RADIO, RF Concepts, and TOS Radio Stack

- Mote Radio Architecture
- RF Propagation
- Information Transport
- TOS Messaging & Radio Stack
- Mote Radio Control

ChipCon Radio System

Single IC Transceiver

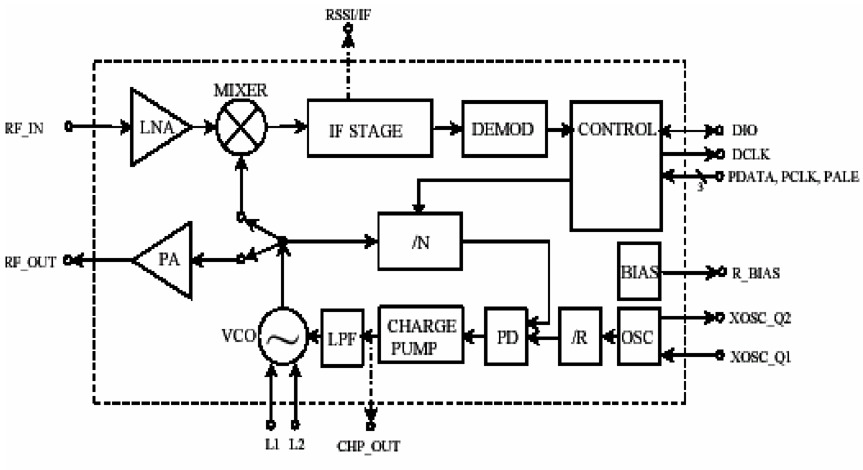
Dual Band 433MHz and 915MHz ISM Bands

38.4KBit/sec Data Rate

Low Power 16mA Tx / 9mA Rx

Programmable Configuration

Chipcon CC1000 Block Diagram



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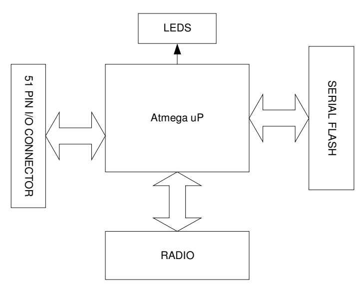
Common Platform Architecture

- **Atmega uP**
  - **32Khz crystal and 4Mhz crystal.**
  - **10 bit ADC**
  - **UARTS (Mica2/Mica2Dot have 2)**
  - **SPI bus**
  - **I2C bus (hardware for mica2/mica2dot)**
- **Radio (Chipcon 1000)**
- **External serial flash memory (512K byte)**
- **Connectors for interfacing to sensor and programming boards**
- **1 programmable led (Mica2Dot)**



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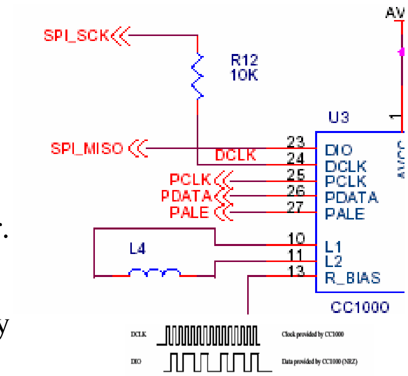
The CC1000 Radio Interface

• Dedicated cpu bus (lines) to configure radio registers for radio frequency, power,…..

• Dedicated SPI bus for data transfer. CC1000 is bus master.

• Radio generates one interrupt every 8 bits when in receive mode.

• Runs usually at 38K or 19K bit rate (default) Manchester (2x bit)



Baud Rate	Xmt or Rcv Time(*)
19K	~40msec
38K	~20msec

(*) Does not include random delay

Chipcon-ATMega Interface

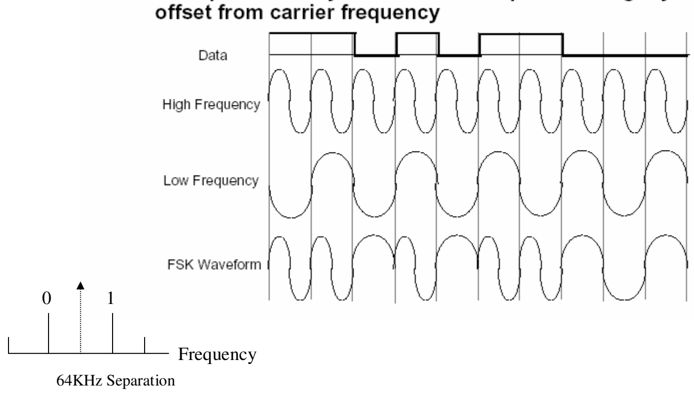
- Configuration Interface
- Communication Interface
  - Data uses ATMega SPI Port
  - CC1000 is SPI Master
- SPI Port
  - Rx Double Buffer
  - Tx Single Buffer

RF Frequencies & Channels

- ISM Bands
  - 902 – 928 MHz US
  - 433– 434.8 MHz Europe
- RF Channel Programmable within a band
- Mote is manufactured for specific band

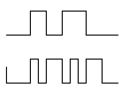
RF Modulation - FSK

- **Frequency Shift Keying (FSK)**
  - **1/0 represented by two different frequencies slightly offset from carrier frequency**



Manchester Encoding

- Every Bit (Zero or One) has a transition
  - Guarantees no run of NRZ ones or zeros
- Ensures Stable Clock Recovery at receiver
  - Clock determines sampling time of data bits
- Implemented in CC1000 hardware
  - Reduced ATMega128 overhead



NRZ Code 0101100

Manchester Code

Monopole Antenna

Simple ¼ wave whip is sufficient for most applications:

•916Mhz => 3.2” wire length

• 433Mhz => 6.8” wire length

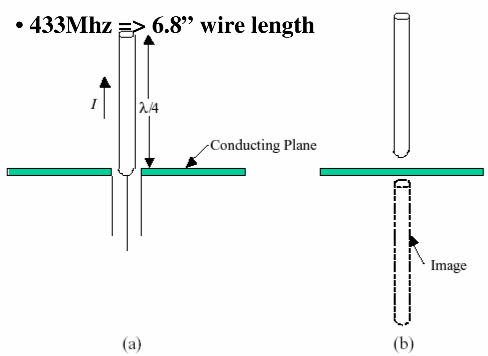


Figure 2. (a) Quarter-Wave Monopole Antenna. (b) Equivalent Half-Wave Dipole Antenna

Antennas and Radio Transmission

•**Polarization:**

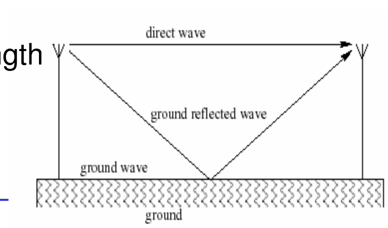
- **Vertical orientation of all antennas in a system is best.**
- **1/10th distance if some antennas are vertical, some horizontal**

• **Transmission Near the Ground**

- **•Mica2 916Mhz, 3' above ground ~>'300' line of sight, 30' on the ground**
- **•Mica2 433 Mhz, 3' above ground ~>500' line of sight, 150' on the ground**

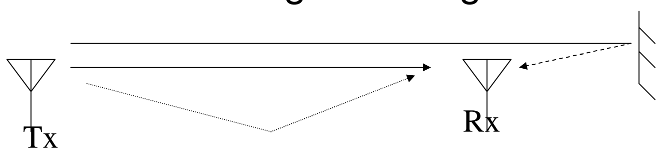
RF Propagation

- Line of Sight
  - Direct path from Transmitter to Receiver
  - Free space attenuation $1/d^2$
    - double distance needs 4x power
- Reflection
  - Off objects large compared to Wavelength
    - walls, buildings
- Scattering
  - Off objects smaller than Wavelength
    - foliage, chairs



MultiPath

- Path lengths => Delayed version of signal
- Path Attenuation => Various signal strengths
- Result looks like Distortion / Interference at Receiver
- Out of Phase Signal Interference creates NULLS – Zero signal strength



Indoor Propagation

- Rapid Signal Attenuation $1/d^{3 \text{ or } 4}$
- People moving around cuts range to 1/3
- Concrete/Steel Flooring to 1/4
- Metallic Tinted Windows to 1/3

Dynamic Fade Effects

•People Moving, Doors Opening & Closing

•Eg. Closing doors in lab changes Strong (Green) to Weak (Blue) RF Regions

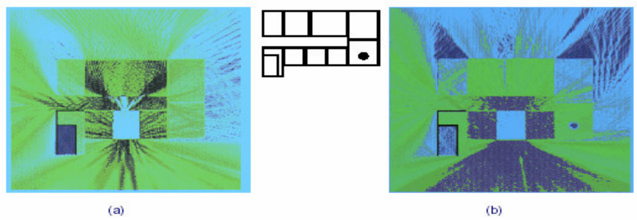


Fig. 4.1. Fluctuations of the electric field in the building that houses the faculty of Electrical Engineering. 2D FDTD code was used in these calculations which include the following: (a) all doors are open with no object present; (b) doors are closed with one object placed in one of the rooms. Green color denotes high electric field values; blue color represents low signal amplitudes.

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Common RF Link Problems

- Signal Strength
  - Weak, Overload
- Collisions
  - Other Motes (independent of GroupID)
- Interferers
- Multi-path
- Cross-talk
  - Adjacent RF Channels

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RF Link Metrics

- Packet Loss
  - Application Layer
- Bit Error Rate
  - Link Layer
- RSSI Received Signal Strength
  - Physical Layer

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RF Solutions
Signal Power & Wavelength

- Transmitter Power Level
- Antenna Efficiency
  - Monopole vs. Dipole
  - Antenna Orientation
  - Antenna Placement
    - Ground Plane
    - Off Ground

- RF Band Choice
  - Installation 433MHz vs. 902MHz
- RF Channel selection default
  - static / compile time
- Frequency Hopping
  - dynamic / run time

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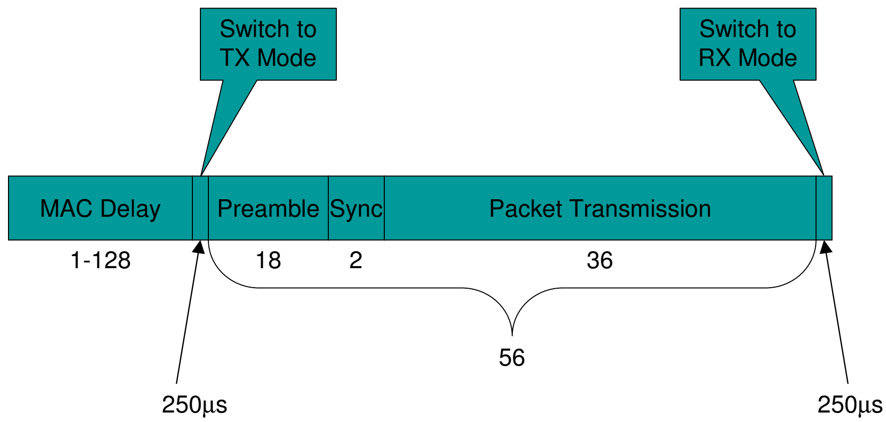
Radio Packets

Data Transport

noise	preamble	sync	TOS Packet	noise

- Packetized Data
  - 18 byte Preamble 1010 pattern for clock recovery
  - 2 byte Frame Sync Start of Data Packet
  - 36 bytes of TOS Packet

Mica2dot



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TOS Message Structure

- Header
  - Address (2bytes)
  - Active Message Type (1byte)
  - Group ID (1 byte)
  - Payload Length (1 byte)
- Payload
  - 29 bytes User/Application defined
- CRC
  - 2 bytes

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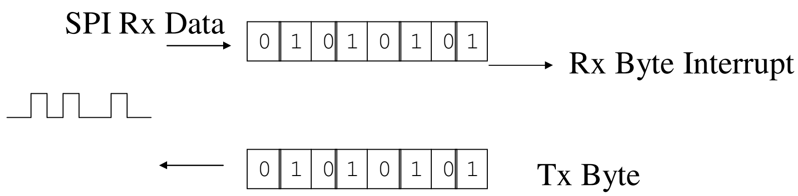
Radio Interface

- Data/ Noise streams in from CC1000 at 19.2Kb/s rate
- SPI Input Interrupt every 416uSec (8bits)
- Triggers RadioIntM.nc Module



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Mica2dot Radio Stack

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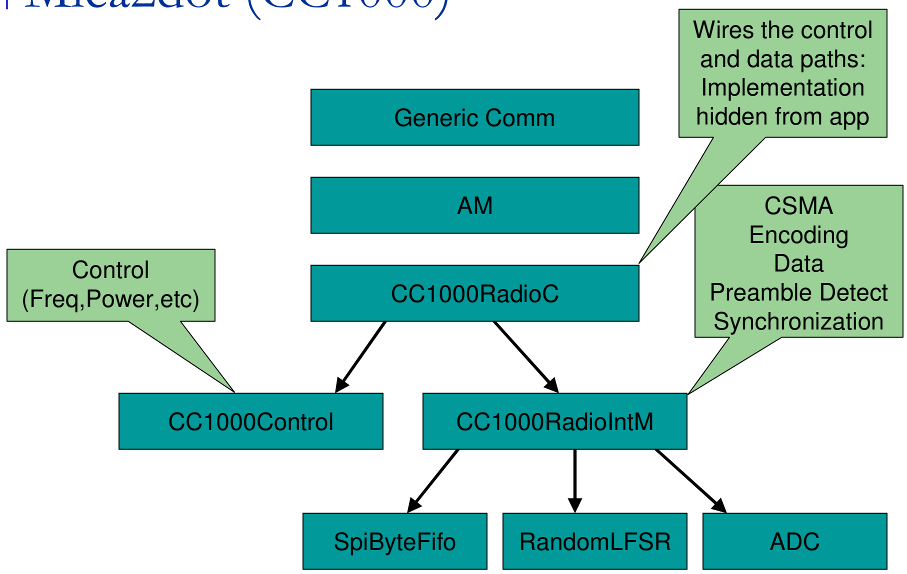
Mica2dot (CC1000)



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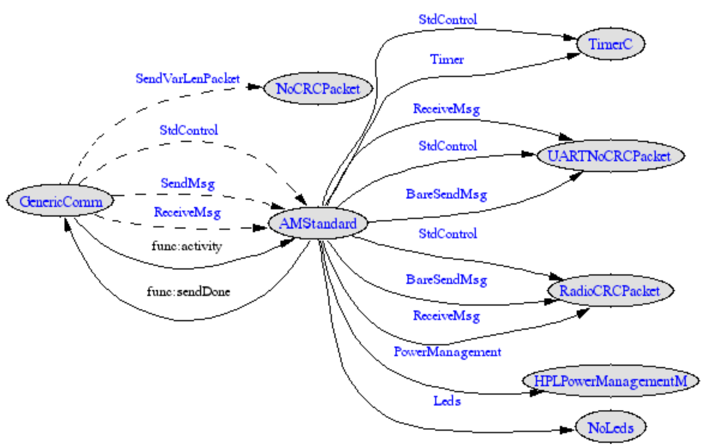
GenericCom Stack
AM Handling & RF/UART



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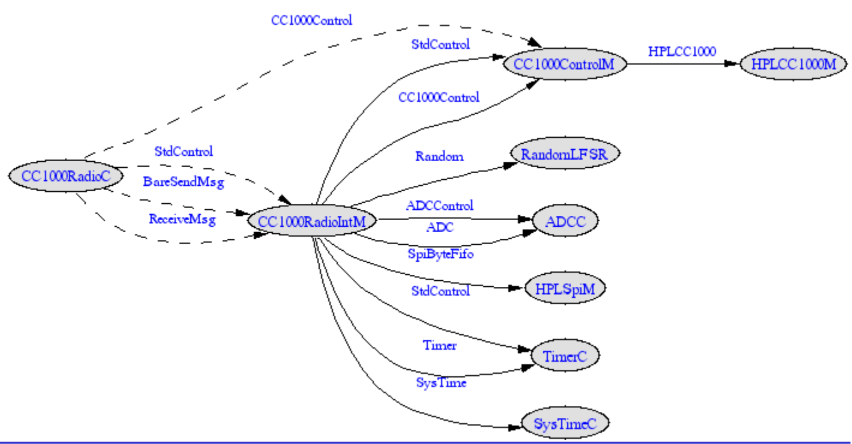
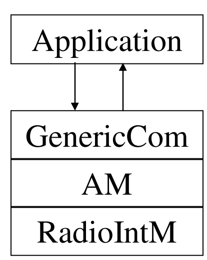
Radio Stack CC1000Radio



TOS Packet Reception

- RadioIntM.nc SPI Port Interrupt Handler
  - Search for Preamble Pattern (10101)
  - Wait for Frame Sync word
- Assemble TOS Packet
- Check CRC – reject if bad
- Route to Active Message Handler
- Check Group ID – reject if not member
- Signal Application ReceivedMsg Event



TOS Packet Transmission

- Packet is routed
  - GenericCom
  - AM Handler –RF or UART
  - TOS CC1000RadioIntM
- Random Delay (0-15 packet times)
- Check for Collision
- Turn On Transmitter
- Send
  - 18-byte Preamble (10101 pattern) & Frame Sync
  - TOS Packet (34 bytes)
  - CRC (2 bytes)
- Turn Off Transmitter
- Signal TxDone event to Application

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CC1000RadioInt State Machine

- Radio SPI Data Port Interrupt triggers every 8 bit times = 416uSec
- Major States
  - IDLE
  - RX Related: Sync, Packet Assemble
  - TX Related: Collision Sense, Preamble, Sync, Packet, CRC, Flush,Done
- Graphically…

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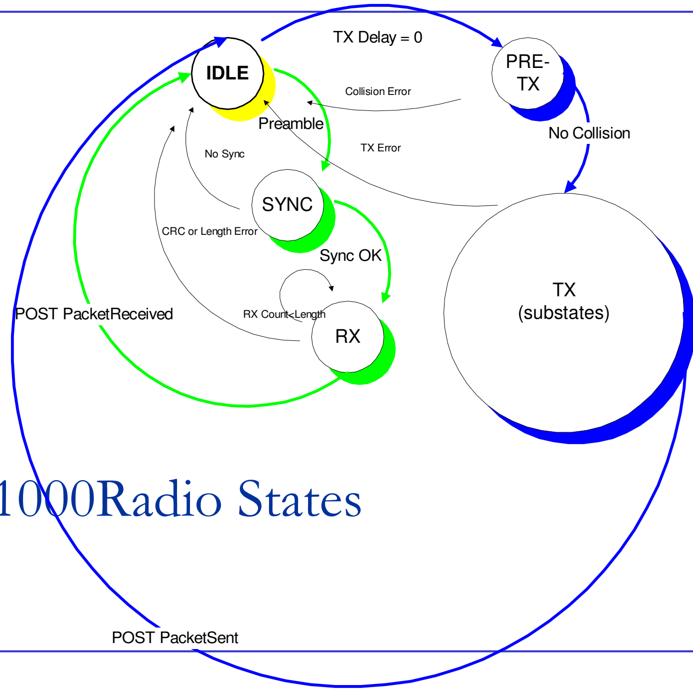

CC1000Radio States

IDLE State

- RXData == Preamble Pattern?
  - Next State = SYNC
- TX Delay (Holdoff) Decrement
- TX Delay == 0?
  - Next State = PRE_TX

SYNC RX State

- Shift RX Byte bit-wise into Word Buffer
  - Word Buffer == SYNC PATTERN?
    - Byte Align = Bit Shift Count
    - Next State = RX
- RX Byte Count > MAX LENGTH ?
  - Next State = IDLE

Word Buffer (Previous RX Byte) ← Incoming RX Byte

10011001	11100110	←	01100001
00110011	11001100		

SYNC PATTERN

RX State

- RXBuffer[RXCount] = RX Data
- RXCount++
- Compute CRC(RXByte)
- RXCount == RXBuffer[Length]+Header?
- CRC = RXBuffer[CRC]?
  - Post PACKETRECEIVED
  - Next State = IDLE
- Error ?
  - Next State = IDLE

Signaling of PacketReceived by CC1000Radio

- …
```
      if (rxbufptr->crc == usRunningCRC) {
          call SpiByteFifo.disableIntr();
          RadioState = DISABLED_STATE;
          rxbufptr->strength = usRSSIVal;
          if (!(post PacketRcvd())) {
// If FALSE there are insufficient resources to process the incoming packet we drop it
              RadioState = IDLE_STATE;
              call SpiByteFifo.enableIntr();
          }
      }
```
- ```
task void PacketRcvd() {
pBuf = rxbufptr;
pBuf = signal Receive.receive((TOS_MsgPtr)pBuf);
}
```

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## PacketReceived EVENT

- Signal Generated in Radio Component.
- Propagates up to AMStandard Component
- ```
// Handle the event of the reception of an incoming message
  TOS_MsgPtr received(TOS_MsgPtr packet)  __attribute__ ((C, spontaneous)) {
    counter++;
    if (   packet->group == TOS_AM_GROUP &&
     (packet->addr == TOS_BCAST_ADDR ||
      packet->addr == TOS_LOCAL_ADDRESS)) {
          uint8_t type = packet->type;
          TOS_MsgPtr tmp;
          // dispatch message
          tmp = signal ReceiveMsg.receive[type](packet);
          if (tmp)
                packet = tmp;
                }
    return packet;
  }
```

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TOS Radio Controls - Frequency

- Frequency Band / RF Channel Choices
  - ```
    #define CC1K_433_002_MHZ  0x00
    #define CC1K_916MHZ       0x01
    ```
- Specify CC1K_DEFAULT_FREQ in makefile
  - `CFLAGS -d:CC1K_DEFAULT_FREQ CC1K_433_002_MHZ`

TOS Radio Controls - Power

- Power On / Off
  - Sleep ~ 2uA
  - Radio Signal Strength (RSSI Valid) ~ 20uS
  - Receiver Packet Acquire Time ~3mSec
  - Re-TUNE Radio after a power off/on cycle
  - `command result_t Tune(uint8_t freq);`
- RF Power Level (@ 915MHz)
  - `command result_t SetRFPower(uint8_t power);`
  - 0xFF is 5dBm
  - 0x80 is 0 dBm (1mW)
  - 0x09 is –10dBm
    ```

Important RF Issues

- Different Motes for Different ISM Bands
- Re-tune after Sleep or Temperature changes
- Keep Motes separated >1m
- Watch out for Multi-path effects
- Different Group id's do NOT prevent RF interference

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Radio Debugging Hints

- Correct Radio Frequency?
  - CC1K_DEFAULT_FREQ
- Correct GroupID?
- GenericBase Hangup
  - Press RESET button
- RF Null Location?
  - Move Mote to different location (+/- 1m)
- RF Overload
  - Separation >3m

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