FM Receiver/Transmitter
Device Overview
Agenda

♦ FM Receiver Overview
♦ FM Transmitter Overview
♦ System Interface
♦ FM Receiver Interface & Enhancement
♦ FM Transmitter Interface & Enhancement
♦ Layout Compatibility
FM Receiver Overview

- Si4700: FM Receiver
- Si4701: FM Receiver with RDS
- Si4702: FM Receiver
- Si4703: FM Receiver with RDS
- Si4704: FM Receiver
- Si4705: FM Receiver with RDS
- Si4720: FM Transceiver
- Si4721: FM Transceiver with RDS
Si4702/03 Broadcast FM Radio Receiver

- Broadcast FM radio receiver IC
  - Over 40 million units shipped
  - CMOS process technology

- Industry leading solution
  - Hundreds of design wins and design ins
  - Mature technology and platform

- Highly integrated solution
  - Minimal external components
  - Easy-to-use, flexible implementation

- Best-in-class performance
  - Superior audio quality and reception
Si470x FM Radio Tuner

♦ Broadcast FM radio receiver
  ➢ FM band (76 to 108 MHz)
  ➢ RDS/RBDS decoder (Si4703)

♦ Fully integrated solution
  ➢ 3 x 3 x 0.55 mm 20-pin QFN
  ➢ 10 mm² board area

♦ Built on the proven Si4700/01
  ➢ Proven hardware foundation
  ➢ Mature firmware

♦ Best-in-class performance
  ➢ Superior audio quality, reception and reliability
Si4702/03 Block Diagram

- Digital Low-IF architecture
- Simplifies PCB layout and programming
  - One external BOM component
  - Pin-compatible RDS (Si4703)
Si4702/03 FM Radio Receiver

- Broadcast FM radio receiver
  - FM stereo radio (76 to 108 MHz)
  - RDS/RBDS decoder (Si4703)

- Highly integrated CMOS solution
  - Digital Low-IF architecture
  - 10 mm² board area
  - 1 ext. component vs. 10-14 for NXP
  - 3 x 3 x 0.55 mm 20-pin QFN

- Excellent user experience
  - More stations, better sound
  - Less interference
Flexible Audio Characteristics

- Si470x allows customization to subjective preferences
  - Adjustable soft mute parameters—attenuates weak, noisy signals
  - Adjustable stereo blend threshold—customizable to environment

![Graph showing soft mute attenuation and stereo blend threshold vs. RF level (dBuVemf)]
Excellent FM Sensitivity

♦ Sensitivity is a measure of the ability to receive weak signals
♦ Example FM plot below shows strong and weak channels
♦ Si470x have excellent, stable sensitivity across the FM band
 Superior Seek Performance

♦ Si470x products have excellent, proven seek performance
♦ Better user experience with more stations found

Stations may fall below the seek threshold, but the Si470x algorithm uses additional qualifiers to reliably find all stations
Si470x receives more weak stations in crowded environments
- "Selectivity" is ability to receive weak signals with large adjacent (one channel off-set) or alternate (two channel off-set) blockers
- Si470x has leading alternate (70 dB) and adjacent (50 dB) channel selectivity

Si470x offers best IP3 blocking for intermodulation products
- IP3 blocking is the ability to receive weak signals in the presence of strong intermodulation products
- Closest competitor is 13 dB worse performance; most are 25 dB worse
Pin-Compatible RDS Solution

- Pin-compatible, drop-in enhancement
  - Si4703 adds RDS/RBDS

- RDS adoption increasing
  - FM w/ RDS ~ MP3 experience
  - GPS & navigation applications using TMC for traffic data

- Millions of Silicon Labs’ RDS devices tested, adopted, and shipped worldwide
Si4704/05 Enhanced FM Radio Receiver

♦ Next generation FM stereo radio receiver (76 to 108 MHz)
  ➢ RDS/RBDS decoder (Si4705)

♦ Enhanced features and performance
  ➢ Integrated tuned loop antenna support
  ➢ Supply current consumption ~15 mA
  ➢ Analog and PCM digital audio outputs
  ➢ Field upgrade and patch capability

♦ 3x3x0.55mm 20 pin package
  ➢ Layout compatible with 3x3 radio product family
Si4704/05 Antenna

♦ Integrated antenna support
  ➢ Loop or PCB trace
  ➢ Listen to FM using phone speaker
  ➢ Send FM to BT headset wirelessly

♦ Analog or digital audio output
  ➢ Digital output eliminates need for additional external codec

♦ Headphone antenna optional
  ➢ Can have both headphone antenna and integrated antenna on same design

♦ Footprint and software compatible with 3x3 mm QFN Radio family
  ➢ Customize feature-set for each region (i.e. India AM/FM, Europe FM + RDS)
Si4704 architecture supports a tuned-loop antenna
  - Optional headphone cable antenna for Rx
Most integrated FM solution
Best FM user experience with Bluetooth
FM Receiver Overview: Benefits

♦ Selectable Antenna
  - Embedded antenna
  - External antenna

♦ Smallest footprint and highest level of integration
  - 2 external components and board area of ~15 mm²
  - Includes an integrated low-drop-out (LDO) regulator for direct battery connection

♦ Ease of design and use
  - Programmable Enhancements enable one design for worldwide applications.
  - Layout compatible with 3x3 family

♦ Si4705/21 includes RDS/RBDS decoder
  - Can receive artist name and song titles from any RDS/RBDS radio

♦ Overall best end-user experience
FM Transmitter Overview

- Si4710: FM Transmitter
- Si4711: FM Transmitter with RDS
- Si4712: FM Transmitter with RPS
- Si4713: FM Transmitter with RDS and RPS
- Si4720: FM Transceiver
- Si4721: FM Transceiver with RDS
FM Tx w/ RDS & RPS (Si4710/11/12/13)

♦ First and smallest digital FM transmitter

♦ First to offer RDS transmit

♦ Digital low-IF architecture with two externals

♦ Most flexible, best performing portable solution available
  ➢ Patented receive power scan (RPS) unprecedented in industry
  ➢ Programmable, stable output power across frequency
  ➢ Digital audio compression and limiter for improved sound
Digital Architecture Improves Performance

- Digital algorithms dramatically improve sound fidelity
- Integrated RDS/RBDS encoder on the Si4711
- Only two external components and board area of 15 mm²
- 1/3 less current consumption than leading part
Si471x offers smallest footprint at ~ 15 mm²

Low BOM count improves manufacturability
Dynamic Range Control Improves Fidelity

Silicon Labs exclusive feature

- Audio quality is much better than competitors
- Increased volume leads to better user experience
Improved User Experience with RPS

- RPS automatically finds best Tx channel
- Removes need for “tune and listen” exercise
Programmable Output Voltage

- Maximizes transmit voltage to regulations
  - Precise output voltage control

- Supports almost any integrated antenna
  - PCB trace antennas
  - Wire antennas
  - Loop antennas
  - Headphone antennas
  - Charger cable antennas
Stable Output Power Across Frequency

- Ability to program output voltage at each frequency maximizes transmit power while staying within FCC or ETSI limits
- On-chip calibration enables variety of antennas
- Minimal external components

Silicon Labs output power flat across frequency

Competitors’ output power can vary across frequency and external component variation

FCC Limit 48dBuV/m
Si472x meets the FCC 20 dB bandwidth requirement while maintaining maximum audio volume (Δf = 75 kHz)

- Competition fails to meet specification and has to lower volume to meet FCC specification

**Silicon Labs Si472x FM Transmitter Feature**

- Δf = 75 kHz
- f_mod = 1 kHz
- f_carrier = 105.3 MHz
- 20 dB BW = 187.2 kHz

**Competition B FM Transmitter**

- Δf = 75 kHz
- f_mod = 1 kHz
- f_carrier = 105.3 MHz
- 20 dB BW = 242.4 kHz
RDS Advertising Your Company Brand

- RDS worldwide adoption increasing
  - FM with RDS ≈ MP3 experience
  - Standard in car radios

- RDS transmitter allows any text-based data to be displayed on target FM RDS receiver

- RDS receiver enables potential revenue after point of sale for service providers and MP3 providers

- Si4721 offers both FM RDS receive and transmit features
Advanced Modulation Control

- Can program audio, pilot, and RDS (Si4711) deviation independently from 0 to 100 kHz
  - Example: Audio = 75 kHz, Pilot = RDS = 0 kHz for strong MONO signal
- Prevents distortion and maximizes volume
Si472x FM Transceiver

- Only single-chip FM Transceiver
  - Integrates Si470x FM Rx and Si471x FM Tx in single IC
  - Only FM transceiver with RDS Rx and Tx capability (Si4721)
  - Worldwide FM band (76-108 MHz)

- Leading performance and features
  - Market-leading Rx performance and adjustability
  - Unmatched Tx performance and adjustability
  - Only FM product to support an integrated antenna
    - Optimized for use with standalone Bluetooth removes headphone cable requirement

- 3x3x0.55 mm 20 pin QFN package
  - Layout compatible with Si47xx family
Si472x—Digital Architecture Advantages

- Receiver and transmitter share circuitry for optimal design and cost
  - Digital audio interface reduces system power and extends battery life
- Integrated FM transceiver with two external components in .15 cm²
- Competing solutions require two chips and up to 50 external components
Si472x vs. Competition

- Si472x is the world’s first single-chip FM radio receiver and transmitter
- Requires only two external components in 15 mm² area
  - Competing solutions require FM receive and transmit chips, up to 50 external components and greater than five times board space
Si4721—Pin Compatible RDS Solution

♦ RDS world wide adoption increasing
  - FM w/ RDS ≈ MP3 experience
  - Standard in car radios

♦ Si4721 offers pin-compatible, drop-in enhancement
  - RDS/RBDS for both FM receive and FM transmit

♦ RDS transmit encoder allows text-based data to be displayed on target FM receiver

♦ RDS receiver performs all processing and error correction on chip
Small, Integrated Rx / Tx Antenna Support

- Si472x architecture supports a single, small integrated antenna for both receive and transmit
  - Optional headphone cable antenna for receive
- No external antennas or cables required
FM Transmitter Overview: Benefits

♦ First FM transmitter with **excellent sound fidelity!**
  ➢ **Precise output power control** – Allows customers to optimize transmit power
  ➢ **Audio dynamic range control** – Customers can better utilize audio dynamic range for increase FM transmit volume which results in better sound quality
  ➢ **Advanced modulation control** – Prevents distortion and maximizes volume

♦ Smallest footprint and highest level of integration
  ➢ 2 external components and board area of ~15 mm²
  ➢ Includes an integrated low-drop-out (LDO) regulator for direct battery connection

♦ Ease of design and use
  ➢ Programmable Enhancements enable one design for worldwide applications.
  ➢ Layout compatible with 3x3 family

♦ Si4711/13 includes RDS/RBDS encoder
  ➢ Can send artist name and song titles to any RDS/RBDS radio

♦ Si4712/13 includes Received Power Scan Feature.
  ➢ Useful for doing the RSSI scan with the same transmit antenna (short antenna) and find an empty channel to do the transmission.

♦ Overall best end-user experience
System Interface – Common to FM Receiver and FM Transmitter

1. Pin 5, 18, 19 : Communication (Bus Mode Selection)
2. Pin 6, 7, 8 : Communication
3. Pin 9 : Reference Clock
4. Pin 10, 11, 12 : Power Supplies
System Interface: Bus Mode Selection

- Common to both FM receiver and FM transmitter
- The bus mode is selected when the chip is being reset.
- On the rising edge of RST~, the state of GPO2 & GPO1 are used to determine the bus mode of the chip.
- The Si4704/05/1x chip supports 3 different bus modes:
  - 2-wire: GPO1 = high, GPO2 = low
  - 3-wire: GPO1 = low, GPO2 = low
  - SPI: GPO1 = high, GPO2 = high
- Refer to AN332 Universal Programming Guide for complete details.
System Interface: Communication

- Common to both FM receiver and FM transmitter
  - SEN~, SCLK and SDIO are used to communicate with the chip
    - 2-Wire, 3-Wire, or SPI
- Command and response architecture
  - Bit definitions are not fixed
  - Send Command along with the Arguments
  - Received Status and Response
Common to both FM receiver and FM transmitter
The RCLK is used as a reference clock for the VCO
User can provide RCLK from 31.13kHz to 40MHz
The RCLK will be divided down by a factor of 1-4095 to a range between 31130Hz and 34406 Hz.
System Interface: Power Supplies

- Common to both FM receiver and FM transmitter
- Vdd can be from 2.7 to 5.5V
- Vio can be from 1.5 to 3.6V
- 22nF bypass capacitor is required for Vdd
- A bypass capacitor is optional for Vio
Si470x FM Tuner
FM Receiver

FM Receiver Interface

♦ Pin 13, 14 : Audio Output (Analog)
♦ Pin 15, 16, 17 : Audio Output (Digital)
♦ Pin 2, 3, 4 : LNA Input and Antenna

FM Receiver Enhancement

♦ Radio Data Service RDS (Si4705/21)
Analog audio signal output from LOUT and ROUT pins

Things to watch out for:

- LOUT and ROUT signal has to be AC coupled and DC biased
Digital audio signals
- DFS (input) = audio sampling rate (eg. 32, 44.1, 48kHz)
- DCLK (input) = digital audio clock (64fs, 128fs, 256fs)
- DOUT (output) = digital audio data

Example:
- DFS = 48kHz
- DCLK = 64fs = 64*48kHz = 3.072MHz
FM Receiver Interface: LNA Input + Antenna

- Requires one external component for each antenna
  - Matching inductor or capacitor used to resonate antenna

- Things to watch out:
  - Minimize parasitic capacitance at FMIP/LPI output
  - Make embedded antenna as long as possible
  - Remove surrounding ground plane
  - FMIP and LPI cannot be used concurrently
The RDS Enhancement allows the user to receive a Radio Data Service text messages along with their FM Reception.

- Si4705/21 Firmware 2.0 has RDS FIFO size of 25
- Three types of RDS /INT:
  - When FIFO is filled
  - When RDS Sync is found
  - When RDS Sync is lost
Si4702/03 Pin Out

- GND
  - 4 GND Pins + GND PAD
- Power
  - VA & VD
  - VIO
- Antenna Interface
  - FMIP
- Audio Interface
  - LOUT & ROUT
- Digital Interface
  - RCLK
  - /RST
  - /SEN, SCLK, SDIO
  - GPIO1, GPIO2, GPIO3
- 2 NC’s
Si470x Functional Description – GPIO Pins

♦ GPIO1-3 can serve multiple functions.

♦ GPIO1
  ➢ Can be used to select the control interface.
    ▪ Will be described in detail in “Control Interface” part.

♦ GPIO2
  ➢ Can be used to indicate STC interrupt or RDS interrupt (Si4701/03).

♦ GPIO3
  ➢ Can be used to select the control interface.
    ▪ Will be described in detail in “Control Interface” part.
  ➢ Can be used as Mono/Stereo Indicator.

♦ All GPIOs’ function can be controlled by register setting except for the control interface selection.
- Stereo Control → BLNDADJ[1:0]
- Volume Control → VOLUME[3:0], VOLEXT
- De-Emphasis → DE
- Soft mute → SMUTER[1:0], SMUTEA[1:0], DSMUTE
Si470x Functional Description – Stereo Audio Processing (2)

- **Soft Mute Attenuation**
  - SMUTEA[1:0]

- **Stereo Blend Threshold**

![Graph showing stereo separation and mute attenuation]
Si470x uses Silicon Labs' patented and proven frequency synthesizer including a completely integrated VCO.

Tuning Frequency
- Freq (MHz) = Spacing(kHz) x Channel + Bottom of Band (MHz)
- Spacing
  - SPACE[1:0]
    - 00: 200 kHz
    - 01: 100 kHz
    - 10: 50 kHz
- Channel
  - CHAN[9:0]
  - READCHAN[9:0]
- Bottom of Band
  - BAND[1:0]
    - 00: 87.5 – 108 MHz
    - 01: 76 – 108 MHz
    - 10: 76 – 90 MHz
Si470x Functional Description – Control Interface

- Si470x supports 2- and 3-wire interface.
- 2-wire interface
  - Device Address: 0010000b
  - Using SDIO and SCLK
- 3-wire interface
  - Chip Address: 0110b
  - Using /SEN, SDIO, SCLK
- Choosing 2- and 3-wire interface

<table>
<thead>
<tr>
<th>Busmode</th>
<th>Select Method</th>
<th>SEN</th>
<th>SDIO</th>
<th>GPIO1</th>
<th>GPIO3</th>
<th>Bus mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>X</td>
<td>0^3</td>
<td>3-wire</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>X</td>
<td>0^3</td>
<td>2-wire</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>X</td>
<td>0^4</td>
<td>3-wire</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2-wire</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>0</td>
<td>1^5</td>
<td>3-wire</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>1</td>
<td>1^5</td>
<td>2-wire</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2-wire</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
</tr>
</tbody>
</table>

Notes:
1. All parameters applied on rising edge of RST.
2. GPIO3 is internally pulled down with a 1 MΩ resistor.
3. GPIO3 should be externally driven low, set to high-Z (10 MΩ or greater pull-up) or float.
4. GPIO3 should be left floating.
5. GPIO3 should be externally driven high (100 kΩ or smaller pull-up).
FAQ#1. Does Si470x support Japan Band?

♦ Answer)

Yes. Si470x can support all FM broadcast band. You don’t need to change any hardware, but only need to set proper register value.

<table>
<thead>
<tr>
<th>7:6</th>
<th>BAND[1:0]</th>
<th>Band Select</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>00</td>
<td>00 = 87.5–108 MHz (USA, Europe) (Default).</td>
</tr>
<tr>
<td></td>
<td>01</td>
<td>01 = 76–108 MHz (Japan wide band).</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10 = 76–90 MHz (Japan).</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>11 = Reserved.</td>
</tr>
</tbody>
</table>

87.5 – 108MHz is most common world wide. 76 – 108 MHz is used in Japan and China.
FAQ#2. Does Si470x support a frequency as **.*5 MHz?

♦ Answer)

This question addresses the fact that Si470x can support 50 kHz channel spacing. In a country such as Thailand, broadcast stations have 50 kHz channel spacing. Si470x family supports 50 kHz channel spacing as well as 100 kHz and 200 kHz channel spacings. The channel spacing can be selected by setting the register.

<table>
<thead>
<tr>
<th>SPACE[1:0]</th>
<th>Channel Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>200 kHz (USA, Australia) (default).</td>
</tr>
<tr>
<td>01</td>
<td>100 kHz (Europe, Japan).</td>
</tr>
<tr>
<td>10</td>
<td>50 kHz.</td>
</tr>
</tbody>
</table>

You don’t need to change hardware. But you have to confirm RCLK tolerance to guarantee the performance with 50 kHz channel spacing.

<table>
<thead>
<tr>
<th>RCLK Frequency</th>
<th>SPACE[1:0] = 00 or 01</th>
<th>32.768</th>
<th>200</th>
<th>kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCLK Frequency Tolerance</td>
<td>SPACE[1:0] = 10</td>
<td>-50</td>
<td>50</td>
<td>ppm</td>
</tr>
</tbody>
</table>

Some competitor parts don’t support 50 kHz channel spacing.
FAQ#3. How Large is the Audio Output on LOUT and ROUT?

Answer)

The maximum audio output is 0 dBFS, which is 80mVrms typical as specified in the datasheet.

<table>
<thead>
<tr>
<th>Audio Output Voltage</th>
<th>72</th>
<th>80</th>
<th>90</th>
<th>mV RMS</th>
</tr>
</thead>
</table>

Audio output voltage has been measured with a frequency deviation of 22.5 kHz. In the case of frequency deviation values greater than 22.5 kHz, audio output can be larger.
FAQ#4. Does Si470x have volume control? What is the gap between each step?

Answer)

Yes. Si470x provides an integrated volume control function. You can control the audio volume through VOLUME[3:0] and VOLEXT. VOLUME[3:0] has 2 dB steps. You can achieve 30 dB attenuation using VOLEXT.

The maximum volume, 0 dBFS, can be obtained by setting VOLUME[3:0]=0xf and VOLEXT=0. The minimum volume, -58 dBFS, can be obtained by setting VOLUME[3:0]=0x1 and VOLEXT=1. VOLUME[3:0]=0 stands for mute regardless of VOLEXT.

<table>
<thead>
<tr>
<th>VOLEXT</th>
<th>VOLUME[3:0]</th>
<th>FW16 (dBFS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>Mute</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>-56</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>-56</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>-54</td>
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</tr>
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<td>1</td>
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<td>-34</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>-32</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>-30</td>
</tr>
</tbody>
</table>
FAQ#5. Can I connect LOUT and ROUT on Si470x directly to an earphone?

Answer)

No. The minimum output load resistance of Si470x is 10 kohm, which would not be enough to drive a low impedance such as 16 or 32 ohms input impedance of the earphone. You have to use an earphone amplifier. However Si470x’s volume control function enables you to choose a very simple amplifier with a fixed gain.
Schematic Considerations
Si4700/01 Application Schematic
Si470x Application Schematic

Mandatory for Core FM
Essential System Components
Strongly Recommended
Optional

Other Option for RCLK

Silicon Laboratories Confidential
Si470x Application Schematic

**Silicon Laboratories Confidential**

- **Ferrite Beads**
  - >2.5 Kohm@100MHz Recommended

- **Antenna Matching Inductor**
  - Q>15 Recommended

- **ESD Protection Diode**
  - Capacitance < 1pF

- **Other Option for RCLK**

- **Bypass Caps**

- **DC Blocking Capacitor**

- **For the Noise Suppression from Digital Signals**

- **Dependent on Amplifier Application**
FAQ#1. Do I Have to Use Ferrite Beads on the Audio Output?

♦ Answer)

Yes. There are two purposes of these ferrite beads.

You will use the audio ground as an antenna, which is connected to the audio outputs through speakers. Usually, the audio outputs on earphone amplifier have low impedance. Without ferrite beads the other ends of antenna will have low impedance. Ferrite beads make these ends high impedance. (Blue Arrows)

In the case the audio outputs with high frequency noise, it will be coupled to FMIP. Ferrite beads prevent this noise be coupled to FMIP. (Red Arrows)
FAQ#2. The Dedicated Antenna Is Available in Our Earphone. Do I Still have to Use Ferrite Beads On the Audio Output?

答)

尽管您使用了一个专用的天线，但在音频输出和天线之间可能存在寄生电容。高频噪声可能通过这种寄生电容耦合到天线。低阻抗耳机放大器输出也可能通过这种寄生电容影响天线阻抗。

高频噪声从音频输出可以耦合到天线。低阻抗耳机放大器输出可能通过这种寄生电容影响天线阻抗。
Layout Example

Layer 1
- Primary

Layer 2
- Ground

Layer 3
- Power

Layer 4
- Secondary
**Place** Ferrite beads close to the earphone jack.

**Place** FM Tuner as close to the earphone jack as possible.

**Place** Matching Coil with the earphone jack away from the noise source.

**Place** FM tuner far from the noise source – System Bus, and etc.

**Place** the bypass cap as close to VD as possible.
Layout Example – Primary Side

Do Not route any trace near or underneath pin 1 and 20.

Connect all GND pins to the GND pad.

Route digital signal from the outside FM tuner.

Should have enough vias to be connected to the main ground.

Do not route power lines underneath FM tuner.
• DO NOT route any trace underneath FM tuner.
• DO NOT break ground underneath FM Tuner.
• Must have solid ground underneath FM Tuner.
Layout Example – Antenna Trace

♦ **Route** the antenna trace as short as possible.

♦ **Do Not Route** digital, analog and RF traces parallel with one-another to minimize inductive and capacitive coupling.

♦ **Route** the antenna trace such that antenna capacitance, CPCBANT (refer to AN231), and therefore CP (refer to AN231), is minimized. To minimize capacitance, keep trace length short and narrow and as far above the reference plane as possible, restrict the antenna trace to a microstrip topology (trace routes on the top or bottom PCB layers only), minimize trace vias, relieve ground fill on the trace layer.

♦ **Route** the antenna trace over an unobstructed ground plane to minimize antenna loop area.
FAQ#1. Do I have to Use Special Impedance for Antenna Trace?

答：

不。Si470x的输入阻抗为高阻抗。您不需要匹配50欧姆的阻抗。您唯一需要关心的是保持天线迹线长度短而窄，并尽可能远离参考平面，以最小化电容，最小化迹线过孔，释放迹线层的填充电平。
FAQ#2. Why do I Have to Protect Pin 1 and 20?

♦ Answer)

Pin 1 and 20 should be left floating. Pin 1 and 20 are connected to VCO internally. If any noise is coupled to these pins, the noise will flow into the VCO. This can cause issues with tuning and sensitivity.
Sensitivity Optimization
Choosing Matching Inductor

- Injecting a test signal from a signal generator.
- Measure signal level on FMIP in either of following ways.
  - Check RSSI[9:0] in register 0Ah.
  - Probe FMIP with low-capacitance FET probe and spectrum analyzer.
- Repeat above measurement on several frequency point.
- Change the matching inductor and repeat the measurement.
- Choose the best inductor.
Si470x FM Transmitter
FM Transmitter

FM Transmitter Interface
♦ Pin 15,16 : Audio Input (Analog)
♦ Pin 13,14,17 : Audio Input (Digital)
♦ Pin 3, 4 : TXO Output and Antenna

♦ FM Transmitter Enhancement
♦ Audio Enhancement (Compressor, Pre-emphasis, Limiter)
♦ RDS/RBDS Encoder
♦ Received Power Scan
FM Transmitter Interface: Audio Input (Analog)

- User provides analog audio signal through LIN and RIN to be transmitted

- Things to watch out for:
  - LIN and RIN signal has to be AC coupled
  - Analog audio signal has to be less than the LINE_ATTENUATION and MAX_LINE_IN_LEVEL property settings
  - Otherwise the signal will clip the ADC and distortion may occur
Digital audio signals
- DFS (input) = audio sampling rate (e.g., 32, 44.1, 48kHz)
- DIN (input) = digital audio data
- DCLK (input) = digital audio clock (64fs, 128fs, 256fs)

Example:
- DFS = 48kHz
- DCLK = 64fs = 64*48kHz = 3.072MHz
FM Transmitter Interface: TXO Output + Antenna

♦ Requires one external component: L tuning inductor

♦ Things to watch out:
  - Minimize parasitic capacitance at TXO output
  - Make antenna as long as possible
  - Remove surrounding ground plane
  - Requires DC path to GND for TXO pin
FM Transmitter Enhancement: Audio Enhancements
The compressor reduces the dynamic range of audio signal which results in increased volume.

- It amplifies signal below the threshold by a fixed gain
- It compresses audio signals above the threshold

Refer to AN332 on Audio Dynamic Range Control Section
Preemphasis and deemphasis are techniques used to improve the SNR of an FM transmitted signal by reducing the effects of high frequency noise.

Refer to AN332 on Preemphasis section
Limiter is available to prevent overmodulation

FCC occupied bandwidth regulation specifies the occupied bandwidth of an FM signal at -20dBc is 200kHz

Refer to AN332 on Limiter section
The RDS Enhancement allows the user to transmit a Radio Data Service text messages along with their FM Transmission

Refer to AN332 on how to program RDS

Refer to Si471x EVB Users Guide on how to demo RDS
RPS allows users to scan the FM Band and find an empty channel to do an FM transmission.
Select tuning inductor LTUNE with a Q > 30 to maximize antenna current, and therefore, radiated power.

Place the antenna, and in particular the end of the antenna opposite the Si4710/11, as far from the ground plane as possible to maximize radiated power.

Place inductor LTUNE and the Si4710/11 U1 as far from potential noise sources as possible to reduce capacitive and inductive coupling.

Place VDD bypass capacitor C1, and optional VIO bypass capacitors C2, as close as possible to supply pins they bypass for maximum effectiveness.

Do Not Route digital, analog, and RF traces parallel with one-another to minimize inductive and capacitive coupling.
Do Not Route traces under the Si4710/11 without a reference plane between the IC and the signal trace. In particular, care should be taken to avoid routing digital signals or reference clocks traces near or parallel to the VCO (pins 1, 20), or audio inputs LIN/RIN (pins 15, 16). This recommendation is made to minimize inductive and capacitive coupling.

Do Not Route digital or RF traces over ground or power plane breaks. Signals and vias should be routed such that the reference plane (either ground or power) is as solid as possible, with no large slots. Ground fills on other layers should have plentiful vias to the ground plane. This recommendation is made to minimize RF radiation.
Route a PCB antenna trace such that antenna capacitance, CPCB, and therefore CP, is minimized. To minimize capacitance, relieve the ground and power planes and ground fill.

Route all Si4710/11 ground pins to the ground paddle to minimize ground potential differences.
Compatibility
Si47XX—Layout Compatibility

- Single PCB layout supports any Silicon Labs broadcast audio solution
- Supports differentiation and flexibility in customer product line
Upgrade Si4702/03 to Si4720/21

- Si4702/03 FM Tuner
  - Need three 0 Ω resistors to upgrade to the Si4720/21
Si4720/21 Application Schematic

- Si4721/21 FM Transceiver
  - Add transmit antenna
  - Replace R0 with L2
  - Stuff C2, C3
  - Remove two 0 Ω resistors
Si4720/21 Loop Antenna Application

- Si4721/21 FM Transceiver
  - Loop antenna for Rx/Tx
Related Documents-FM Receiver

♦ Si4700/01/02/03/04/05/06 Datasheet
♦ AN230: Si4700/01/02/03 programming guide
♦ AN231: Headphone and antenna interface
♦ AN234: Si4700/01/02/03 evaluation board test procedure
♦ AN235: Si4700/01/02/03 evaluation board quick start guide
♦ AN243: Using RDS/RBDS with the si4701/03
♦ AN284: Si4700/01 firmware 15 seek adjustability and settings
Related Documents-FM Receiver

♦ AN281: Si4700/01/02/03 Firmware Change List
♦ AN299: External 32.768 kHz crystal oscillator
♦ AN326: Si4704/05 fm receiver programming guide
♦ AN383: Si47xx 3 mm x 3 mm QFN universal layout guide
♦ AN332: Si4704/05/06/1X/2X/3X/4X FM Transmitter/AM/FM/SW/LW/WB receiver programming guide
Related Documents-FM Transmitter

♦ AN305:Si471x FM transmitter programming guide
♦ AN306:Si4710/11 short monopole antenna interface
♦ AN307:Si4712/13/20/21 receive power scan
♦ AN308:Si4710/11 FM transmitter evaluation board test procedure
♦ AN309:Si4710/11 evaluation board quick-start guide
♦ AN319:Si472x FM transceiver programming guide
FM Embedded Antenna
Agenda

1. Device Overview
2. Integrated Antenna Overview
3. Embedded Antenna Implementations
4. Debugging Tips
5. Design Guidelines
6. Common Q&A
# Device Overview

<table>
<thead>
<tr>
<th>Part Number</th>
<th>General Description</th>
<th>FM Transmitter</th>
<th>FM Receiver</th>
<th>AM Receiver</th>
<th>SW/LW Receiver</th>
<th>WB Receiver</th>
<th>RDS</th>
<th>RPS</th>
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<tbody>
<tr>
<td>Si4704</td>
<td>FM Receiver</td>
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<td>Si4737</td>
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<td>Si4738</td>
<td>FM / WB Receiver</td>
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<td>Si4739</td>
<td>FM / WB Receiver w/ RDS</td>
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<td>Si4749</td>
<td>RDS Only Receiver</td>
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</tr>
</tbody>
</table>

= supports embedded antenna
Si47xx Enables BT+FM Vision = FM without wires

- Si47xx patented technology enables BT+FM wireless vision
  - Headphone cable antenna is *optional* for FM reception
  - Use FM Headphone or integrated antenna
  - FM over Bluetooth headset
  - FM over speaker phone (wake up to FM)
FM Antenna Overview

- There are numerous options for the embedded antenna
- Antennas are traditionally optimized using fixed resonance
- Silabs uses patented tunable resonance circuit

Example of embedded foil antenna

Typical headphone ¼ wave length FM antenna

24x5x1.2mm³ Chip Antenna

6 - 10cm PCB trace antenna or wire
Embedded TX/RX Antenna: Design Goals

♦ Receiver:
  - The design goal is to maximize the voltage received at the LNA input for best sensitivity.

♦ Transmitter:
  - The design goal is to maximize the voltage at the antenna for maximum radiated power.

♦ One antenna design can achieve both goals.
Ideal parallel LC circuit has an infinite impedance

However the component Q will limit this impedance

Q of capacitor ~ 50

Q of inductor ~30

The equivalent impedance is 1.4k ohm
RX Antenna: Advantage of the Resonant Match

- Embedded antenna has a high characteristic impedance.
- Any parasitic capacitance at the LNA input reduce the effective antenna impedance and reduce the voltage at LNA.
- The resonant circuit topology alleviates this problem by adjusting the overall system capacitance at the desired frequency ensuring the impedance at will be high.
**TX Antenna: Advantage of the Resonant Match**

![Diagram showing embedded antenna without and with resonant circuit](image)

- Similar to embedded antenna for FM Receive, for the same amount of output current, an FM transmitter with a resonant circuit will produce a much larger output voltage.
Fixed Antenna Resonance

Resonance with $Q = 5$

Loss at band edges

10 dB Gain at band center

18 dB Gain at band center

6 dB Gain at band center

Difference between gain at center of band and edge of band is 20 dB
To overcome the bandwidth limitations with a high Q, fixed resonance, the Si4704/05/20/21 incorporates a tunable resonance circuit.

At each tuned frequency, the device tunes the resonance circuit for the best performance.

Tuning the resonance with frequency provides increased selectivity and maximizes received signal strength across the entire FM band.

Tunable resonance is patented and unique to the Si4704/05/20/21 devices.
Tunable Resonance Benefits

Voltage gain achieved from tuning resonance at station #1 (Approximately 15dB)

Retuning resonance boosts gain for station #2

12dB lower gain at station #2 unless resonance retuned

Tunable resonance required to position response optimally for other stations
Antenna Open Circuit Voltage
Antenna Capacitance (or inductance)
Antenna Resistance
Matching Inductor and Resistance
On-chip Varactor
LNA Bias Resistance
LNA
10 cm antenna (red), 100 cm antenna (yellow)
SNR delta is ~1dB
SNR dominated by environmental noise
Received signal strength delta is less than 20dB
SNR – Weak Signal / Weak Noise

- 10 cm antenna (red), 100 cm antenna (yellow)
- SNR delta is ~1dB
- SNR is dominated by circuit noise (10cm)
- SNR is dominated by environmental noise (100cm)
- Received signal strength delta is less than 20dB
Antenna Implementation

- The embedded antenna for FM Transmit and Receive is the same and follow the same guidelines:
  - Keep the antenna as far away from ground plane as possible
  - Keep parasitic capacitance low at the TXO/LPI pin
  - Choose high-Q tuning inductor component
  - For stub antenna, make it as long as possible
  - For loop antenna, make it as large as possible

- Implementation and Design Guidelines
  - 4 Types of embedded antenna for the Si4704/05/1x/2x
    - Stub - Wire implementation
    - Stub - PCB trace implementation
    - Loop – Wire implementation
    - Loop – PCB trace implementation

- Antenna Comparison
Stub Antenna

- Typically a floating wire 10cm or longer and embedded inside the device

- The material for an embedded stub antenna can be an actual wire, PCB trace, or a flexible PCB trace

- Characteristic impedance: capacitive (typically 1~3pF)

- Tuning component: shunt inductor
- Route the antenna as a “U” shape as shown above
  - A > 5mm
  - B + C + D > 10cm
  - C > 3cm
- Route the antenna as an “L” by removing segment D if a “U” is not possible.
- Maximize antenna length (B+C+D >10cm) to provide sufficient radiating power for transmit and maximize voltage for receive.
- Keep the antenna as far from the ground plane and shield as possible (A > 5mm), and make the enclosure from non-conductive material (plastic), to minimize parasitic capacitance and maximize radiation for transmit or maximize voltage for receive.
♦ Route the antenna as a “U” shape as shown above
  - A > 5mm
  - B + C + D > 10cm
  - C > 3cm
♦ Route the antenna as an “L” by removing segment D if a “U” is not possible.
♦ Maximize antenna length (B+C+D >10cm) to provide sufficient radiating power for transmit and maximize voltage for receive.
♦ Keep the antenna as far from the ground plane and shield as possible (A > 5mm), and make the enclosure from non-conductive material (plastic), to minimize parasitic capacitance and maximize radiation for transmit or maximize voltage for receive.
Example: Stub Antenna in Small Form Factor

A: Wire Isolation from GND Plane
B: Wire Length
C: Wire Length
D: Wire Length

- FM TX/RX
- Antenna

LCD

GND Plane

Keypad

Battery
Loop Antenna – Wire/PCB Trace Implementation

♦ Typically a floating wire constructed with a 13cm or greater and embedded inside the device

♦ The material for an embedded loop antenna can be an actual wire, PCB trace or flexible PCB trace

♦ A loop antenna is similar to a stub antenna with the exception the other end of the antenna is grounded

♦ Characteristic impedance: inductive

♦ Tuning component: shunt inductor, shunt capacitor, or no tuning component at all
Loop Antenna – Wire Implementation

- Route the antenna as shown above
  - A > 5mm
  - B + C + D + E > 13cm
  - C > 3cm
- Maximize antenna length (B+C+D+E >13cm) to provide sufficient radiating power for transmit and maximize voltage for receive.
- Keep the antenna as far from the ground plane and shield as possible (A > 5mm), and make the enclosure from non-conductive material (plastic), to minimize parasitic capacitance and maximize radiation for transmit or maximize voltage for receive.
Loop Antenna – PCB Trace Implementation

♦ Route the antenna as shown above
  - A > 5mm
  - B + C + D + E > 13cm
  - C > 3cm
♦ Maximize antenna length (B+C+D+E >13cm) to provide sufficient radiating power for transmit and maximize voltage for receive.
♦ Keep the antenna as far from the ground plane and shield as possible (A > 5mm), and make the enclosure from non-conductive material (plastic), to minimize parasitic capacitance and maximize radiation for transmit or maximize voltage for receive.
<table>
<thead>
<tr>
<th>Antenna</th>
<th>Description</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stub – Wire Implementation</td>
<td>Wire attached to or molded inside product case</td>
<td>- Placement flexibility</td>
<td>- Mechanical attachment to case required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Minimum PCB space</td>
<td>- Performance can be impacted by case shielding.</td>
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<tr>
<td></td>
<td></td>
<td>- Easy to adjust length during design testing</td>
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</tr>
<tr>
<td>Loop – Wire Implementation</td>
<td>Loop attached to or molded inside product case</td>
<td>- Higher efficiency for same length</td>
<td>- Mechanical attachment to case required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Placement flexibility</td>
<td>- Performance can be impacted by case shielding.</td>
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<tr>
<td></td>
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<td>- Minimum PCB space</td>
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<tr>
<td></td>
<td></td>
<td>- Easy to adjust length during design testing</td>
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</tr>
<tr>
<td>Stub - PCB Trace Implementation</td>
<td>Wire trace fabricated on outer PCB copper layer</td>
<td>- No mechanical attachment to case</td>
<td>- PCB keep out regions required around antenna</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Ease of product assembly</td>
<td>- Additional PCB space</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Ease of product assembly</td>
<td>- Performance can be impacted by case shielding.</td>
</tr>
</tbody>
</table>
Debug: Monitoring Tuning Cap

♦ It is very important to always keep monitoring the tuning cap during the antenna design to make sure that the circuit is always tuned thus it resonates properly (the circuit achieves the highest Q possible)

♦ Tuning Cap Range = 1 to 191
  ➢ Each number represents 0.25pF

♦ Tuning Cap value will go down as frequency goes up

♦ Try to achieve a tuning cap value of 20 (equals to 5pF) at 108MHz
Debug: TX_TUNE_STATUS / FM_TUNE_STATUS

- Tuning cap can be monitored by sending TX_TUNE_STATUS command in FM Transmitter or FM_TUNE_STATUS command in FM Receiver

**TX_TUNE_STATUS**
- Tuning cap value is DATA6 on the returned Response

**FM_TUNE_STATUS**
- Tuning cap value is DATA7 on the returned Response

### Command Arguments
- **Data6**
- **Data7**

### Response
- **Data6**
- **Data7**
Monitor three parameters:

1. RF RSSI
   - Data4 from FM_TUNE_STATUS response
2. RF SNR
   - Data5 from FM_TUNE_STATUS response
3. Audio SNR
   - Connect the audio output to audio analyzer and/or do a listening test
Embedded Antenna Design Guidelines

♦ Schematic
  - Follow the recommendation listed in the AN383
  - VCO spur circuit is optional
  - ESD protection diode circuit is optional
  - Resistors on digital lines are optional

♦ Bill of Materials
  - Follow the recommendation listed in the AN383
  - Select optimal tuning component with high Q

♦ Layout
  - Follow the recommendation listed in the AN383
  - Minimize parasitic capacitance
  - Minimize coupling
Schematic & BOM Guidelines: Top Rules

♦ Select tuning inductor (or capacitor) with a Q>30

♦ Select tuning inductor as large of possible to maximize radiated power and received voltage

♦ Select ESD diode (optional) with minimum capacitance

♦ Resistors (optional) on digital lines to reduce coupling
Layout Guidelines
Layout Guidelines: Top Rules

- Place the antenna as far from the ground plane as possible. End of antenna opposite the device is most critical.
- Place tuning inductor (or capacitor) as far from potential noise sources as possible to reduce coupling.
- Place VDD and VIO bypass capacitor as close as possible for maximum effectiveness.
- Do NOT route digital, analog, and RF traces parallel with one another to minimize coupling.
- Route reference plane between the IC and signal trace to minimize coupling.
Common FM Receive Antenna Q&A

♦ Does a short antenna perform as well as a long headphone antenna?
  - The headphone antenna performs better, however, short antenna performance is very good.
  - Perceived performance with a short antenna and internal speaker is excellent.

♦ Does our short antenna recommendation work as well as a chip antenna?
  - All embedded antennas perform better when resonated with 4704/05/1x/2x on-chip varactor.
  - The resonated short antenna works as well or better than a resonated chip antenna.
  - Unresonated short antenna and unresonated chip antenna performance is similar.

♦ Can I use the same antenna for transmit and receive?
  - A single transmit/receive antenna can be connected to pin4 (TXO/LPI).
  - A separate receive antenna can be connected to pin2 (FMI).
  - An internal switch selects between pin2 and pin4.
Common FM Transmit Antenna Q&A

♦ Does the transmitter meet FCC and ETSI power limits?
  ➢ Handset, PND and mp3 customers have designs that meet or exceed these limits. Antenna design is critical.

♦ Does the transmitter generate any spurious emissions?
  ➢ It’s possible for the VCO (~3.5 GHz) to radiate from the antenna. Refer to AN383 for a filter recommendation if this is an issue.