ABSTRACT
This application report describes how to get 10 dBm @2.4 GHz using less than 23 mA @ 3.0 V and using the SimpleLink™ CC1352P Wireless MCU. The hardware and software implementations to achieve this performance are described.

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1 Introduction

The SimpleLink CC1352P device is a multiprotocol, multiband Sub-1 and 2.4-GHz wireless MCU supporting Wireless M-Bus, IEEE 802.15.4g, IPv6-enabled smart objects (6LoWPAN), Thread, Zigbee®, KNX RF, Wi-SUN®, Bluetooth® Low Energy, and proprietary systems. The device contains an integrated high-power amplifier (PA) with best-in-class efficiency for long-range applications delivering up to 20 dBm.

In case of coin cell battery operated devices, having an optimized design compatible for coin-cell is important. The PA has separate RF pins that make it possible to use optimized matching for the high-power PA without impacting the other RF interfaces.

This document outlines an optimized match for the high-power amplifier to get +10 dBm from this path @2.4 GHz with a current draw less than 20 mA.

2 Matching circuit

The match contains a balun and filter. The combination of the balun and filter also transforms the impedance. From the impedance, the PA wants to see a 50 Ω interface. To output +20 dBm, the balun has to be biased with VDDS to allow a large enough voltage swing. For a +10 dBm solution, the balun is biased from VDDR. This gives lower max output power since the voltage swing is lower, but is sufficient for +10 dBm VDDR. Using the DCDC to generate this voltage gives a low current consumption for high values of VDDS due to the high efficiency in the DCDC.

A load pull was done and the optimal load impedance was found when the balun is biased with VDDR and the output is 10 dBm. The optimal load impedance is different for a +20 dBm and a +10 dBm solution due to the change in biasing, therefore, the matching components are also different. The resulting component values can be found in the reference design.

The schematic is shown in Section A.1.

The layout is based on the LAUNCHXL-CC1352P-2 design files. The top layer is equal to the top layer in LAUNCHXL-CC1352P-2 from the RF pins to the 50 Ω point. The difference in the layout is that VDDR is routed to the balun instead on VDDS. Section A.2 is a zoomed in version of the layout showing how VDDR is routed to the high power PA.

3 System Considerations

This application report describes how to use the high-power PA to get +10 dBm output power with the low current consumption (TX only). The output from the high-power PA has to be combined with 2.4 GHz RF interface if a system is wanted that can do TX and RX, not just TX. An RF switch can be used to combine the RF paths. For more information, see the LAUNCHXL-CC1352P1 Design Files.

According to EN300, 328 max output power is 10 dBm e.i.r.p. without duty cycle limitations.

When selecting an output power setting, the max output power and the loss in switch has to be taken into consideration.

An example: Given an antenna gain of 3 dB and the loss in the switch is 1 dB, the max conducted output power will be 8 dBm to give 10 dBm e.i.r.p.

4 Results

Measured on the design presented in Appendix A with Tc= 25, VDDS = 3.0 V, DCDC enabled, fRF = 2440 MHz, unless otherwise noted. All measurements are done at +10 dBm 2.4 GHz SMA connector (J3). The measurements are done on a pre-RTM version of the chip and a total of 6 EMS are measured. The PA table may change some in the final version of the chip. This application report will be updated with the numbers for the RTM version when this is available.

The numbers are measured by setting up the chip in continuous TX. In an application, the average current consumption is lower since the PA is only used a fraction of the total time.
### Table 1. Output Power and Harmonics

<table>
<thead>
<tr>
<th>Override</th>
<th>Output Power [dBm]</th>
<th>2. Harmonic</th>
<th>3. Harmonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x226F31</td>
<td>9.9</td>
<td>-52.7</td>
<td>-51.4</td>
</tr>
<tr>
<td>0x145B32</td>
<td>8.9</td>
<td>-52.7</td>
<td>-51.5</td>
</tr>
<tr>
<td>0x144F2D</td>
<td>8.1</td>
<td>-52.5</td>
<td>-51.6</td>
</tr>
<tr>
<td>0x144728</td>
<td>7.1</td>
<td>-52.7</td>
<td>-51.6</td>
</tr>
<tr>
<td>0x144324</td>
<td>6.1</td>
<td>-52.6</td>
<td>-51.6</td>
</tr>
</tbody>
</table>

### Table 2. Output Power Over Temperature

<table>
<thead>
<tr>
<th>Override</th>
<th>Output Power @ -40 °C [dBm]</th>
<th>Output Power @ 25 °C [dBm]</th>
<th>Output Power @ 85 °C [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x226F31</td>
<td>9.8</td>
<td>9.9</td>
<td>9.9</td>
</tr>
<tr>
<td>0x145B32</td>
<td>8.9</td>
<td>8.9</td>
<td>8.8</td>
</tr>
<tr>
<td>0x144F2D</td>
<td>8.2</td>
<td>8.1</td>
<td>8.0</td>
</tr>
<tr>
<td>0x144728</td>
<td>7.3</td>
<td>7.1</td>
<td>7.0</td>
</tr>
<tr>
<td>0x144324</td>
<td>6.1</td>
<td>6.1</td>
<td>6.1</td>
</tr>
</tbody>
</table>

### Table 3. Current Consumption

<table>
<thead>
<tr>
<th>Override</th>
<th>Current Consumption @VDSS = 3.0 V [mA]</th>
<th>Current Consumption @VDSS = 3.6 V [mA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x226F31</td>
<td>23.3</td>
<td>19.1</td>
</tr>
<tr>
<td>0x145B32</td>
<td>21.1</td>
<td>17.8</td>
</tr>
<tr>
<td>0x144F2D</td>
<td>19.8</td>
<td>16.9</td>
</tr>
<tr>
<td>0x144728</td>
<td>18.6</td>
<td>16.0</td>
</tr>
<tr>
<td>0x144324</td>
<td>17.7</td>
<td>15.2</td>
</tr>
</tbody>
</table>

### 5 Settings

The following is valid for SmartRF™ Studio 2.11 or later.

The power table exported by SmartRF Studio should be changed to the following:

```c
RF_TxPowerTable_Entry txPowerTable[TX_POWER_TABLE_SIZE] =
{
    {5, RF_TxPowerTable_HIGH_PA_ENTRY(32, 0, 1, 31, 14) },
    {6, RF_TxPowerTable_HIGH_PA_ENTRY(36, 0, 1, 33, 14) },
    {7, RF_TxPowerTable_HIGH_PA_ENTRY(40, 0, 1, 35, 14) },
    {8, RF_TxPowerTable_HIGH_PA_ENTRY(45, 0, 1, 39, 14) },
    {9, RF_TxPowerTable_HIGH_PA_ENTRY(50, 0, 1, 45, 14) },
    {10, RF_TxPowerTable_HIGH_PA_ENTRY(49, 0, 1, 55, 22) },
    RF_TxPowerTable_TERMINATION_ENTRY
};
```
For applications that do not use this table, the output power is set in the following struct:

```c
// Overrides for CMD_PROP_RADIO_DIV_SETUP_PA
uint32_t pOverridesTx20[] = {
    TX20_POWER_OVERRIDE(override),
    // The TX Power element should always be the first in the list
    // The ANADIV radio parameter based on the LO divider (0) and front-end (0) settings
    (uint32_t)0x11C10703,
    // override_phy_tx_pa_ramp_genfsk_hpa.xml
    // Tx: Configure PA ramping, set wait time before turning off (0x2F ticks of 16/24 us = 31.3 us).
    HW_REG_OVERRIDE(0x6028,0x002F),
    (uint32_t)0xFFFFFFFF,
};
```

Where the value of override can be taken from *Table 1* according to the output power wanted.

6 Regulations

To be able to pass regulatory band edge requirements, an output power back-off may be required for the lowest and highest channel.

More details and final measurement results will be added when measuring on the final chip revision.

7 References

LAUNCHXL-CC1352P-2 Design Files
A.1 Schematic

Figure 1 shows the schematic for the board used for testing. Only the 10 dBm 2.4 Ghz path has been tested.

Figure 1. CC1352PEM-XD7793-XD24-PA24_10dBm Schematic
A.2 Layout

The two plots below show the layout. Figure 2 shows the layout of the full board used for testing. Figure 3 shows a zoomed in version showing the VDDR traces.

Figure 2. CC1352PEM-XD7793-XD24-PA24_10dBm Layout, Full
Figure 3. CC1352PEM-XD7793-XD24-PA24_10dBm Layout, Zoomed
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