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Operational Description of XYR 6000 FHSS Radio

1. CC2400 Radio Transceiver Description

The CC2400 is a single-chip 2.4 GHz RF transceiver designed for low-power and low-voltage wireless applications. It contains an RF frequency synthesizer, baseband signal processing modem, RF up-converter, down-converter, amplifier in transmit front end and low noise amplifier in receive front end. It is capable of generating 1mW RF power at its output and its stand alone sensitivity is -91dBm. A BALUN network converts differential RF signal to single-ended RF signal, and LC network provides the lead-lag functionality to convert the impedance to a 50Ω real impedance RF output. In transmission mode the RF output is switched to a power amplifier to generate required 40mW(ie.,16dBm) power to drive the antenna. In reception mode the RF signal from antenna is passed through a LNA which increases the sensitivity of the receiver by 8dBm to -97dBm. The CC2400 core operates at 1.8V and the other IC's and digital I/O operate at 3.3V. Additional signals are provided to allow the MSP430 microcontroller to enable and disable the PA, LNA and various status lines of CC2400.

The RF transceiver is integrated with an on chip base band modem supporting data rates of 10kbps, 250kbps and 1 Mbps. Among the three data rates the optimum data rate decided for FHSS communication is 250kbps.

2. RF Frequency range

The Radio air interface operates in the 2400MHz to 2483.5MHz global ISM band. The frequency synthesizer has step size of 1MHz across the ISM band. The frequencies are tunable within 100 kHz. The frequency characteristics include:

- Center of lowest frequency channel (#0): 2402MHz
- Center of highest frequency channel (#79): 2481MHz
- Lower guard band: 1.5MHz (2400-2401.5MHz)
- Upper guard band: 2MHz (2481.5-2483.5MHz)

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3. Modulation & Data rates

Modulation is Gaussian Frequency Shift Keying (GFSK) modulation provided with BT=0.5 It is software selected by setting the LSB bit in the GRMDM (0x20) register.

- Data Rate: 250kbps.
- Deviation: ± 250 KHz (Programmable through software).
- Data bit mapping: 0 low frequency, 1 high frequency.
- Data coding: NRZ.
- Preamble length: 4 byte

4. Received Signal Strength Indication (RSSI)

The Radio measures the radio link quality as received from other radios. This measurement provides a digital value representing the received signal level. The RSSI / Carrier Sense range is greater than or equal to 80 dB. The RSSI is accurate to within ± 4 dBm as per the datasheet of CC2400. The time required for clear channel assessment is less than 0.1 ms. The data is accessible through one of the registers from CC2400 radio chip. It can be used for measuring the link quality.

5. TX-to-RX and RX-to-TX Transition time

The time required for getting the radio to transmit after the Clear Channel Assement (CCA) decision is made in receive mode is less than 0.2ms. This is the time between the CCA *idle* decision until the preamble begins coming out of the antenna (includes Rx to TX switch time, PA ramp-up time, radio reconfiguration time, and transmit buffer loading time). The total time required to perform CCA and get ready to transmit if channel is idle is less than 0.4 ms. The time required for a Tx to Rx switch is less than 0.4 ms, including the PA ramp down time.

6. BALUN Network

The BALUN network is an LC network which converts the differential complex impedance to real 50Ω single-ended impedance. The inductor placed across the differential output of the CC2400 radio chip cancels out the capacitive reactance from the chip. This is followed by an LC low-pass and high-pass configuration which act as a lead-lag network to convert the impedance to single ended 50Ω. The DC bias from Tx/Rx switch is fed to the CC2400 front end amplifier externally through the balun network with RF blocked from leaking into the DC bias of the chip. The DC bias is coupled with external logic to switch on/off the LNA and PA chip. The logic interface is designed such that the MSP430 can override the CC2400 DC bias control whenever

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it must shutdown the PA or the LNA on the board. If the PA is controlled through DAC, then the PA is not coupled to CC2400 DC bias control. For RF power settings through DAC in transmit mode, it is not synchronized with CC2400 chip. To avoid any loss of initial transmission bits, the PA has to be enabled before the CC2400 radio is put in transmit mode.

7. RF Transmitter spectrum mask

In GFSK mode, the 3dB bandwidth of the transmitted baseband signal is defined by a Gaussian filter's BT factor. BT is 0.5 for data rate of 1Mbps as per the datasheet where B is the 3dB bandwidth of the Gaussian filter and T is the symbol time period. For data rates below 1Mbps, BT factor is higher than 0.5. In GFSK mode, the 3dB bandwidth of the transmitted signal is 500 KHz tuned for ± 250 kHz deviation. The 20dB bandwidth is 1 MHz. BT factor for data rate of 250kbps which is actually used for operation is 2.

8. Transmit Power

The CC2400 radio with external power amplifier is capable of delivering 40mW (16dBm) output power to the selected antenna. The output power is within +/-1dB of the rated output power across the operating range of input voltage, operational frequencies and temperature.

The radio power amplifier is controlled with an external DAC. The DAC is programmed to give a full-scale voltage range of 0V to 2.5V to the control input i.e., bias of the power amplifier. This can serve as an option to reduce or increase the transmit power of the radio depending upon external conditions such as temperature. Note that although the power amplifier in the radio is capable of delivering 100mW of power, it is being reduced to 40mW (16dBm) with maximum bias voltage limited to 2v.

9. RF Receiver sensitivity

The Radio receiver sensitivity is better than -97dBm at the required data rate over the specified temperature and supply voltage ranges. The packet error rate (PER) is less than 10^{-2} using packets consisting of 4 byte preamble, SFD, 50 bytes of data and 16 bit CRC.

The 3dB bandwidth of the receiver is a minimum of 1MHz for GFSK mode for 250Kbps data rate and +/- 250 KHz deviation. The channel filter bandwidth of CC2400 is selected by GRDEC (0x21) register.

The sensitivity of the radio transceiver is -91dBm with system noise figure of 10dB. In this design an additional low noise amplifier MAX 2645, with noise figure less than 2.0dB, is used to decrease the overall noise figure of the system and thus increase the sensitivity by another 8dBm.

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The gain of the LNA is greater than 12dB in 2.4GHz band and with this gain the total reduction in noise figure is 8dB and thus increasing the sensitivity of the radio board to -97dBm.

10. Receiver Dynamic range

The Radio receiver dynamic range for received signal power is from -10dBm to -98dBm and it is greater than 75dB with PER maintained below 10^{-2}. The dynamic range of the radio is from -10dBm to -98dBm, i.e., around 88dB dynamic range.