Application Report
SWRA527–December 2016

CC1310 Skyworks PA Chinese AMR Reference Design Rev 2.x

Albin Zhang and Richard Wallace

ABSTRACT

Automatic Meter Reading (AMR) is to collect the information of the amount of water, electric or gas consumed automatically that has been used from each household. When the AMR information has been received then the exact energy amount can be charged from the energy supplier company. Traditionally, this has been done by manual reading of meters but with wireless technology this can now be done automatically. Several countries now have laws requiring energy companies to charge for the exact amount of energy being consumed and not just a predicted energy bill. Each country has specific regulatory requirements for AMR.

This application report is targeting the Chinese AMR market (470 MHz to 510 MHz) with CC1310 [2]. To enhance the wireless operation range in China, TI provides the range extender reference design. The initial design was based upon a discrete PA solution [7]. To simplify the RF front design, TI worked with Skyworks Solutions to integrate the CC1310 wireless MCU with a compact, cost-effective front-end module (FEM). The CC1310 wireless MCU, together with SKY66115-11 [4] addresses customers' needs for easy-to-use, long-range, low-power and low-cost solutions serving applications across the Internet of Things (IoT). The reference design covered in this application report can support up to +20 dBm TX power with high power efficiency.

Contents

List of Figures

List of Tables

Trademarks

SmartRF is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

1 Introduction

The Chinese AMR market has been allocated a frequency range of 470 MHz to 510 MHz. The maximum radiated output from the metering unit is not to exceed 17 dBm effective radiated power (ERP). The majority of meters are quite compact and require a compact antenna. The antenna efficiency is normally quite low due to the physical size so higher output power is desired to compensate for the antenna losses. The design covered in this application reort is based on the CC1310 from the CC13xx family.

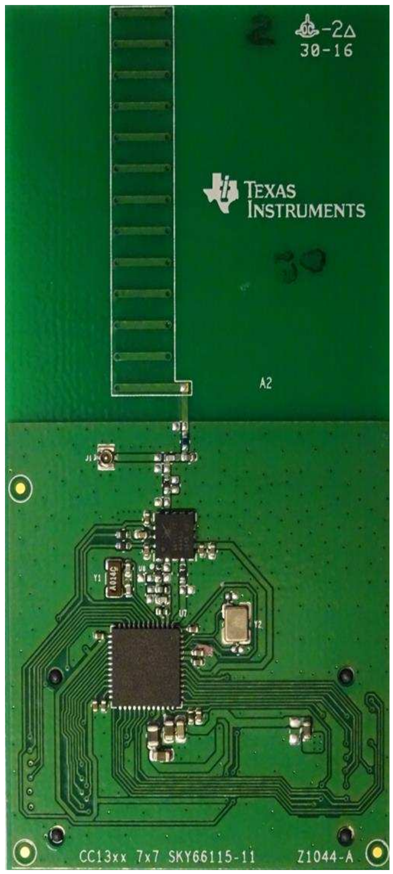


Figure 1. CC1310EM-SKY66115-4051 Board

2 Design

When designing an AMR system, the maximum range between the transmitter and receiver is one of the most important parameters that will dominate the system configuration and installation. In the AMR system, the range is critical so that all households' meters can be read otherwise this must be done manually or adding more concentrators, which is expensive. To achieve a long range the output power can be increased to the maximum limit specified by the regulations and the data rate reduced as much as possible for the application.

The AMR system must be able to work in a noisy RF environment since the number of meters in industrial complexes or high rise buildings can be positioned very close to each other so blocking and selectivity are critical requirements. More information on achieving optimum radio distance and blocking/selectivity is available in a device-specific application report [1].

2.1 CC1310

The CC1310 has been specifically designed for long range, city-wide low power networks. This is used in home automation, building automation and outdoor wide-area networks. The main advantages of CC1310 are high sensitivity (-124 dBm with a 0.625 kbps data rate), strong co-existence (up to 80 dB blocking), lowest power consumption (61 µA / MHz ARM Cortex M3).

CC1310 can be basically split into four low-power sections as shown in Figure 2:

- Main CPU with Cortex M3
- RF Core with radio controller. The RF core is a highly flexible and capable radio system that interfaces the analog RF and base-band circuitries, handles data to and from the system side, and assembles the information bits in a given packet structure.
- General Peripherals
- Sensor Controller

For more in-depth information on the CC1310, see the *CC1310 SimpleLink™ Ultra-Low-Power Sub-1 GHz Wireless MCU Data Sheet* (SWRS181).

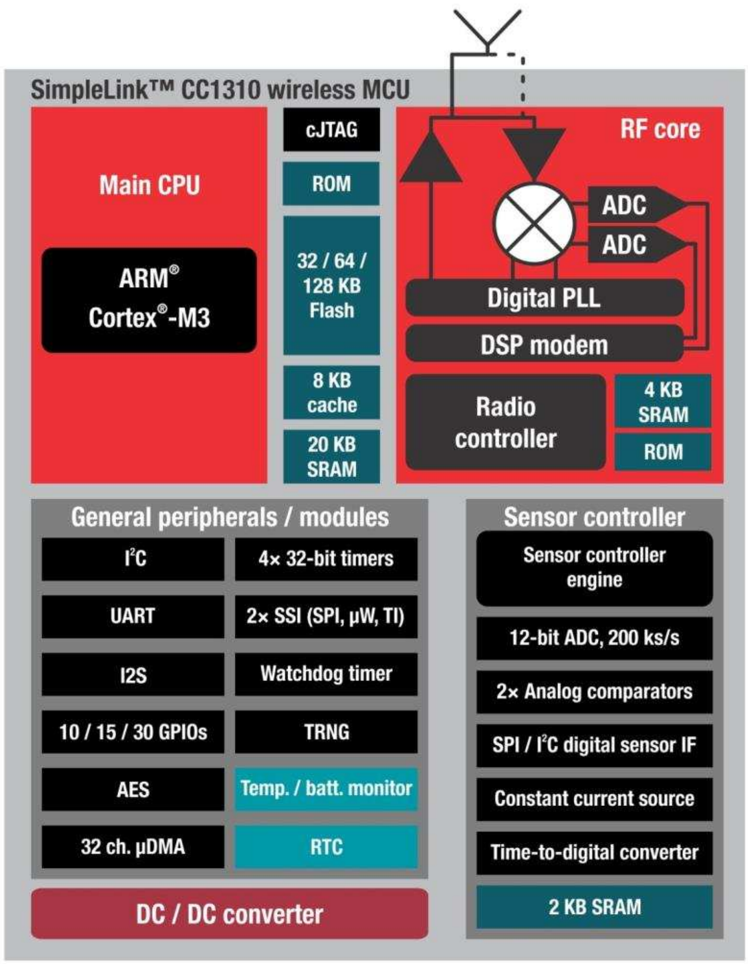


Figure 2. CC1310 Block Diagram

2.2 Schematic

The RF core of CC1310 is highly configurable and the radio front-end can be set to differential or single ended. With a differential output configuration, the maximum output is 14 dBm. With a single ended output, the maximum output is 11 dBm. Since many AMR customers have requested an output power up to 20dBm, the CC1310 transmitter was configured as a single ended port (RF_P set to Tx) connected to an external FEM with an integrated amplifier, see Figure 3. If an output power of 14 dBm is sufficient then the standard reference design for 420 MHz to 510 MHz can be used [8].

The schematic shown in Figure 3 is a general schematic (Rev 2.0.x) to cover the ISM frequency bands from 400 MHz to 510 MHz; the BOM is specified for three different ISM frequency bands:

- 470 MHz – 510 MHz: BOM - CC1310EM-SKY66115-4051 Rev 2.0.1
- 420 MHz – 440 MHz: BOM - CC1310EM-SKY66115-4051 Rev 2.0.2
- 400 MHz – 420 MHz: BOM - CC1310EM-SKY66115-4051 Rev 2.0.3

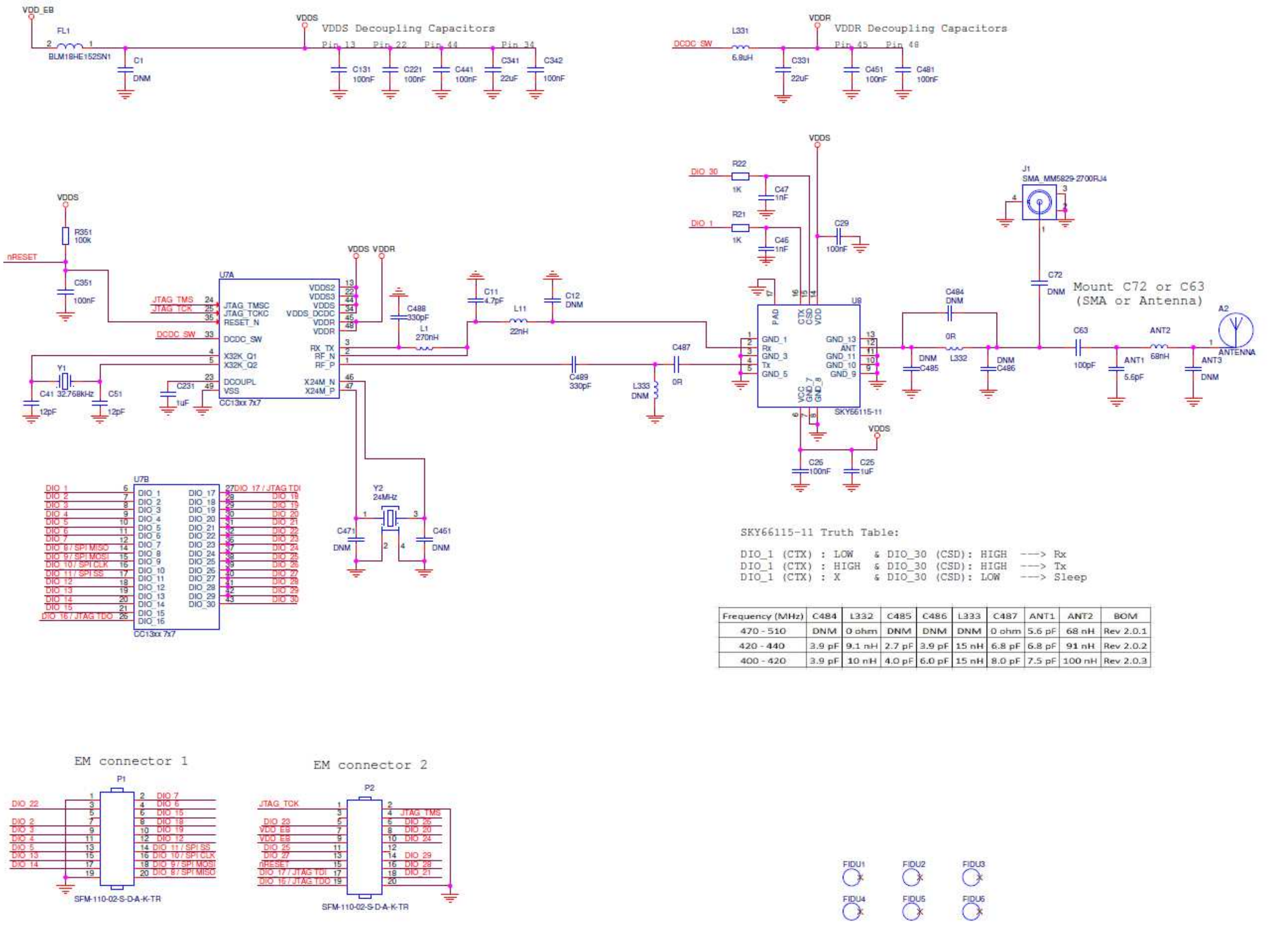
The FEM used is from Skyworks (SKY66115-11). The SKY66115-11 consists of an amplifier and a switch contained in the package. It also includes a shutdown mode to minimize power consumption. The transmit path contains an amplifier optimized for saturated performance. SKY66115-11 is specifically matched for CC1310 which enables optimum transmit output power and efficiency for 50 Ω load impedance. The transmit path passes through a low-pass filter before being entering to one side of the SPDT switch. The receive path has a bypass function from the other side of the SPDT switch.

The reference design [3] shown in Figure 3 is based upon 3.3 V supply voltage. Two RF output options are available. Mounting C72, the RF path is routed to the RF connector (J1) that allows an external antenna or conductive RF testing. Mounting C63, connects the compact PCB antenna. ANT1, ANT2 and ANT3 compose of the antenna matching circuit.

An optional low-pass filter (LPF) (C484, C485, C486 and L332) can be incorporated on the ANT port to provide additional rejection of PA output harmonic levels and/or limit unwanted signals from entering the receive path. For 470 MHz – 510 MHz band, there is no external LPF circuit needed. Since the FEM is specifically designed for the CC1310 470 MHz – 510 MHz band, there is no matching circuit needed on the TX inputs of the SKY66115-11. C487, C489 and L333 are only required for 433 MHz and 408 MHz.

CC1310 can support a several RF port options, which is described in the wiki page [9]. For better Rx sensitivity, the reference design adopts a single-end, external-bias RF front-end design. L1 is used for the external bias circuit. C11, L11 and L12 compose a matching circuit to optimize the RX sensitivity.

The reference design [3] utilizes noise decoupling filtering on the power and control lines of the SKY66115-11.



Frequency (MHz)	C484	L332	C485	C486	L333	C487	ANT1	ANT2	BOM
470 - 510	DNM	0 ohm	DNM	DNM	DNM	0 ohm	5.6 pF	68 nH	Rev 2.0.1
420 - 440	3.9 pF	9.1 nH	2.7 pF	3.9 pF	15 nH	6.8 pF	6.8 pF	91 nH	Rev 2.0.2
400 - 420	3.9 pF	10 nH	4.0 pF	6.0 pF	15 nH	8.0 pF	7.5 pF	100 nH	Rev 2.0.3

Figure 3. Schematic - CC1310EM-SKY66115-4051 Rev2_0_x

2.3 Layout

The design [3] is based upon a 0.8 mm thick, two-layer PCB. The top layer and bottom layer are shown in Figure 4. All components are positioned on the top layer apart from the evaluation module (EM) connectors. The CC1310EM-SKY66115-4051 is based upon the 7x7 QFN package. The RF frond-end design can be re-used for 5x5 QFN and 4x4 QFN packages.

A PCB helical antenna is incorporated in the EM design. The antenna is routed on both the top and bottom layers. It is important to incorporate the matching components (ANT1, ANT2 and ANT3) as well if the antenna structure is to be copied to another design. Changing the PCB thickness will change the resonance of the antenna and this would require new antenna matching values for ANT1 and ANT2 (ANT3: DNM).

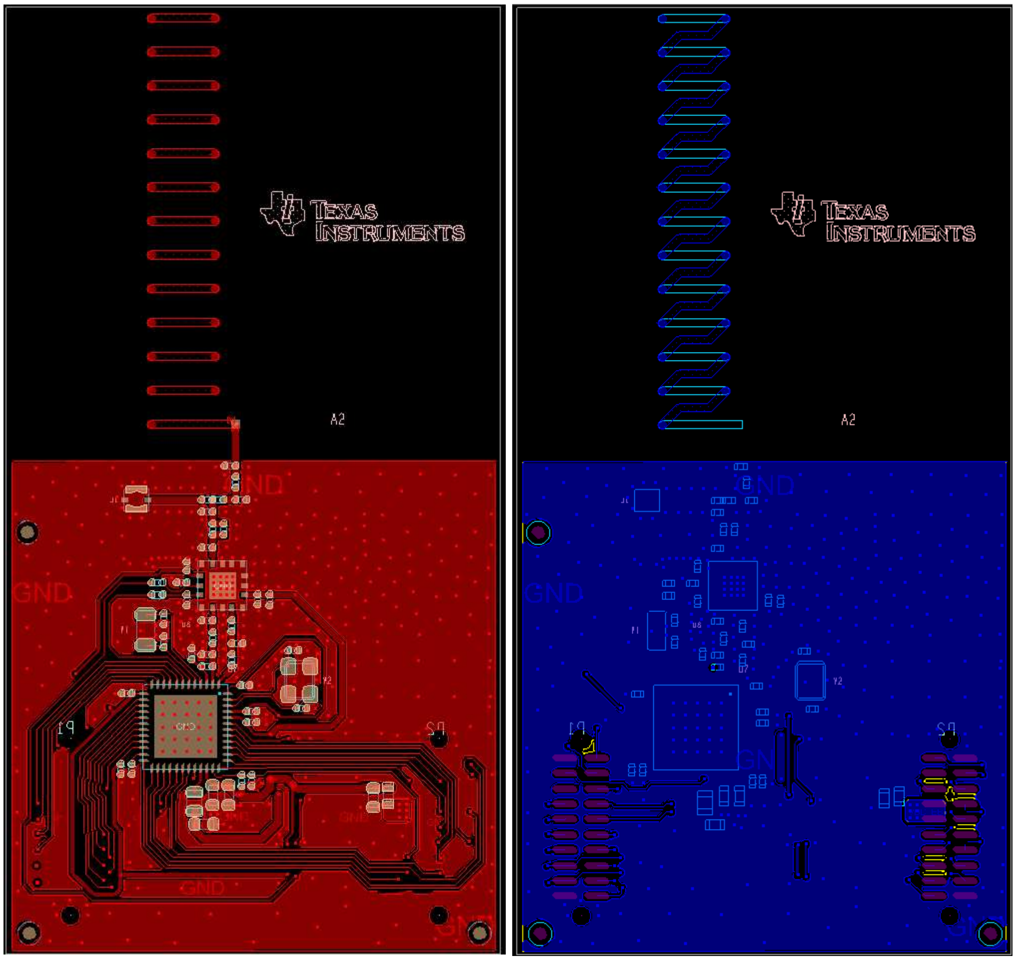


Figure 4. CC1310EM-SKY66115-4051 Layout

The top view is shown on the left side; the bottom view is shown on the right side.

2.4 SmartRF™ Studio

To evaluate the reference design it is recommended to use the EM on the SmartRF06EB with SmartRF Studio software. The supported functions are continuously being updated and the software can be downloaded [6].

With SmartRF studio 7 (version 2.4.3), new features have been added to support 433 MHz – 510 MHz reference designs.

- Default recommended setting on 430-510MHz band.
- DIOs configuration based on the truth table of the FEM.
- RF front-end mode configuration.

For more information on SmartRF Studio7, see http://www.ti.com/tool/smartrftm-studio. Figure 5, Figure 6 and Figure 7 illustrate how to configure the CC1310EM-SKY66115-4051 board.

2.4.1 DIO Configuration

Based on the truth table of the SKY66115-11 shown in Table 1, SmartRF Studio should have the DIO configured as shown in Figure 5.

Table 1. SKY66115-11 Truth Table

```
DIO_1 (CTX) : LOW & DIO_30 (CSD) : HIGH ----> Rx
DIO_1 (CTX) : HIGH & DIO_30 (CSD) : HIGH ----> Tx
DIO_1 (CTX) : X & DIO_30 (CSD) : LOW ----> Sleep
```

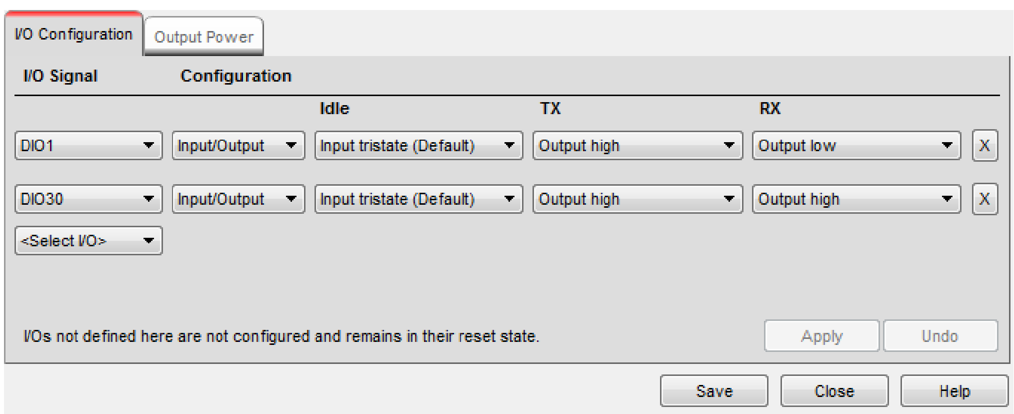


Figure 5. DIO Configuration in SmartRF Studio 7

2.4.2 RF Front-End Configuration

Figure 6 and Figure 7 show the configuration of Tx and Rx modes separately. This is configured in the CMD_PROP_RADIO_DIV_SE radio operation commands.

For the Tx path configuration shown in Figure 6, RF_P is set to single-end option. The txpower parameters should also be configured based on Table 3.

For the Rx path shown in Figure 7, RF_N is set to single-end option.

Figure 6. Tx Mode Configuration

Figure 7. Rx mode configuration

3 Measurement Results

All measurements results were performed on the CC1310EM-SKY66115-4051 at 470 MHz – 510 MHz (BOM Rev 2.0.1) mounted on the SmartRF06EB. The V_{USB} power source is nominally 3.3 V on the SmartRF06EB. Software control is based upon SmartRF Studio 2.4.3.

3.1 Spurious Emission

This design is fully compliant with Chinese Sub-1G SRRC regulation.

The ERP requirements set by the regulation requirements is 17 dBm_max. Note that the EIRP = ERP + 2.15 dB. Therefore, the peak EIRP should not exceed 19.15 dBm.

Tx: the emissions should not exceed -36 dBm for 30 MHz – 1GHz, and -30 dBm for 1 GHz – 12.75 GHz.

Rx: the emissions should not exceed -57 dBm for 30 MHz – 1GHz and -47 dBm for 1 GHz – 12.75 GHz.

The conductive spurious emissions are fully compliant and Figure 8 shows one measurement in the 510MHz-566MHz band. In the Chinese regulation, the specification is -54 dBm for radiated measurements. The conductive test results shows 2.4 dB margin on the spurs in Figure 8 with txpower register 0x18C6. Further margin will be gained when measuring this parameter in radiated mode due to antenna efficiency. The solution passes the SRRC regulation with good margin.

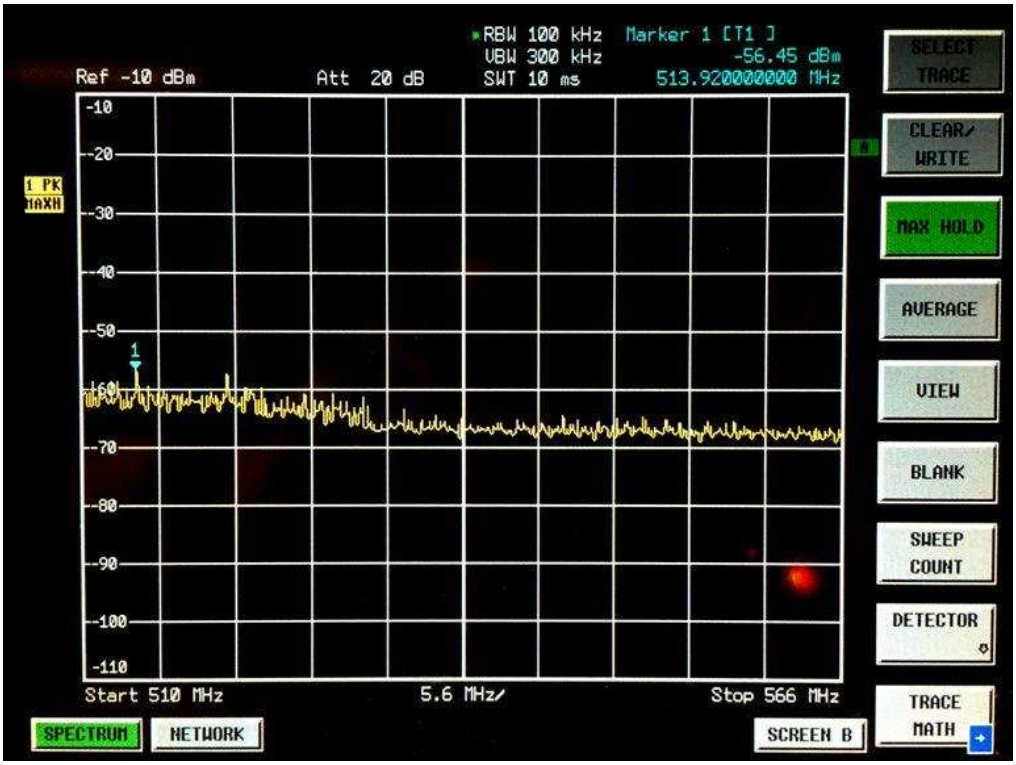


Figure 8. Conductive Spurious Emission on 510 MHz to 566 MHz

3.2 Tx Output Power and Harmonics

The output power was measured at 470 MHz, 490 MHz and 510 MHz. For each frequency, the harmonics were measured up to the 10th harmonic. The txpower register is set to 0x18C6.

Table 2. Conducted Output Power and Harmonics, 3.3 V

fc	2fc	3fc	4fc	5fc	6fc	7fc	8fc	9fc	10fc	
470	940	1410	1880	2350	2820	3290	3760	4230	4700	MHz
19.8	-40	-45	-49	-54	-55	-55	-55	-55	-55	dBm
490	980	1470	1960	2450	2940	3430	3920	4410	4900	MHz
20.1	-38	-47	-50	-55	-55	-55	-55	-55	-55	dBm
510	1020	1530	2040	2550	3060	3570	4080	4590	5100	MHz
19.7	-39	-46	-51	-54	-55	-55	-55	-55	-55	dBm

3.3 Tx Output Power Dynamic Range and Current Consumption

Output power and current consumption were measured across the power table at 470 MHz, 490 MHz and 510 MHz. The average results are shown in Table 3.

In the CMD_PROP_RADIO_DIV_SETUP, the power can be configured in the txpower register, which is shown in Figure 6.

Table 3. TX Output Power, Current Consumption vs. Power Table, 3.3 V

Power Table	0x08C0	0x0041	0x10C3	0x1043	0x14C4	0x18C5	0x18C6	0x1CC7	
Output power	14.9	18	18.9	19.3	19.5	19.7	19.9	19.9	dBm
Current consumption	56.5	68.1	72.6	75	76.6	77.8	78.7	79.4	mA
Solution efficiency	17.4	28.6	33	34.8	35.6	35.9	36.2	36.1	%

The SKY66115-11 maximum input power rating on the PIN_TX is limited to 10dBm. CC1310 should limit the TX Power control IB bit of txpower register below 0x07. For optimized current consumption, the recommended value of the txpower is 0x18C6.

3.4 Rx Current Consumption

The static Rx current consumption was measured at 6.3 mA with 3.3 V power supply.

3.5 Sensitivity

The sensitivity was measured with 50 kbps datarate setting on CC1310EM-SKY66115-4051 at 470 MHz – 510 MHz (BOM Rev 2.0.1) to -107.5 dBm during normal temperature and 3.3 V power supply.

For the differential reference design with external biasing, the sensitivity is approximately -109.5 dBm for a data rate of 50 kbps. This reference design shown in Figure 3 uses single ended configuration of Rx and Tx to avoid the need for another switch component and balun circuit. The sensitivity is reduced by 1 dB with single ended configuration compared to differential configuration. External biasing of the LNA is adopted for better Rx sensitivity. The SKY66115-11 switch has an insertion loss of approx. 0.6 dB. To keep the external BOM costs as low as possible, LQG inductors are used instead of wire-wound (WW) inductors which also causes an additional 0.4 dB of loss.

Therefore, the sensitivity delta of this reference design [3] with single-ended configuration, switch and LQG components compared to the standard reference design [8] with differential configuration is -2.0 dB.

The initial AMR 20 dBm China reference design based upon a discrete PA [7] had a sensitivity of approximately -106.5 dBm. This updated design with the Skyworks FEM has been improved by 1 dB to -107.5 dBm.

If the data rate is reduced from 50 kbps and Long Range Mode utilized, then the following sensitivity levels can be achieved on the on CC1310EM-SKY66115-4051 at 470 NHz – 510 MHz (BOM Rev 2.0.1) Ref Design:

- 5 kbps sensitivity: -117.5 dBm
- 2.5 kbps sensitivity: -119.5 dBm
- 1.25 kbps sensitivity: -120.5 dBm
- 0.625 kbps sensitivity: -121.5 dBm

3.6 Antenna Design

The PCB helical antenna shown in Figure 4 has been matched to 470 MHz – 510 MHz with ANT 1: 5.6 pF and ANT2: 68 nH. For more information, see Figure 9. The antenna is matched for the complete band of 470 MHz – 510 MHz. For more information, see Figure 10. The antenna was tested at 510 MHz in the anechoic chamber and the antenna efficiency is -4.1 dB (38.6 %). For the complete CTIA report summary, see Figure 11.

This antenna design, matching tuning and testing results are based on the CC1310EM-SKY66115-4051 board at 470 MHz – 510 MHz (BOM Rev 2.0.1) plugging on the SmartRF06EB board with the free space environment. In antenna design theory, some of the nearby materials will impact the antenna performances, for example, grounded conductor, plastic/rubber cases, and so forth. For a realistic product antenna design, it is necessary to consider the mechanical case impacts and do proper tuning.

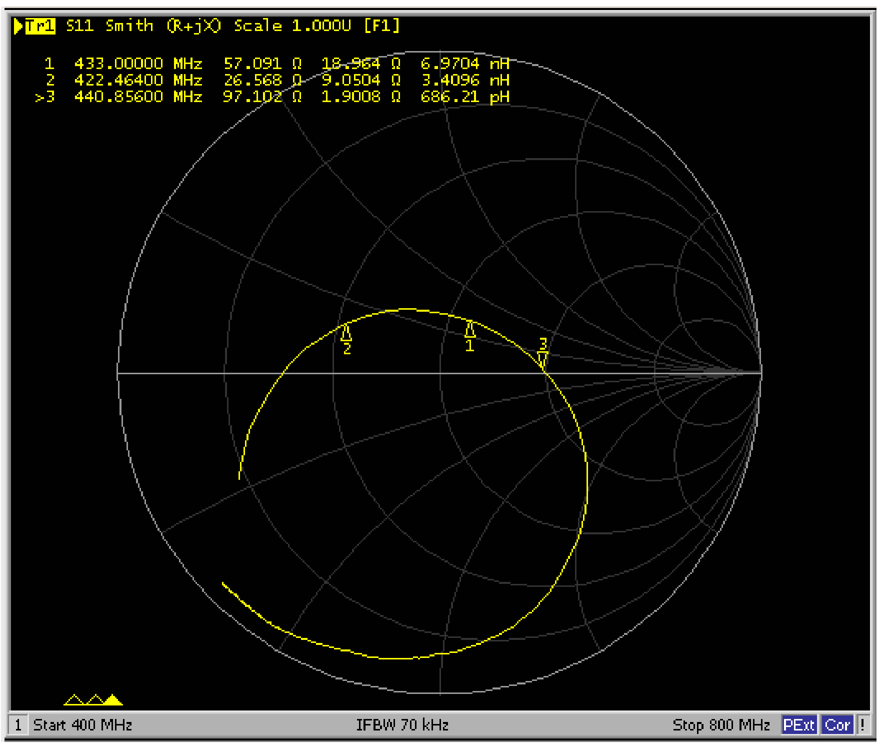


Figure 9. Matching of the Antenna With ANT1 and ANT2 Components

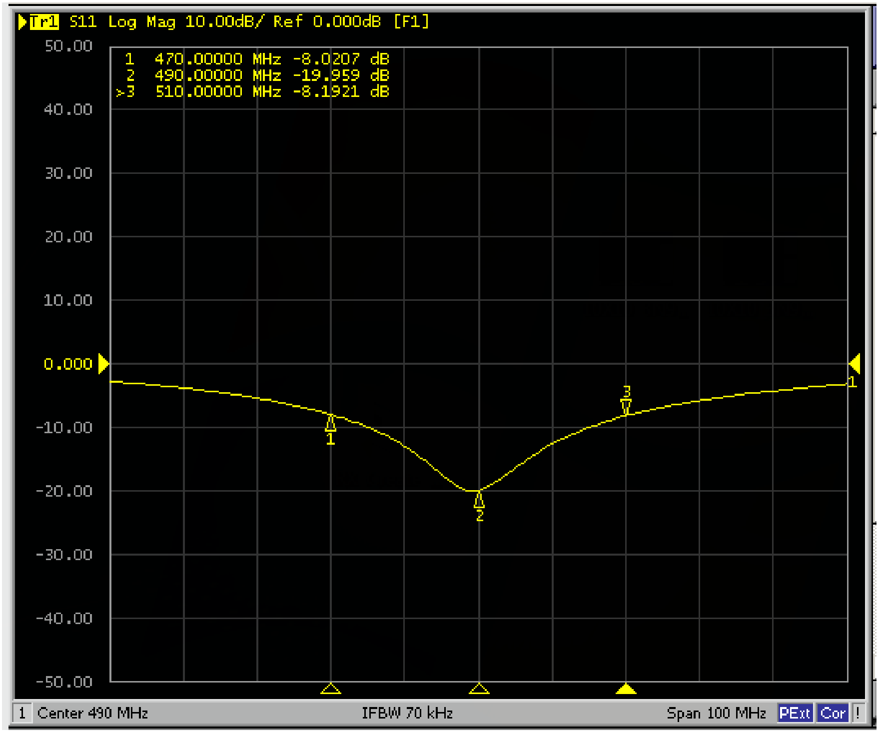


Figure 10. Return Loss With ANT1 and ANT2 Components

OTA Evaluation Results:

Total Radiated Power	-4,14 dBm
Peak EIRP	-1,04 dBm
Directivity	3,09 dBi
Efficiency	-4,14 dB
Efficiency	38,58 %
Peak Gain	-1,04 dBi
NHPRP 45°	-4,86 dBm
NHPRP 45° / TRP	-0,72 dB
NHPRP 45° / TRP	84,63 %
NHPRP 30°	-5,89 dBm
NHPRP 30° / TRP	-1,76 dB
NHPRP 30° / TRP	66,72 %
NHPRP 22.5°	-6,96 dBm
NHPRP 22.5° / TRP	-2,83 dB
NHPRP 22.5° / TRP	52,15 %
UHRP	-7,83 dBm
UHRP / TRP	-3,69 dB
UHRP / TRP	42,76 %
LHRP	-6,56 dBm
LHRP / TRP	-2,42 dB
LHRP / TRP	57,24 %
PGRP (0-120°)	-4,99 dBm
PGRP / TRP	-0,85 dB
PGRP / TRP	82,20 %
Front/Back Ratio	3,53
PhiBW	360,0 deg
PhiBW Up	360,0 deg
PhiBW Down	360,0 deg
ThetaBW	92,6 deg
ThetaBW Up	30,9 deg
ThetaBW Down	61,8 deg
Boresight Phi	285 deg
Boresight Theta	105 deg
Maximum Power	-1,04 dBm
Minimum Power	-25,38 dBm
Average Power	-5,16 dBm
Max/Min Ratio	24,34 dB
Max/Avg Ratio	4,12 dB
Min/Avg Ratio	-20,22 dB
Worst Single Value	-38,05 dBm
Worst Position	Azi = 15 deg; Elev = 165 deg; Pol = Ver
Best Single Value	-1,34 dBm
Best Position	Azi = 195 deg; Elev = 105 deg; Pol = Hor

Figure 11. PCB Helical Antenna Efficiency

4 Summary

AMR products are normally very compact with a small antenna, physically positioned in locations near metal objects and normally hidden in a remote storage area of a building. This causes a reduction in the ERP. The output power can be increased to assure a maximum ERP suited for each application.

The CC1310EM-SKY66115-4051 reference design at 470 MHz – 510 MHz (BOM Rev 2.0.1) is a low cost, easy-to-use, high efficiency solution with 20 dBm output power for 3.3 V supply. Tx current consumption at 20 dBm is approx. 79 mA. The antenna is also integrated into the PCB which provides a compact, costless antenna solution.

The initial AMR 20 dBm China reference design for 470 MHz – 510 MHz was based upon a discrete PA Rev 1.x.x [7]. The updated design with the Skyworks FEM Rev 2.0.1 [3] has improved sensitivity, lower component count and greater margins to Tx spurious emissions.

5 References

1. *Achieving Optimum Radio Range* (SWRA479)
2. *CC1310 SimpleLink™ Ultra-Low-Power Sub-1 GHz Wireless MCU Data Sheet* (SWRS181)
3. *CC1310EM-SKY66115-4051 Reference Design (Rev: 2.0.x)* (SWRC334)
4. SKY66115 -11 Data Sheet
5. *Antenna Quick Guide* (SWRA351)
6. SmartRF Studio Download
7. *CC1310EM-7PA-4751 Reference Design for China* (SWRC311)
8. *SimpleLink CC1310 4-Layer 5x5 Differential 779-930 MHz v1.0.0 Design Files* (SWRC311)
9. CC1310 Front-end Configurations Wiki page