SKY66407-11: 2.4 GHz Low-Power, Low-Profile Front-End Module for Bluetooth® IoT Applications

Applications
- Wearables
- Trackers
- Beacons
- Sensor networks
- Home automation
- Internet of Things (IoT) devices

Features
- Adjustable gain, output power, and current consumption
- Max BT EDR output power: +11.5 dBm
- Wide supply range: 1.7 to 3.6 V
- High ESD rating: 2 kV
- Low sleep current: < 1 uA
- Low Rx bypass loss
- Small CSP (9-pin, 1.2 x 1.2 x 0.35 mm) package (MSL1, 260 °C per JEDEC-J-STD-020)

Description
The SKY66407-11 is a highly integrated front-end module (FEM) designed for Bluetooth IoT applications operating in the 2.4 to 2.4835 GHz range.

The device is provided in a 1.2 x 1.2 x 0.35 mm 9-pin CSP package. A functional block diagram is shown in Figure 1. Pin assignments are shown in Figure 2. Signal pin assignments and functional pin descriptions are provided in Table 1.
Table 1. SKY66407-11 Signal Descriptions

<table>
<thead>
<tr>
<th>Bump</th>
<th>Name</th>
<th>Description</th>
<th>Bump</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>VCC2</td>
<td>Positive power supply</td>
<td>B3</td>
<td>T/R</td>
<td>Connect to 50 Ω transceiver output</td>
</tr>
<tr>
<td>A2</td>
<td>GND</td>
<td>Ground</td>
<td>C1</td>
<td>ANT</td>
<td>Connect to 50 Ω antenna</td>
</tr>
<tr>
<td>A3</td>
<td>VCC1</td>
<td>Positive power supply</td>
<td>C2</td>
<td>CTX</td>
<td>Tx control signal</td>
</tr>
<tr>
<td>B1</td>
<td>GND</td>
<td>Ground</td>
<td>C3</td>
<td>CRX</td>
<td>RX control signal</td>
</tr>
<tr>
<td>B2</td>
<td>GND</td>
<td>Ground</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Electrical and Mechanical Specifications

The absolute maximum ratings of the SKY66407-11 are provided in Table 2. The recommended operating conditions are specified in Table 3.

Electrical specifications are provided in Tables 4 through 6.

Table 2. SKY66407-11 Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>VCC1, VCC2</td>
<td>0.3</td>
<td>4.0</td>
<td>V</td>
</tr>
<tr>
<td>Control voltages</td>
<td>CTX, CRX</td>
<td>0.3</td>
<td>4.0</td>
<td>V</td>
</tr>
<tr>
<td>Transmit input power at T/R port</td>
<td>P_{IN}, TX</td>
<td>+8</td>
<td>dBm</td>
<td></td>
</tr>
<tr>
<td>Receive input power at ANT port(^2)</td>
<td>P_{IN}, RX</td>
<td>+20</td>
<td>dBm</td>
<td></td>
</tr>
<tr>
<td>Voltage standing wave ratio</td>
<td>VSWR</td>
<td>10:1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating temperature</td>
<td>T_A</td>
<td>-40</td>
<td>+105</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>T_STG</td>
<td>-40</td>
<td>+125</td>
<td>°C</td>
</tr>
<tr>
<td>Electrostatic discharge:</td>
<td>ESD</td>
<td>2000</td>
<td></td>
<td>V</td>
</tr>
</tbody>
</table>

ESD HANDLING: Although this device is designed to be as robust as possible, electrostatic discharge (ESD) can damage this device. This device must be protected at all times from ESD when handling or transporting. Static charges may easily produce potentials of several kilovolts on the human body or equipment, which can discharge without detection. Industry-standard ESD handling precautions should be used at all times.
### Table 3. Recommended Operating Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage V CC1, VCC2</td>
<td>VCC1, VCC2</td>
<td>1.7</td>
<td>3.3</td>
<td>3.6</td>
<td>V</td>
</tr>
<tr>
<td>Control voltages CTX</td>
<td>CTX</td>
<td>1.0</td>
<td>1.8</td>
<td>2.2</td>
<td>V</td>
</tr>
<tr>
<td>Operating temperature TA</td>
<td>TA</td>
<td>-40</td>
<td>+25</td>
<td>+85</td>
<td>°C</td>
</tr>
</tbody>
</table>

### Table 4. SKY66407-11 DC Electrical Specifications

(VCC1 = VCC2 = 3.3 V, CTX = 1.8 V, TA = +25 °C, Characteristic Impedance [Zo] = 50 Ω, Unless Otherwise Noted)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Test Condition</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit operating current I CC_TX</td>
<td>ICC_TX</td>
<td>TX mode (Pf = 0 dBm):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>VCC2 = 1.8 V</td>
<td>13</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VCC2 = 3.3 V</td>
<td>16</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VCC2 = 3.6 V</td>
<td>17</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Transmit quiescent current I CQ_TX</td>
<td>ICG_TX</td>
<td>TX mode</td>
<td>8</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Receive (bypass) current I CC_RX</td>
<td>ICRX</td>
<td>RX mode</td>
<td>4.0</td>
<td></td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>Sleep mode current I CC_OFF</td>
<td>ICC_OFF</td>
<td>Sleep mode</td>
<td>0.1</td>
<td>1</td>
<td></td>
<td>µA</td>
</tr>
</tbody>
</table>

**Logic Characteristics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>V</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control voltage:</td>
<td>VH</td>
<td>1.6</td>
<td></td>
<td>VCC1</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>VL</td>
<td>0</td>
<td></td>
<td>0.3</td>
<td>V</td>
</tr>
<tr>
<td>Tx bias current (CTX pin)</td>
<td>IBIAS_TX</td>
<td>30</td>
<td></td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>Rx control current (CRX pin)</td>
<td>IBIAS_RX</td>
<td>1.0</td>
<td></td>
<td></td>
<td>µA</td>
</tr>
</tbody>
</table>

1 Performance is guaranteed only under the conditions listed in this table.
2 The current will be the same as sleep current if logic high levels are equal to VCC1.
Table 5. SKY66407-11 AC Electrical Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Test Condition</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit Characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency range</td>
<td>f</td>
<td></td>
<td>2400</td>
<td></td>
<td>2483.5</td>
<td>MHz</td>
</tr>
<tr>
<td>Output power</td>
<td>P_OUT</td>
<td>VCC2 = 1.8 V BDR</td>
<td>+9.5</td>
<td></td>
<td></td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VCC2 = 3.3 V BDR</td>
<td>+12</td>
<td></td>
<td></td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VCC2 = 3.6 V BDR</td>
<td>+12.5</td>
<td></td>
<td></td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VCC2 = 3.3 V EDR-3</td>
<td>+10.0</td>
<td></td>
<td></td>
<td>dBm</td>
</tr>
<tr>
<td>Saturated gain&lt;sup&gt;3&lt;/sup&gt;</td>
<td>G_SAT</td>
<td>Pin = 0 dBm</td>
<td>12</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Small signal gain</td>
<td>S21_TX</td>
<td>Pin = -25 dBm</td>
<td>13</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Gain slope</td>
<td>G_SLOPE</td>
<td>Over frequency range</td>
<td>+1</td>
<td></td>
<td></td>
<td>dBp-p</td>
</tr>
<tr>
<td>Input return loss&lt;sup&gt;3&lt;/sup&gt;</td>
<td>S11_TX</td>
<td>T/R port</td>
<td>-10</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Output return loss&lt;sup&gt;3&lt;/sup&gt;</td>
<td>S22_TX</td>
<td>ANT port</td>
<td>-12</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; harmonic&lt;sup&gt;3&lt;/sup&gt;</td>
<td>2fo</td>
<td>POUT = +10 dBm, CW signal source</td>
<td>-40</td>
<td></td>
<td></td>
<td>dB/MHz</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; harmonic&lt;sup&gt;3&lt;/sup&gt;</td>
<td>3fo</td>
<td>POUT = +10 dBm, CW signal source</td>
<td>-30</td>
<td></td>
<td></td>
<td>dB/MHz</td>
</tr>
<tr>
<td>TX turn-on time&lt;sup&gt;3&lt;/sup&gt;</td>
<td>t_ON_TX</td>
<td>50% VCTX to 90% RF</td>
<td>800</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>TX turn-off time&lt;sup&gt;3&lt;/sup&gt;</td>
<td>t_OFF_TX</td>
<td>50% VCtx to 10% RF</td>
<td>200</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>Stability&lt;sup&gt;3&lt;/sup&gt;</td>
<td>STAB</td>
<td>CW, Pin = 0 dBm, 0 GHz to 20 GHz, load VSWR = 6:1</td>
<td>All non-harmonically related outputs &lt; -42 dBm/MHz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruggedness&lt;sup&gt;3&lt;/sup&gt;</td>
<td>RUG</td>
<td>CW, Pin = 0 dBm, load VSWR = 10:1</td>
<td>No permanent damage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receive Characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency range</td>
<td>f</td>
<td></td>
<td>2400</td>
<td></td>
<td>2483.5</td>
<td>MHz</td>
</tr>
<tr>
<td>Insertion loss</td>
<td>S21_RX</td>
<td></td>
<td>-1.0</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Input return loss&lt;sup&gt;3&lt;/sup&gt;</td>
<td>S11_RX</td>
<td>ANT port</td>
<td>-15</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Output return loss&lt;sup&gt;3&lt;/sup&gt;</td>
<td>S22_RX</td>
<td>T/R port</td>
<td>-15</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>RX turn-on time&lt;sup&gt;3&lt;/sup&gt;</td>
<td>t_ON_RX</td>
<td>50% Vctx to 90% RF</td>
<td>800</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>RX turn-off time&lt;sup&gt;3&lt;/sup&gt;</td>
<td>t_OFF_RX</td>
<td>50% Vctx to 10% RF</td>
<td>200</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>

1 Performance is guaranteed only under the conditions listed in this table.
2 Refer to Bluetooth EDR section for higher output power operation.
3 Guaranteed by characterization.

Table 6. SKY66407-11 Mode Logic Truth Table

<table>
<thead>
<tr>
<th>Mode</th>
<th>CTX</th>
<th>CRX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep mode</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Receive (RX) mode</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Transmit (TX) mode</td>
<td>1</td>
<td>X</td>
</tr>
</tbody>
</table>
**CTX Pin Usage**

The SKY66407-11 CTX pin supplies the bias to the internal PA. By varying the voltage at this pin, PA operating parameters including gain, supply current, and efficiency can be adjusted.

The CTX pin can also be used to adjust the SKY66407-11 output power when the RF source (transceiver or baseband) has a fixed level.

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**Figure 3.** $P_{out}$ vs CTX and Pin ($V_{CC} = 3.3$ V)

**Figure 4.** Gain vs $P_{out}$ and CTX ($V_{CC} = 3.3$ V)

**Figure 5.** $I_{CC}$ vs $P_{out}$ and CTX ($V_{CC} = 3.3$ V)

**Figure 6.** Power-Added Efficiency vs $P_{out}$ and CTX ($V_{CC} = 3.3$ V)
In many applications, a variable DC supply voltage may not be available. The desired bias voltage can be generated by connecting CTX to the GPIO controlling CTX with a resistor (refer to Figure 13). With no RF input, the CTX pin draws very little current. Toggling the CTX from the GPIO also causes the PA to turn off when CTX is pulled low, reducing the RX and shutdown mode current.

Table 7 lists the relationship between CTX voltage/current and bias resistance.

<table>
<thead>
<tr>
<th>RBIAS (kΩ)</th>
<th>CTX (V)</th>
<th>ICTX (µA)</th>
<th>ICC (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>2.2</td>
<td>58</td>
<td>12.9</td>
</tr>
<tr>
<td>27</td>
<td>2.1</td>
<td>55</td>
<td>11.5</td>
</tr>
<tr>
<td>32</td>
<td>2</td>
<td>50</td>
<td>10.2</td>
</tr>
<tr>
<td>39</td>
<td>1.9</td>
<td>46</td>
<td>8.9</td>
</tr>
<tr>
<td>47</td>
<td>1.8</td>
<td>40</td>
<td>7.6</td>
</tr>
<tr>
<td>59</td>
<td>1.7</td>
<td>36</td>
<td>6.4</td>
</tr>
<tr>
<td>76</td>
<td>1.6</td>
<td>32</td>
<td>5.2</td>
</tr>
<tr>
<td>99</td>
<td>1.5</td>
<td>28</td>
<td>4.1</td>
</tr>
<tr>
<td>133</td>
<td>1.4</td>
<td>24</td>
<td>3.1</td>
</tr>
<tr>
<td>200</td>
<td>1.3</td>
<td>20</td>
<td>2.1</td>
</tr>
<tr>
<td>310</td>
<td>1.2</td>
<td>16</td>
<td>1.3</td>
</tr>
<tr>
<td>600</td>
<td>1.1</td>
<td>14</td>
<td>0.7</td>
</tr>
</tbody>
</table>
If a fixed CTX voltage (for example, from an LDO) is available in the application circuit, using this instead of a resistor reduces the variation of output power with VCC. To minimize SKY66407-11 current consumption in RX bypass and shutdown modes, the voltage to the CTX pin should be switched off when the CTX is logic low.

**Bluetooth EDR Adjacent Channel Power**

The SKY66407-11 benefits from excellent adjacent channel power (ACP) performance in Bluetooth EDR applications. Typical ACP measurements for both EDR modulations (π/4-DQPSK with 2-DH5 packets and 8-DPSK with 3-DH5 packets) are shown in Figures 8 through 11 (Note: CTX =2.2 V).
Evaluation Board Description

The SKY66407-11 Evaluation Board is used to test the performance of the SKY66407-11 front-end module. The board is optimized for evaluation, experimentation, and investigation with a BLE or 802.15.4 signal source. The design and layout can be quickly and easily transferred into a production design.

A reference design schematic is provided in Figure 12. An Evaluation Board schematic diagram is provided in Figure 13. A photograph of the Evaluation Board is shown in Figure 14. The Evaluation Board Bill of Materials (BOM) is listed in Table 8.

Evaluation Board Setup Procedure

1. Connect system ground to pin 1 of the J3 header.
2. Apply 3.3 V to pin 2 of the J3 header.
3. Select a path according to the information in Table 6 (L = 0 V, H = 3.3 V) using pin 6 (VCTX) and pin 10 (VCRX) of the J3 header.

Figure 12. SKY66407-11 Reference Design Schematic

Figure 13. SKY66407-11 Evaluation Board Schematic
Figure 14. SKY66407-11 Evaluation Board

Table 8. SKY66407-11 Evaluation Board Bill of Materials (BOM)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Value</th>
<th>Manufacturer</th>
<th>Mfr Part Number</th>
<th>Package</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C2, R3, C4, C5</td>
<td>DNI</td>
<td></td>
<td></td>
<td>0402</td>
<td>DNI</td>
</tr>
<tr>
<td>C3</td>
<td>4.7uF</td>
<td>muRata</td>
<td>GRM21BR71C475KA73L</td>
<td>0805</td>
<td>Ceramic capacitor, 4.7 uF, 16 V, X7R</td>
</tr>
<tr>
<td>J1, J2</td>
<td>SMA</td>
<td>Johnson Components</td>
<td>142-0701-851</td>
<td>End Launch</td>
<td>Connector SMA jack, STR, 50 Ω, edge mount</td>
</tr>
<tr>
<td>J3</td>
<td>Header 6X2 PTH 100</td>
<td>Samtec</td>
<td>TSW-106-07-G-D</td>
<td></td>
<td>Connector header, 12 POS, 100&quot; DL gold</td>
</tr>
<tr>
<td>L1</td>
<td>0 Ω</td>
<td></td>
<td></td>
<td>0402</td>
<td></td>
</tr>
<tr>
<td>PCB1</td>
<td>Z1257-A</td>
<td>Skyworks</td>
<td>Z1257-A</td>
<td></td>
<td>PCB</td>
</tr>
<tr>
<td>R1</td>
<td>1 kΩ</td>
<td>Panasonic</td>
<td>ERJ-PA2F1001X</td>
<td>0402</td>
<td>Resistor, SMD, 1 kΩ, 1%, 1/5 W</td>
</tr>
<tr>
<td>R2</td>
<td>47 kΩ</td>
<td>Multi-vendor</td>
<td>5424R27-134</td>
<td>0402</td>
<td>Resistor, 47 kΩ, jumper, 0.063 W</td>
</tr>
<tr>
<td>U1</td>
<td>SKY66407-11 CSP</td>
<td>Skyworks Solutions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Package Dimensions

The PCB layout footprint for the SKY66407-11 is provided in Figure 15. The typical part marking is shown in Figure 16. Package dimensions are shown in Figure 17, and tape and reel dimensions are provided in Figure 18.

Package and Handling Information

Instructions on the shipping container label regarding exposure to moisture after the container seal is broken must be followed. Otherwise, problems related to moisture absorption may occur when the part is subjected to high temperature during solder assembly.

The SKY66407-11 is rated to Moisture Sensitivity Level 1 (MSL1) at 260 °C. It can be used for lead or lead-free soldering. Care must be taken when attaching this product, whether it is done manually or in a production solder reflow environment. Production quantities of this product are shipped in a standard tape and reel format.
Figure 16. Typical Part Marking

Figure 17. SKY66407-11 Package Dimensions

NOTES:
1. DIMENSIONS ARE IN MILLIMETERS.
2. TOLERANCING (UNLESS OTHERWISE SPECIFIED).
   DECIMAL TOLERANCE: ± 1/2'
   ANGULAR TOLERANCE:
   X.X (1 PLC) ± 0.1mm
   X.X (2 PLC) ± 0.05mm
   X.XXX (3 PLC) ± 0.025mm
3. UNLESS SPECIFIED DIMENSIONS ARE SYMMETRICAL
   ABOUT CENTER LINES.

BUMP SIDE DOWN

BUMP SIDE UP
Figure 18. SKY66407-11 Tape and Reel Dimensions

All dimensions are in millimeters.
## Ordering Information

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Product Description</th>
<th>Evaluation Board Part Number</th>
</tr>
</thead>
<tbody>
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<td>SKY66407-11</td>
<td>2.4 GHz Low-Power, Low-Profile FEM for Bluetooth IoT Applications</td>
<td>SKY66407-11EK1</td>
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