume control range is over 60 dB. The audio outputs are DC biased, and hence audio coupling capacitors are required. A value of 470 nF is adequate.

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3.4.2 Software

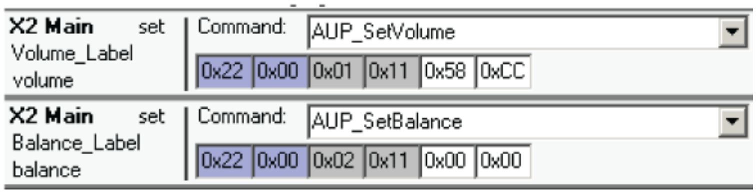

Figure 7 Command for volume and balance control

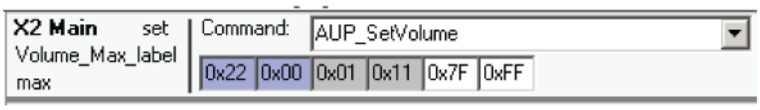

Figure 8 Maximum volume setting (0x7FFF)

Figure 9 GUI control (Main window):

3.5 Tuning system

3.5.1 FLL synthesizer

In contrast to the TEA576x FM-radio family having a PLL controlled local oscillator at approximately 200 MHz, the TEA599x's DCO, running at approximately 3GHz, is controlled by a Frequency Locked Loop (FLL). A FLL synthesized oscillator is essentially a free running oscillator, which is adjusted in steps (DCO) when its frequency starts to run outside a certain window. The oscillator's frequency is actually counted, and on regular time intervals compared to the reference frequency. Is the oscillator frequency count too low, or too high, it will be corrected in steps until the error falls in the pre-defined window.

Thanks to this FLL, the oscillator is less sensitive to jitter or noise on the reference clock with respect to a PLL controlled oscillator.

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3.5.2 DCO

The digital controlled oscillator (DCO) frequency is divided into lower frequencies for e.g. the DSP, the ADCs, the DACs and the RF-mixer. Hence all clocks are coupled to the DCO, and vary in case the DCO is changed. As said, the DCO frequency lies around 3 GHz, and for example for the RF-mixer it is divided by 32 to have a local oscillator frequency around 100 MHz. See block diagram below (Figure 10).

The DCO frequency range has been chosen for co-existence with for example GSM, WiFi and Bluetooth in mind.

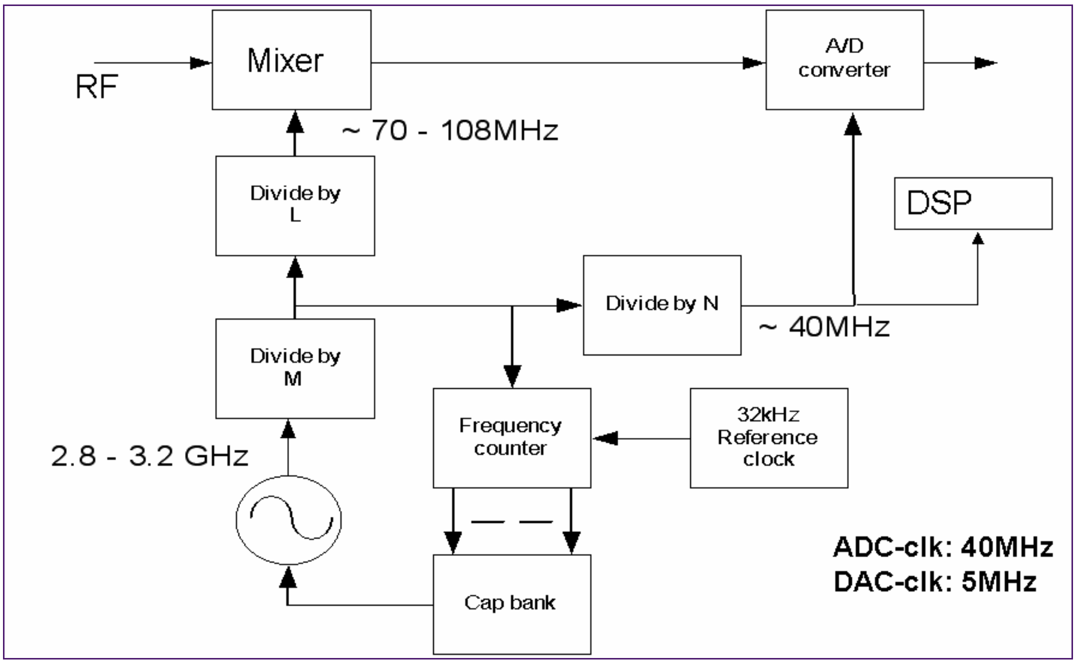

Figure 10 Frequency plan for TEA5991 DCO and clocks

3.5.3 Tuning algorithms

Preset tuning

Preset tuning is used to set the tuning frequency of the receiver to a certain channel number defined by the host. By default the radio is set to channel 0. The radio is muted during the tuning operation. The radio signals the host that tuning is finished by setting a flag and/or by generating an interrupt.

Search tuning

Search tuning is provided to automatically search for the next available valid channel in increasing (search up) or decreasing (search down) the frequency direction. A channel is valid when first the RSSI level exceeds a programmable threshold level and second when the measured noise (USN) level is below a programmed threshold.

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The search grid can be programmed at:

50 kHz
100 kHz (default)
200 kHz

The search operation starts at the currently tuned channel and searches in the desired direction by frequency steps defined by the programmed search grid. The search only examines channels that are on-grid. Channel 0 must be an on-grid channel.

The search algorithm automatically wraps around the selected band edges. In case the whole band is searched without finding a valid channel, the search stops at the start channel. The radio signals the host that tuning is finished by setting a flag and/or by generating an interrupt. The search operation can be stopped at any time by the host.

Stepped tuning

Stepped tuning is provided to easily step one channel in increasing (step-up) or decreasing (step-down) frequency direction. The function only steps to channels that are on grid.

Band-scan for auto store

This is used to scan the selected FM band for available radio channels. The radio determines the RSSI value of every on-grid channel within the selected band, where channel 0 must be an on-grid channel. The radio internally stores the strongest channels that are below a programmed noise (USN) threshold and above a programmable RSSI threshold level. The latter can be omitted by setting the RSSi threshold value very low, e.g. 0x0001. In this case all stations will be found, even very weak ones. The maximum number of channels to be stored is programmable between 1 and 32. The band-scan operation starts at the currently tuned channel. The radio signals to the host that the operation has finished by setting a flag and/or by generating an interrupt. Upon request by the host, the radio sends information about the stored channels to the host. The band-scan can be stopped any time by the host. In this case, the radio returns to the start channel and un-mutes if it was not explicitly muted by the host. The same holds in case the band-scan operation is stopped by a standby-powerup sequence.

See Figure 11.

Automatic HI-side / LOW-side injection switching

For image reception avoidance an auto hi/lo algorithm is implemented. This algorithm does not require any interaction from the host side. The algorithm is such that it verifies the image frequency interference level and selects between hi/lo mixing to obtain minimum interference. This is done for any tuning operation.

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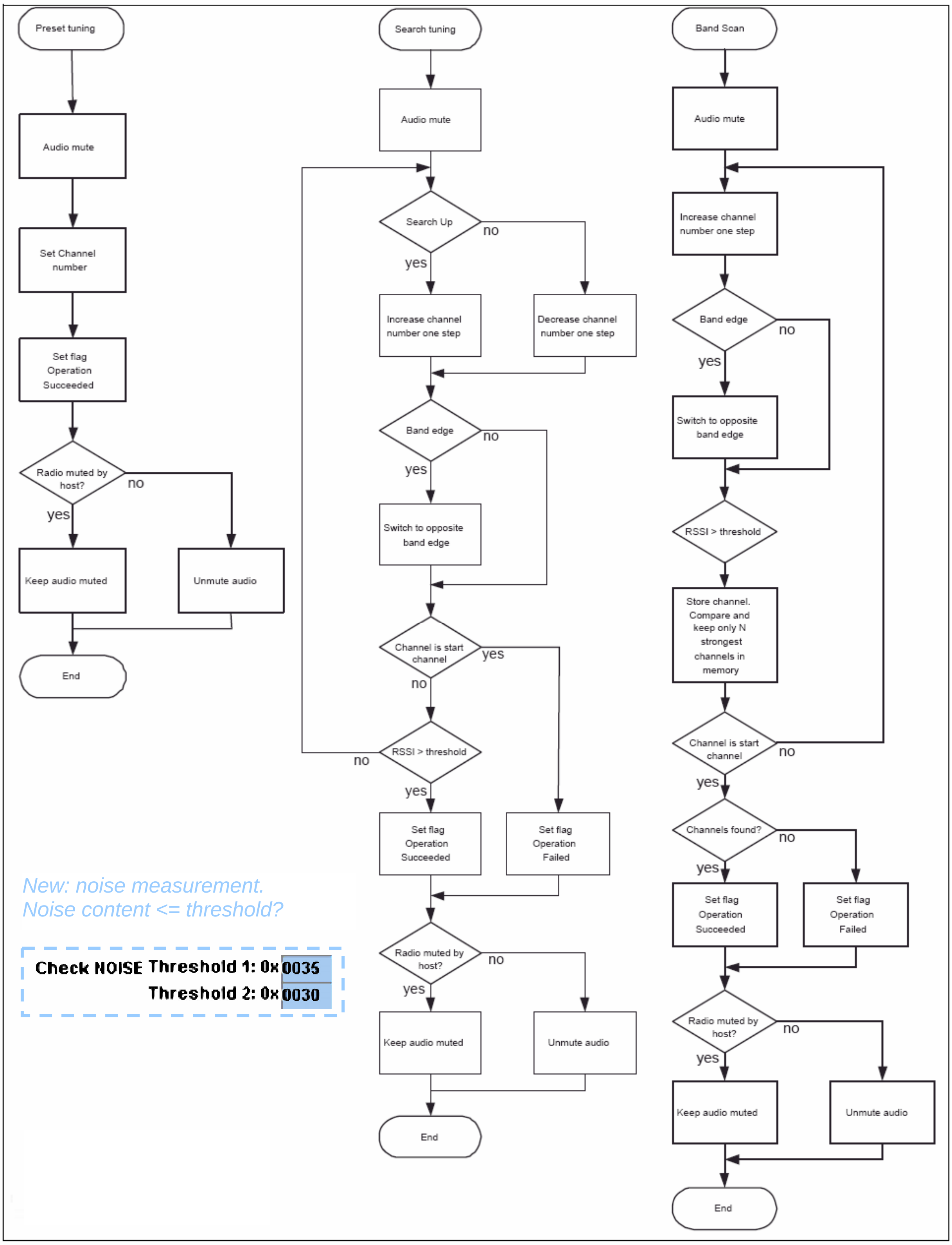

Figure 11 Tuning algorithms

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3.6 RDS

3.6.1 RDS / RBDS decoder

The RDS decoding is a DSP algorithm, and has two modes: Standard (0x01) and Enhanced (0x02). The latter has enhanced multi path performance and sensitivity.

3.6.2 Basic RDS data reading

The RDS data can be read in three different ways:

- reading after an Interrupt is given for (RDS) BufferFull (mask must be set)
- polling for flags, a flag is set for (RDS) BufferFull (mask must be set)
- reading on timer, e.g. every 1 second. The RDS Buffer is able to store 22 RDS groups, which corresponds to approximately 2 seconds.

See Figure 13 and Figure 15.

3.6.3 Software

Before RDS data can be read, the RDS demodulation must be activated and handling method must be set by pressing the Auto button: see Figure 12.

Figure 12 RDS auto activation (in GUI Main window)

RDS decoding will be enabled, and reading method will be set to “Interrupt polling”, but this can be changed to e.g. “Timer”.

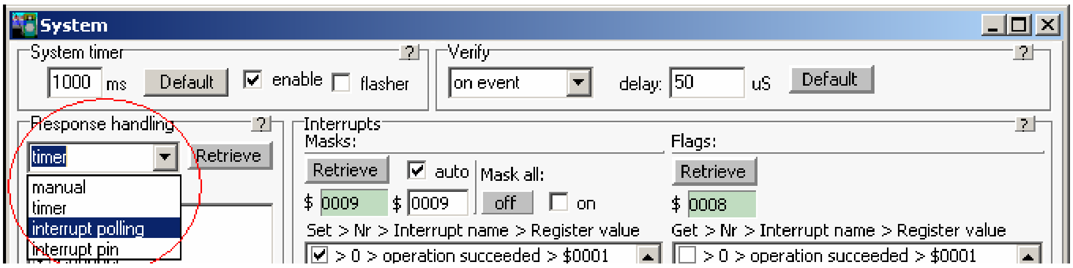

Figure 13 RDS handling (GUI System window)

Basic RDS quality parameters can be checked in the RDS-AF window: 2nd column. For more extensive RDS quality reading and more detailed RDS data info, the RDS monitor can be activated by pressing the RDS Monitor button (GUI Main window).

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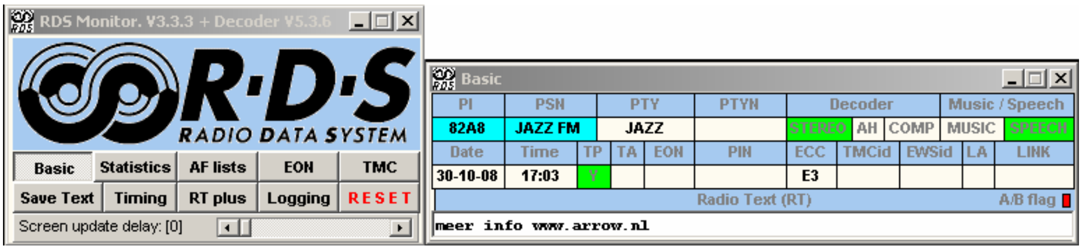

Figure 14 RDS monitor windows

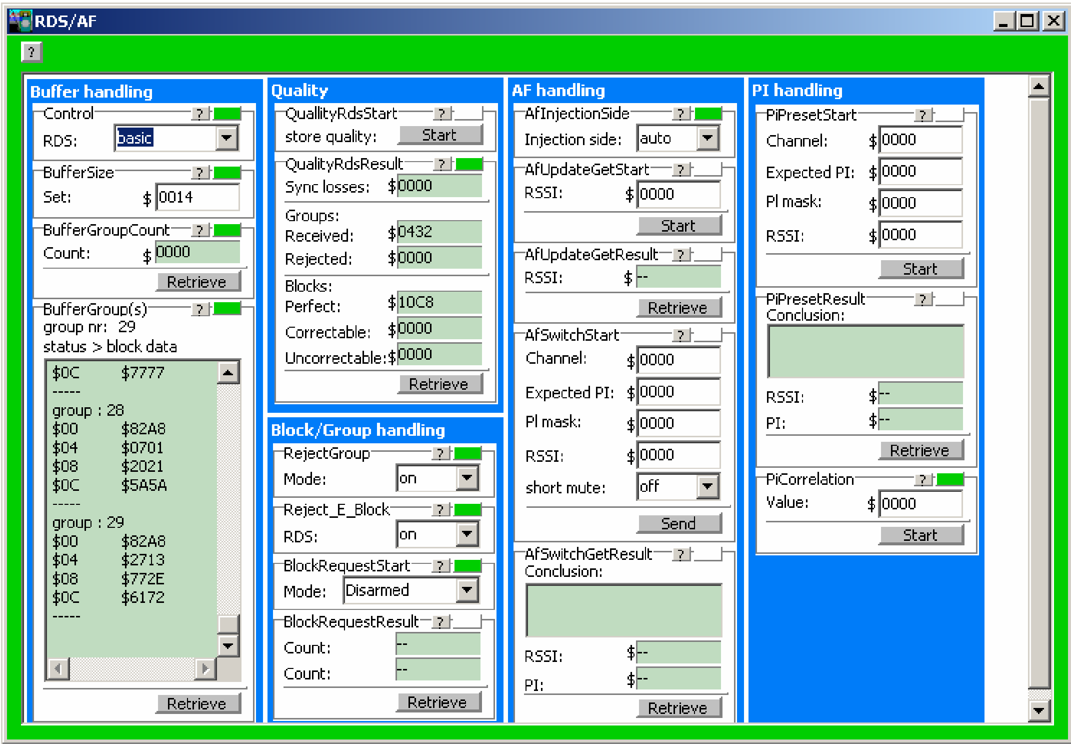

Figure 15 RDS-AF Window: Buffer handling, AF- and Pi-handling,

3.6.4 RDS algorithms

RSSI and RDS algorithms

In order to signal the host that the quality of the received channel decreases, a programmable RSSI threshold can be set. The threshold level is used to monitor the RSSI against, when the RSSI drops below the programmed threshold a flag is set and an interrupt is given. The host can use this information to support an RDS AF algorithm.

RDS preset tuning with PI-code

The host sends the preset channel number and the expected PI-code. The radio determines if the received PI-code matches with the host defined PI-code. The radio notifies the host that RDS synchronization is detected as well as whether PI-correlation is detected or not (see Figure 16).

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RDS E-block rejection

The RBDS standard has additional to the RDS standard an E-block type defined. E-blocks are used exclusively for a proprietary paging system (MMBS). When MMBS is set the RBDS decoder also passes all E-block information. By default the RBDS mode is off.

Inaudible AF check algorithm

The inaudible check algorithm provides the host with the option to verify the RSSI value of a single AF frequency. The alternative frequency channel number is programmable by the host. The radio tunes to the alternative channel and measures the RSSI level. The radio returns to the previously tuned channel and indicates to the host that the AF update has succeeded. The host can read the RSSI level of the alternative frequency. The audio signal is muted in such way that it is inaudible for the user.

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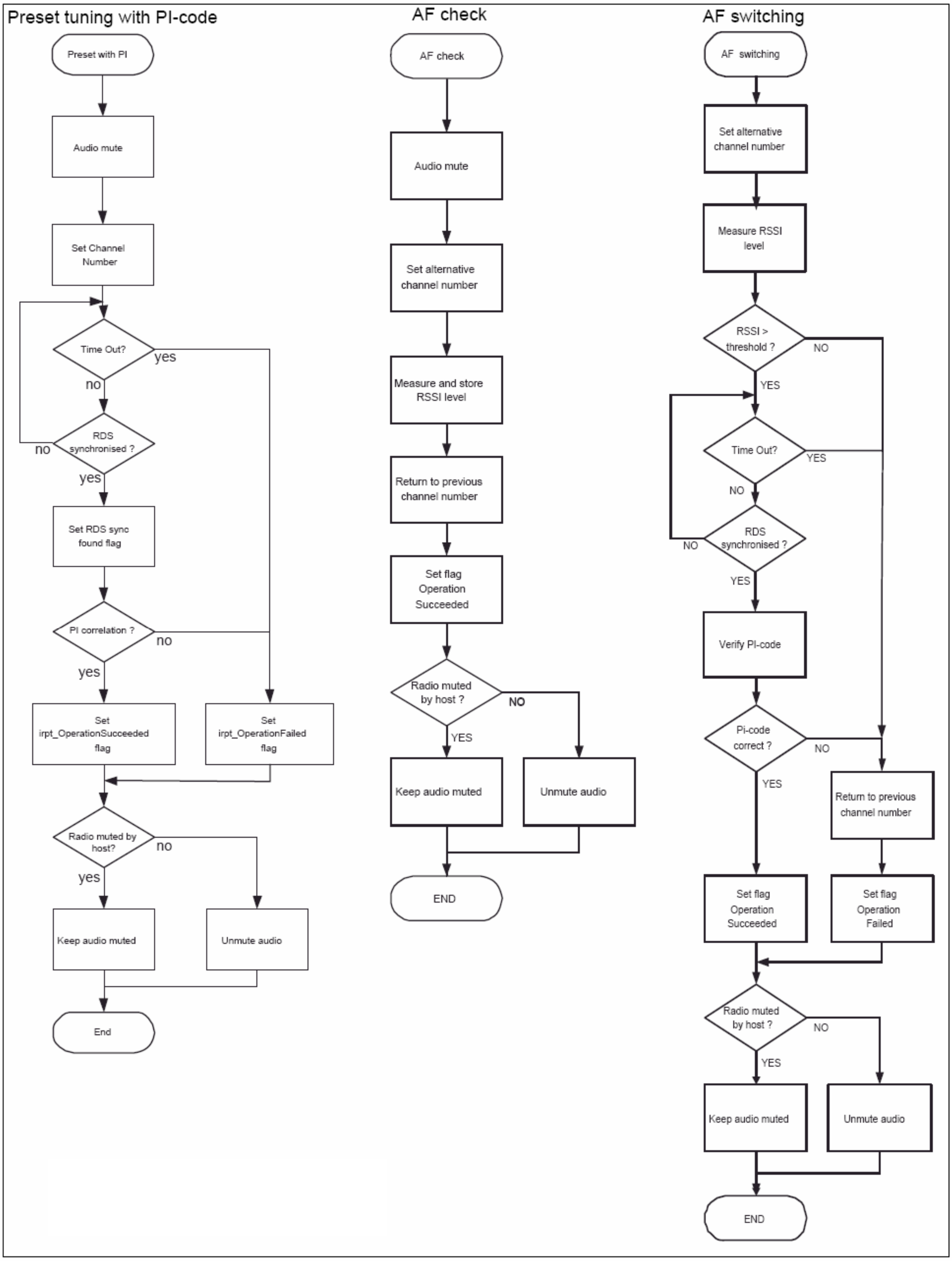

Figure 16 RDS algorithms

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3.7 Supply

3.7.1 Hardware

Thanks to the TEA5991 integrated voltage regulators the device power supply rejection ratio (PSRR) is very good, there is no additional power supply filtering required for the TEA5991 FM-radio chip.

Typical PSRR value is 60dB. So there is not a high requirement on power supply filtering. A decoupling capacitor with a value of 10nF for Vcc and Vdd combined, and 10nF for Vrefdig is sufficient. Also no additional resistors or beads are required.

See the demo board schematics for details (chapter 5).

3.7.2 Software

With the software PowerDown command, the TEA5991 radio can be set in a very low power state (OFF), there is no need to switch off the Vcc/Vdd/Vrefdig supply voltages.

The drawn current in this PowerDown OFF state is just several micro-amps.

However, the TEA5991 can be switched off completely by removing the Vrefdig supply voltage. For more info: TEA5991 datasheet, Ch.10. Operating modes.

3.7.3 Tips and tricks

For short term switching off the TEA5991 FM-radio (for example when receiving a phone call), the radio can be set in standby mode. The current is higher than when in power down mode, but the radio can be switched on again very quickly by a single PowerUp command; all settings a.o. the tuned station and ref-freq. offset are memorized.

For long term switching off the TEA5991, the radio must be switched off by giving the PowerDown command. In this case the settings are lost. For activating the radio again, at least the following actions must be performed: give a PowerUp command, give GoTo FM (FMRX) command, and switch on the AudioDacs and (re-) tune.

3.8 Connections

3.8.1 I2C and SPI bus interface

The TEA5991 incorporates three control interface protocols: I²C, SPI 3-wire and SPI 4-wire. The I²C bus uses the SCL and SDA pin. In this case the SEN pin (the third line used for 3-wire SPI) is not used, and has to be connected to ground or Vrefdig (+1.80 V). The fourth pin used for 4-wire SPI (SDO), pin GPIO2, can be left open or used as GPIO when in I²C mode.

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The SCL and SDA inputs are typically used for I²C with voltage levels of +1.8 V, but are tolerant for levels up to +3.3 V. This in contrast to the other communication bus pins (SEN, GPIO2) and all other input/output pins including RST and INTX: these are limited to Vrefdig voltage + 0.5 V.

I²C SIGNAL	TEA5991 pin	DESCRIPTION
SCL	SCL	I²C clock input line
SDA	SDA	I²C serial data input of slave and serial data output of slave

Figure 17 I²C connections

SPI SIGNAL	TEA5991 pin	DESCRIPTION
SS	SEN	SPI select (active low)
SCK	SCL	SPI Clock input line
SDI	SDA	3 wire mode: serial data input of slave and serial data output of slave 4-wire mode: serial data input of slave
SDO	GPIO2	4-wire mode serial data output of slave

Figure 18 3w/4w SPI connections

BUSSEL2	BUSSEL1	Control Bus Selected
0	0	I²C
0	1	reserved
1	0	SPI 3 wire
1	1	SPI 4 wire

Figure 19 Bus mode selection

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3.8.2 Antenna and earphone

A wire (separate line in the earphone cable) used as FM-antenna can be directly connected to the FM-input of the TEA5991. No capacitor or inductor is required.

In case the grounding or shielding of the earphone cable (in most cases also the return path for the audio) is to be used as FM-antenna, some measures have to be taken to prevent FM-signal leaking into the audio circuits and/or audio signals present at the FM-input. In this case, three inductors, with a value larger than 1 µH, and a capacitor are required.

Preferably the inductors should have their resonance frequency (highest impedance) in the middle of the FM-band, e.g. at 98 MHz. The capacitor C is not critical; C0G/NP0 types with values between 100 pF and 470 pF are OK.

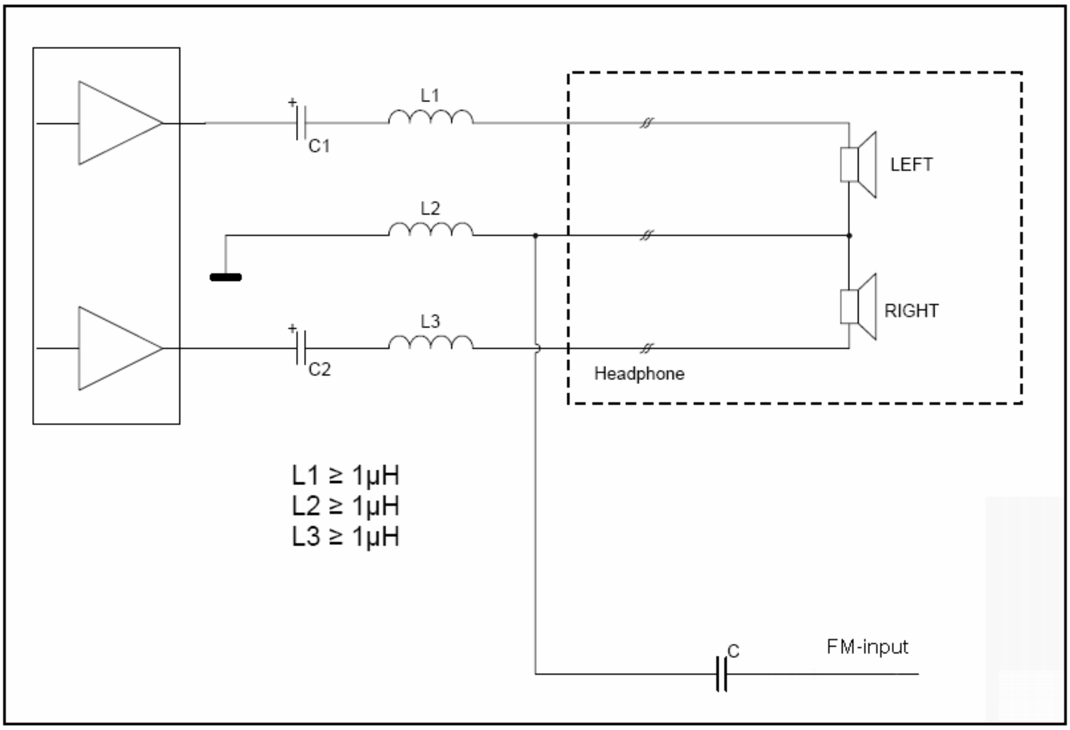

Figure 20 Earphone cable shielding used as FM-antenna

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4 TEA5991 interfacing

4.1 General conditions for TEA5991

Note *all I/O pins (BUSSEL1, BUSSEL2, SEN, GPIO1, GPIO2, INTX, RST) are in the +1.80V domain. The I²C pins SCL and SDA are +3.3V tolerant.*

The TEA5991 FM-radio requires the following voltages and signals to function:

- Analog and digital supply [VCC, VDD]: 2.4 – 3.6V
- Reference voltage for the IOs [VREFDIG]: 1.8 V
- Reference frequency [FREF]: 32.768kHz, 1.8 Vpp
- I²C [SDA, SCL]: levels between 1.8V and 3.3 V.
- In case of SPI (3w/4w) [SEN, GPIO2]: 1.8V level.

Optional: operating mode change/reset [RST]: 1.8 V level.

Optional: the interrupt [INTX] pin: 1.8 V level.

Reading data from the IC can be done by flags-polling or on timer-basis.

Further pin description:

- SEN is enable line for SPI bus. For I²C bus mode this pin must be connected to either ground or to Vrefdig (+1.8 V).
- T-EN: for normal operation this pin must be grounded.
- BUSSEL1, BUSSEL2: for I²C both must be grounded. For SPI 3w and 4w respectively these must be Low/High and High/High (see Ch 3.8).

4.2 Example for the SySol5210 platform

The SySol5210 platform consists of the baseband processor PNX5230 and PMU PCF50611.

The PMU delivers a 32.768 kHz clock with the right amplitude: 1.8Vpp. Also the Vdd_IO_High and Vdd_IO_Low supplies have the right voltage for the TEA5991, respectively +2.9V and +1.8 V.

The PNX5230 has several I/O's in the 1.8V domain, which can be used for e.g. RST and INTX (when required). These I/O's are labeled GPIOA1 to GPIOA11.

The I²C signal levels of this baseband IC are approximately 2.8V, and suitable to be connected to the TEA5991's SCL and SDA pins.

See the simplified diagram below, Figure 21.

Similar connections can be made when using e.g. Sy.Sol7210 and PNX6515.

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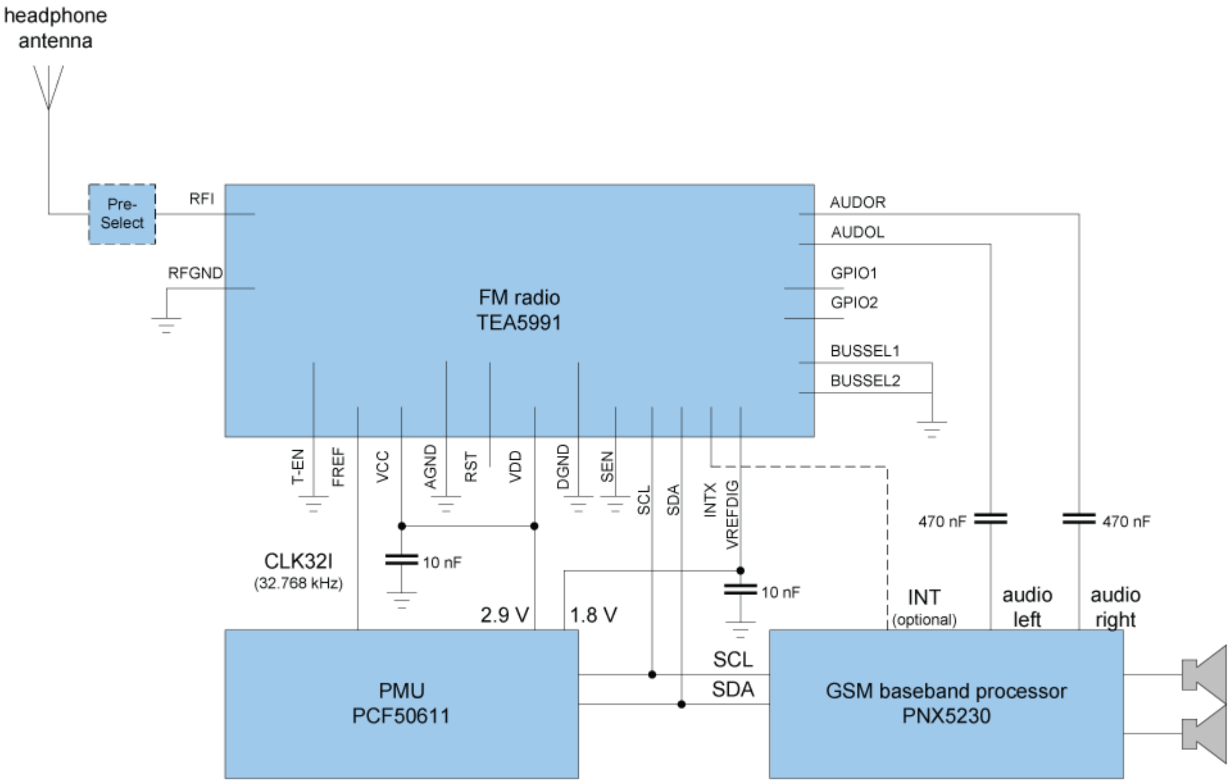

Figure 21 Simplified connections to the SySol5210 platform

TEA5991:

INTX: optional. Instead of using interrupts, polling can be used for e.g. reading flags.
The INTX pin can be left open or can be connected to Vrefdig.
The RST pin can be left open or can be connected to Vrefdig.
BUSSEL1, BUSSEL2: grounded for I2C mode.
T_EN: must be grounded for normal operation.
SEN: must be connected to Vrefdig or Ground, not left open.

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5 TEA5991 demo board schematics

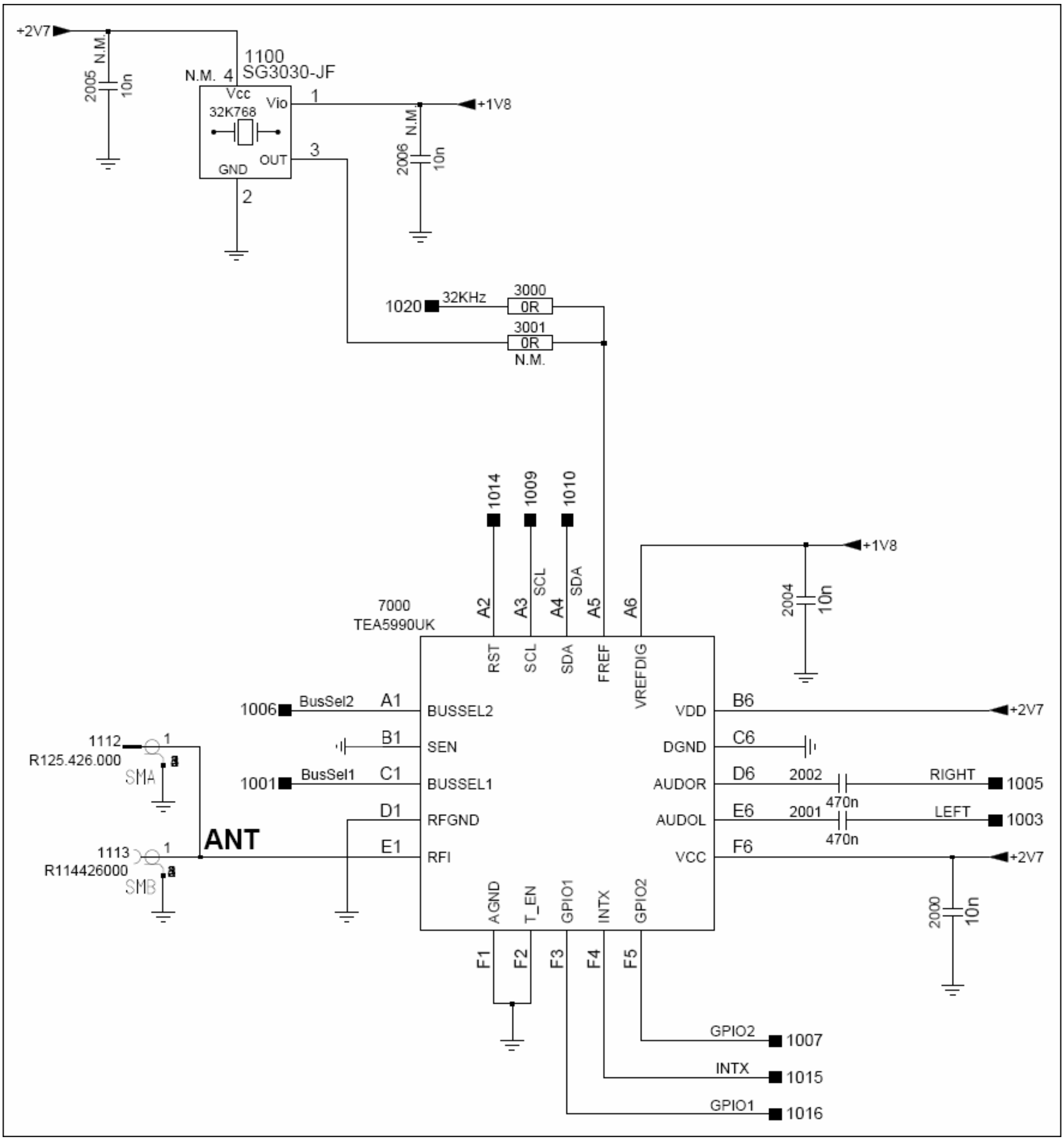

Figure 22 Schematics for the TEA5991uk (CSP package) demo board GH1183.

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5.1 GH1183 TEA5991uk demo board lay-out

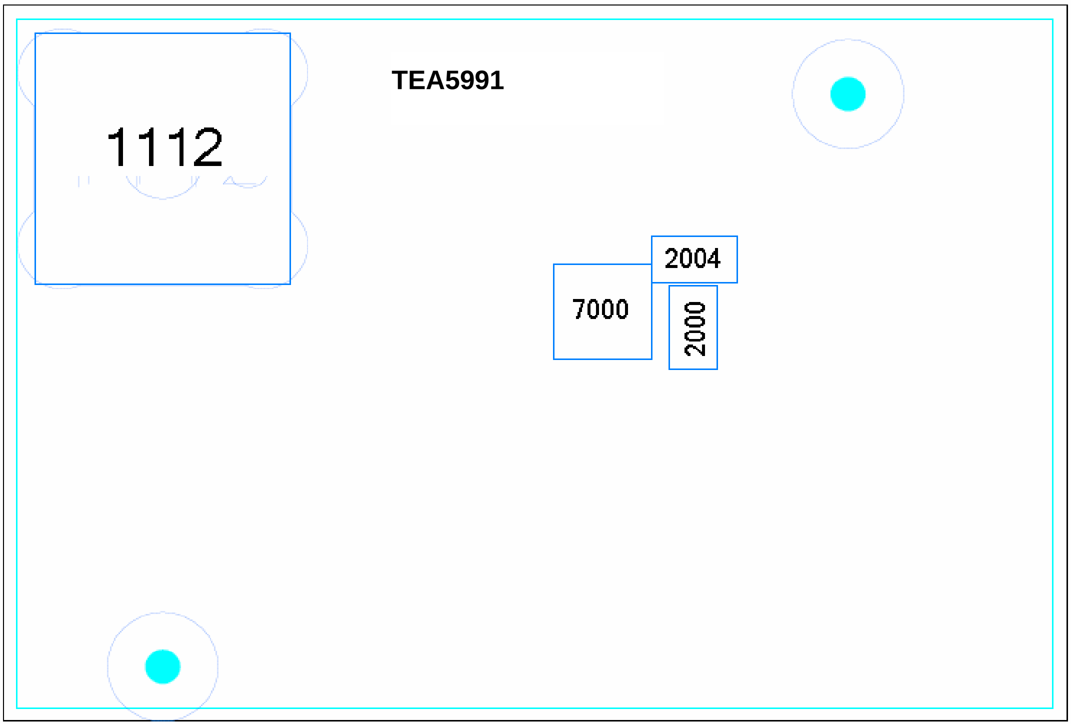

Figure 23 GH1183 demo board (WL-CSP package); component placement of the top-side (SMA connector 1112, FM-radio 7000 + decoupling caps 2000 & 2004).

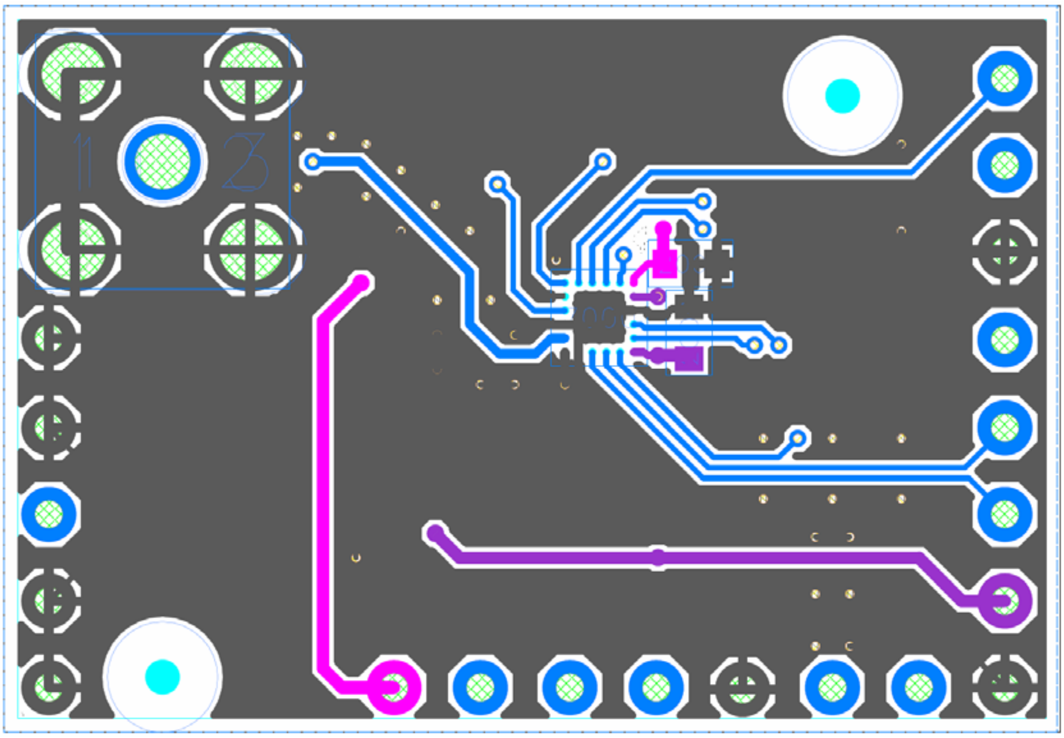

Figure 24 Top-side copper: note the separate Agnd, RFgnd and Dgnd connections.

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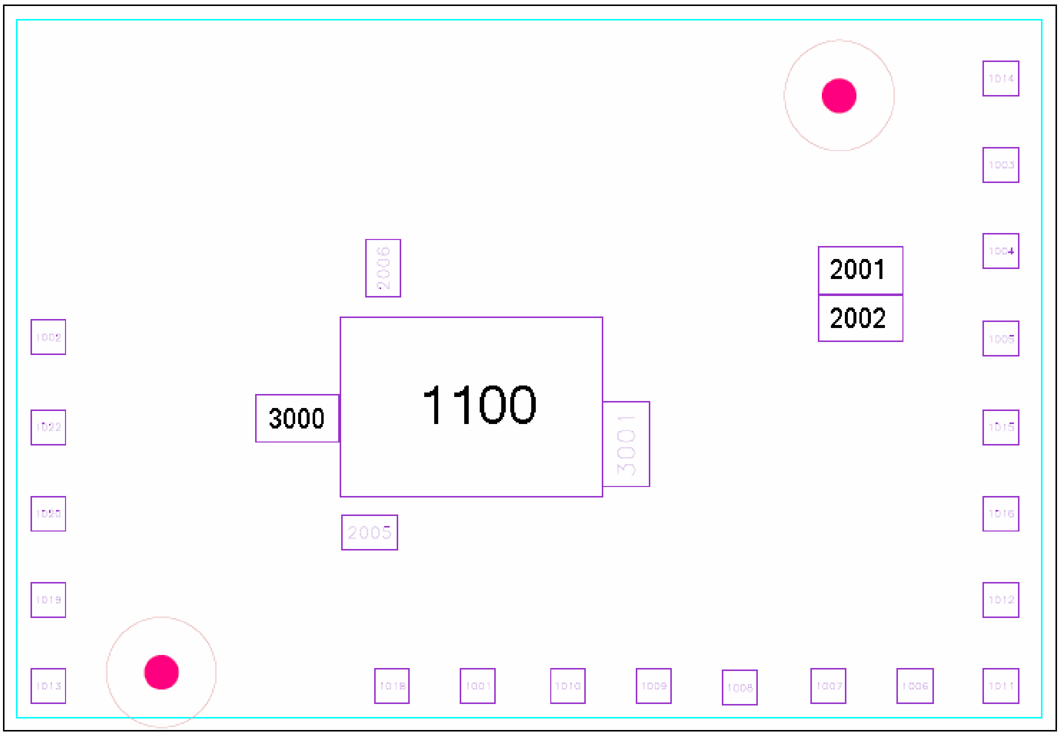

Figure 25 Bottom-side placement: the optional Epson 32.768kHz reference clock module (1100), audio coupling capacitors (2001, 2002).

5.2 Layout considerations (EMC-ESD)

Grounding of the Digital ground pin (DGND), the Analog ground pin (AGND) and the RF ground pin (RFGND) must be paid attention to. The AGND and the RFGND can be combined, but the DGND must be connected separately to the ground, at least not to be combined with the RFGND. If not done so, some interference coming from digital currents flowing from the DGND into the FM-input circuits can be expected. This occurs especially in the Japanese FM-band with so-called star connections, when using separate vias from each GND-pin to a ground plane are beneficial.

Some notes for the FM-antenna connection:

- Keep the connection as short as possible to avoid picking up noise or interferences.
- When it is not possible to keep it short, make sure the antenna trace is shielded, if possible make it a transmission line by using microstrip or stripline techniques.
- Keep it away from digital clocks. The antenna trace should certainly not run parallel to such signals.

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6 TEA5991 FM-radio GUI – getting started

This IS Based on GUI Xman2 version 0.5.

Step 1: start the Xman2 GUI. The first time, the default settings are loaded in the TEA5991: the radio is powered up, the audio DACs are enabled, and the radio is tuned to 87.5 MHz, FM-noise should be heard.

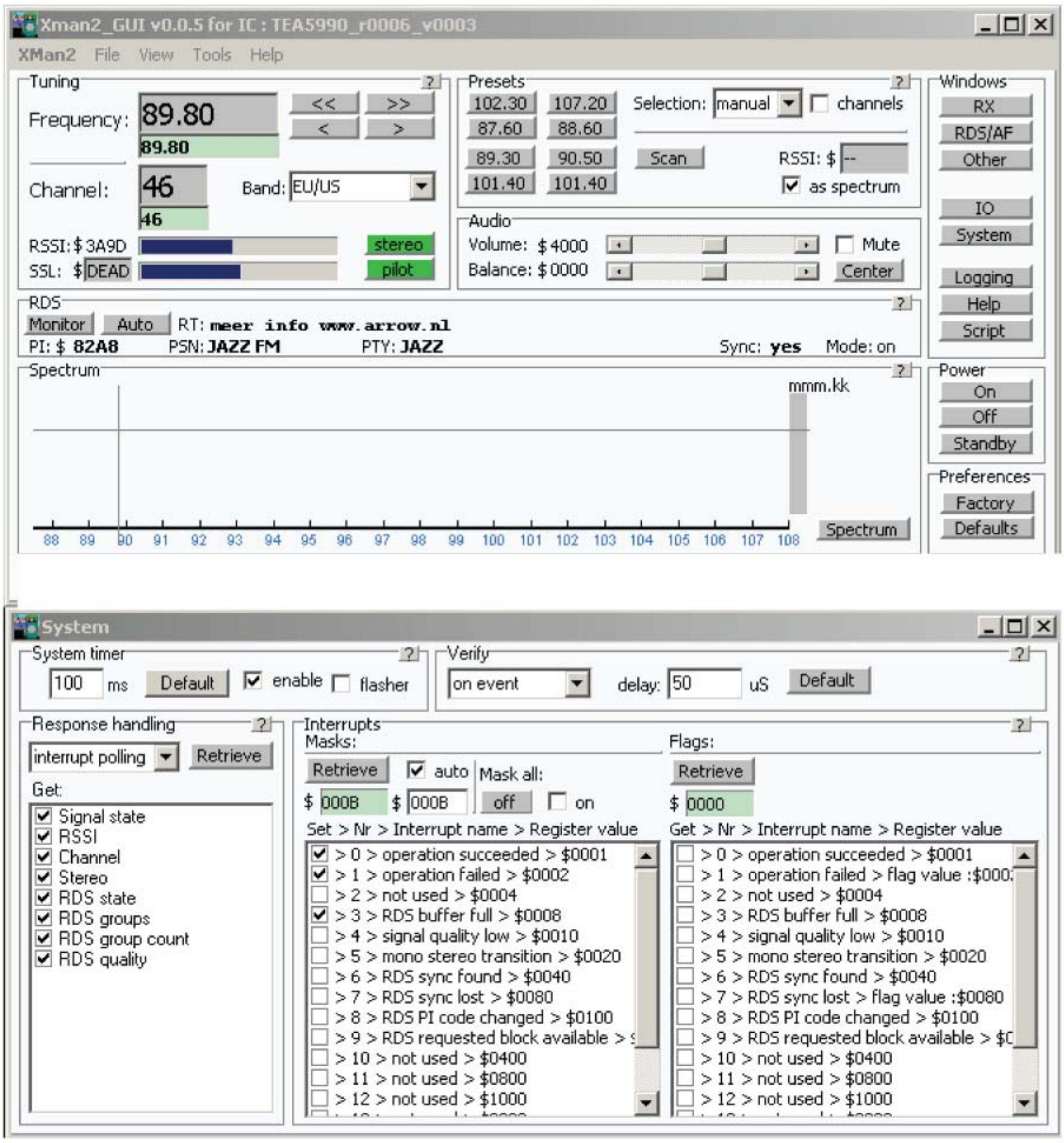

Figure 26 Windows released once Xman2 GUI is started

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Step 2: after the program has started and the TEA5991 is initialized, the radio can be tuned to a desired station, by assigning the frequency in MHz, the channel number, or by clicking in the Dial window in the lower part of the "Main" window.

Available FM-stations can be checked by making a spectrum scan of the FM-band (Spectrum button), clicking on a 'peak' will tune the FM-radio to that channel.

Additionally, a search-down/-up can be started (<< and >> buttons), or a band Scan can be executed: searching for the FM-stations, and storing the 32 strongest stations.

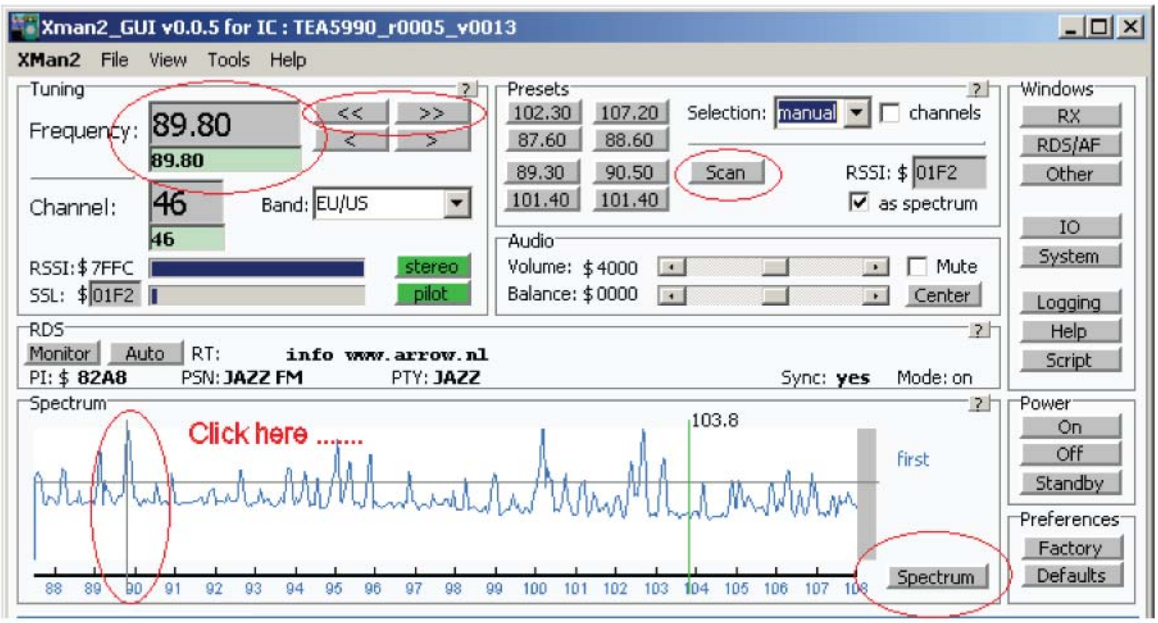

Figure 27 Step 2. Tuning, Spectrum scan, Search-up/down and Band-scan

If not yet enabled, the RDS can be activated by pressing the Auto button next to the RDS Monitor button ("Main" window: in the middle, left hand side).

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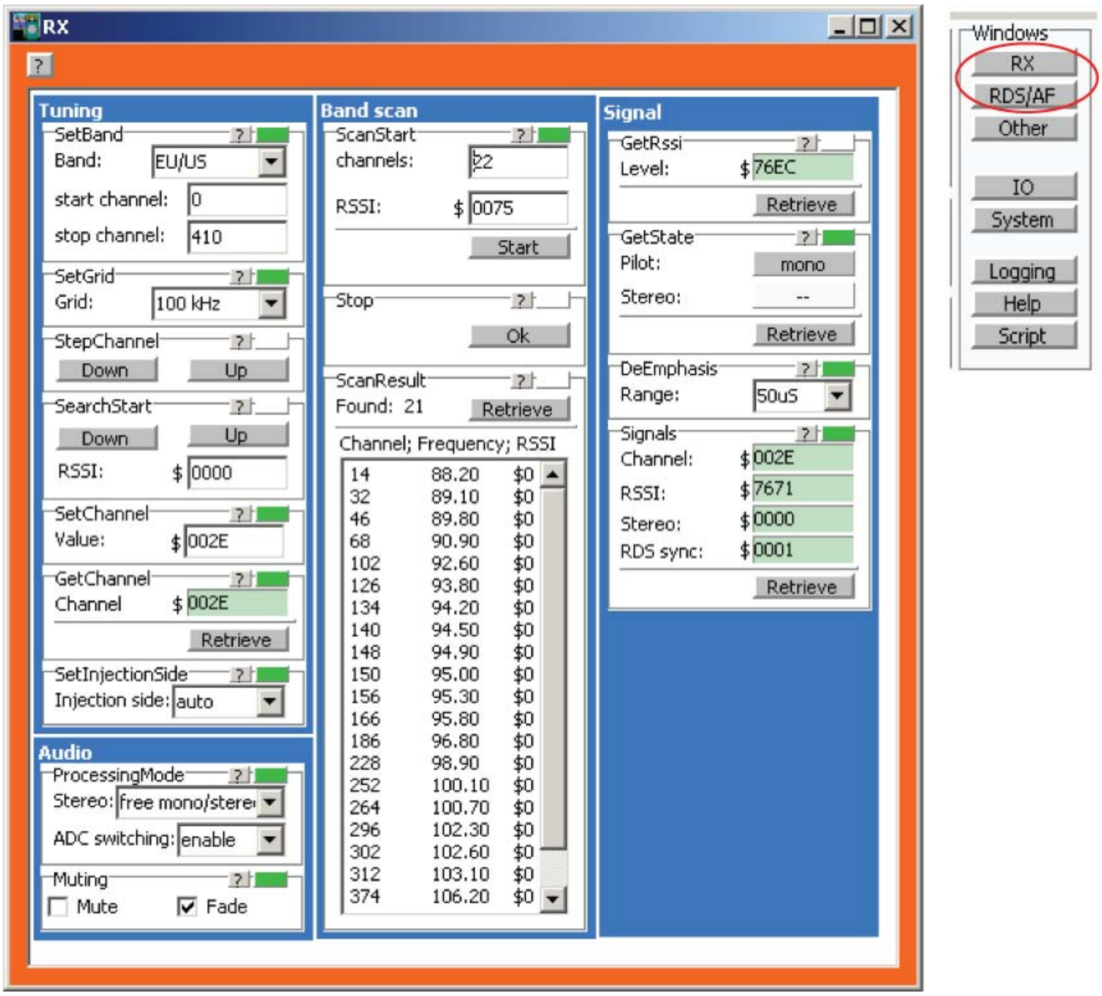

Figure 28 "Rx" window: middle column showing the band scan result (22 stations in this case)

In this "Rx" window, the FM-band (Eu/US, Japan, China), grid step (50, 100, 200 kHz) and audio processing-mode can be selected.

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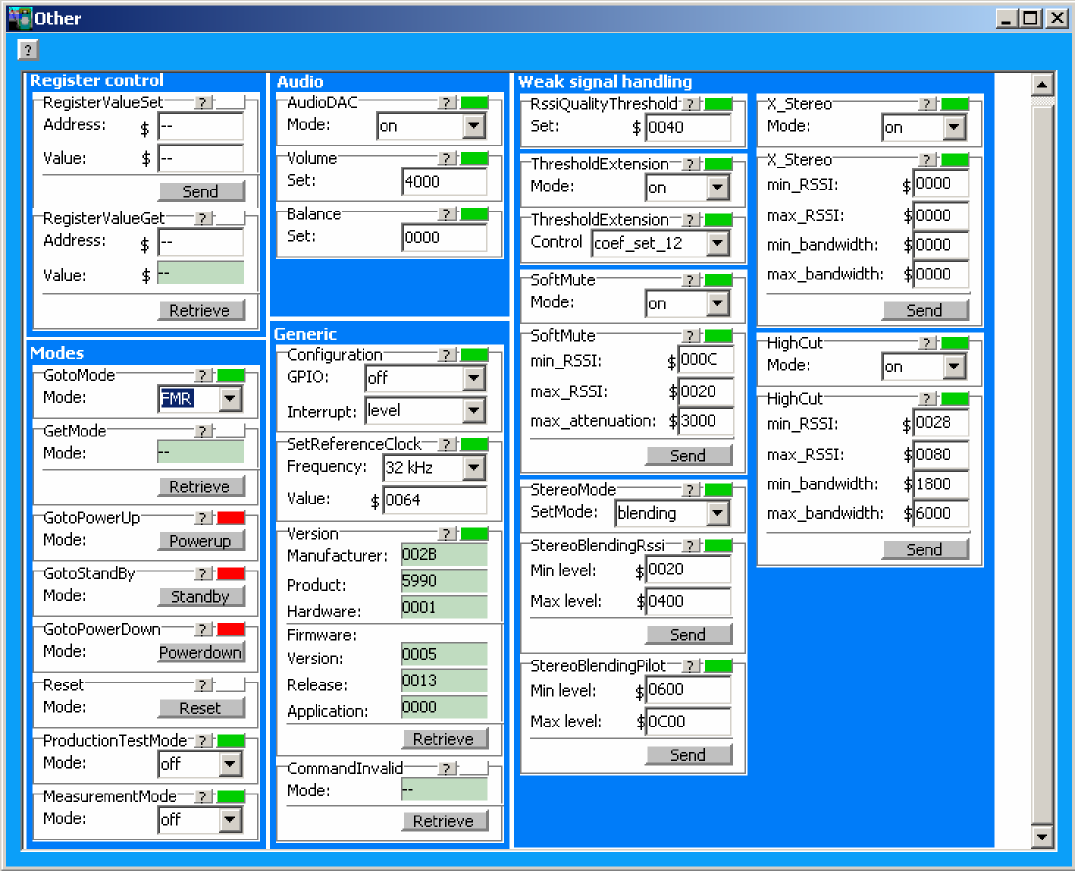

Figure 29 Step 3: the “Other” window

In the “Other” window the power modes, audio-settings, reference frequency offset and weak signal handling can be controlled.

The RDS related windows are discussed in section 3.3.2.

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Glossary

ADC	Analog to Digital Converter
AF	Alternative Frequency
AM	Amplitude Modulation
BER	Bit Error Rate
BQR	Bit Quality Rate
DAC	Digital to Analog Converter
DCO	Digital Controlled Oscillator
DSP	Digital Signal Processor
FLL	Frequency Locked Loop
FM	Frequency Modulation
GUI	Graphical User Interface
IP2	Second Order Intercept Point
IP3	Third Order Intercept Point
LNA	Low Noise Amplifier
PLL	Phase Locked Loop
PSRR	Power Supply Rejection Ratio
RBDS	Radio Broadcast Data System
RDS	Radio Data System
RSSI	Received Signal Strength Indication
THD	Total Harmonic Distortion
VCO	Voltage Controlled Oscillator

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