Hardware Description for the Advanced Subminiature Telemetry System

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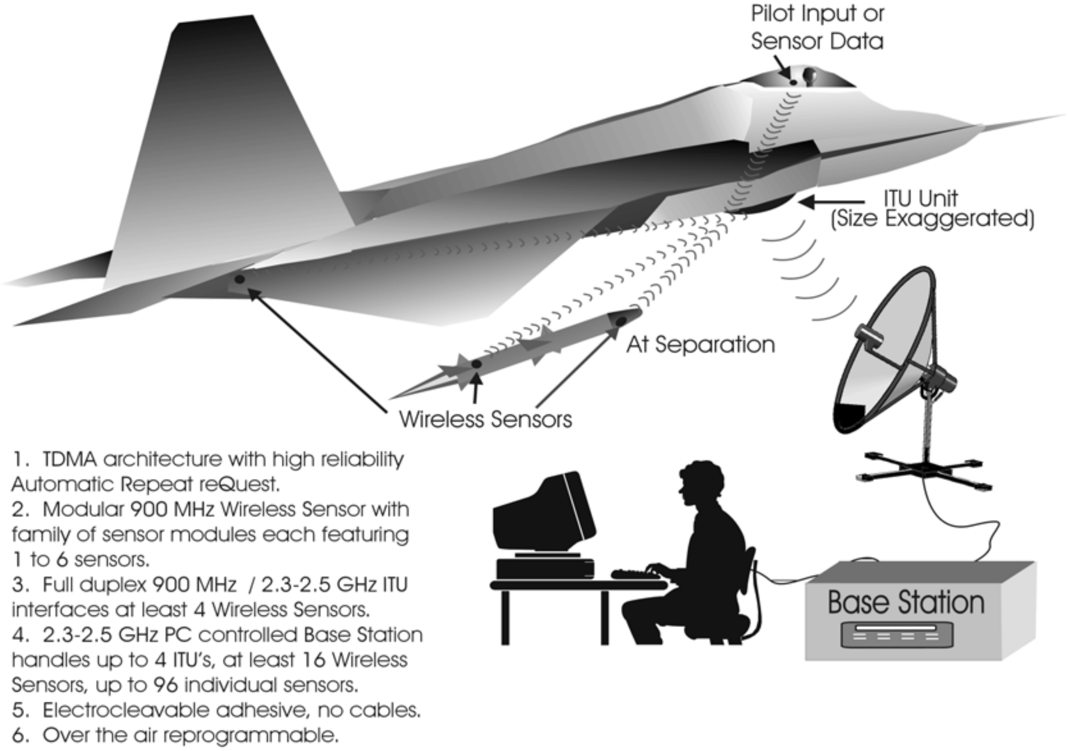
ABSTRACT

The Advanced Subminiature Telemetry System (ASMT) contract was awarded several years ago and the basic framework for the overall system has been described in earlier papers. This paper discusses an overview of the design of the hardware pieces to create the ASMT system.

ASMT CONCEPT REVIEW

The Air Force SEEK EAGLE Office (AFSEO) identified the need for a highly compact, low cost, sensor, data acquisition, and radio telemetry system that could be easily used on inventory aircraft. It was envisioned to use a "Peel and Stick" method of hardware mounting that allowed easy removal for use on other aircraft or store, and provide quick return of inventory aircraft to standard duties. An "electro-cleavable" adhesive has been successfully developed by EIC Laboratories for this function. Hardware cost was desired to be sufficiently low as to allow sacrifice in destructive testing when necessary. This methodology avoids the need to always use expensive, low availability, pre-configured test aircraft for all testing. Not only could this concept lower test expenses, it could also result in better test programs by eliminating aircraft availability delays and allowing more testing per mission. In this same period of time, Cleveland Medical Devices has been pursuing dual use of the Air Force technology with the development of wireless patient monitoring systems based on shrinking cellular methods in physical size and power consumption down to the point that they become "wearable". We refer to these highly compact but still intelligent radio systems as "MicroSynth". The size, performance, physical character, complete software control via generic PC platforms, and commercial electronics base of this technology provided and ideal "tool kit" from which to begin development of the desired Air Force system.

The operational concept for the ASMT system is shown in Figure 1. The operator(s) may monitor and control the test, including reprogramming data acquisition parameters, from the keyboard. The system consists of the major components: Wireless Sensor, ITU, and Base Station. The ground station utilizes PC controlled Based Stations that communicate with the airborne station in upper S band, 2310 to 2390 MHz and in the 2400 to 2483.5 MHz Industrial, Scientific, and Medical (ISM) band. The airborne station consists of an Integrated Telemetry Unit (ITU) with an intelligent 2300 to 2500 MHz transceiver, data processing board for encryption and storage, and one or two 18 channel data acquisition boards. There are built in generic sensors for acceleration, air pressure, and temperature, and the data acquisition boards interface over cables to off board sensors mounted where needed by a particular test. There are also optional highly compact Wireless Sensors that may be mounted up to 100 to 200 feet from the ITU in order to eliminate the need to run long wires, or that can be used on released stores for separation studies. The Wireless Sensors consist of a size reduced 902 to 928 MHz ISM band transceiver and up to a six channel data acquisition board. An ITU with a wireless sensor trades off one of its two data acquisition boards for a 900 MHz transceiver to serve the wireless sensor to ITU link. By using 900 MHz for the wireless sensor to ITU link and 2300 to 2500 MHz for the air to ground link, both links may be simultaneously operated and throughput is maximized.



1. TDMA architecture with high reliability Automatic Repeat reQuest.
2. Modular 900 MHz Wireless Sensor with family of sensor modules each featuring 1 to 6 sensors.
3. Full duplex 900 MHz / 2.3-2.5 GHz ITU interfaces at least 4 Wireless Sensors.
4. 2.3-2.5 GHz PC controlled Base Station handles up to 4 ITU's, at least 16 Wireless Sensors, up to 96 individual sensors.
5. Electrocleavable adhesive, no cables.
6. Over the air reprogrammable.

Figure 1: ASMT Wireless Data System

The air interface chosen is one based on Time Division Multiple Access (TDMA) using a technique similar to Gausssian Minimum Shift Keyed (GMSK) binary frequency modulation. The system covers the full upper S band from 2310 to 2390 MHz and the 2400 to 2483.5 MHz ISM band in dedicated 300 kHz channels or using frequency hopping spread spectrum mode. The maximum airborne transmit power is + 30 dBm, and the maximum planned ground (Base Station) power is also + 34.8 dBm. The relatively low transmit powers used in combination with continuous transmit power level control will minimized interference to the users. The modest data rate per ITU of 230 kBPS, narrow receive bandwidth of approximately 230 kHz and high gain ground antennas allow ranges up to 50 miles at these power levels. Automatic retransmission of any data packet errors ensures high data integrity without having to go to excess in transmit power, antenna gain, Forward Error Correction (FEC), or other link parameters.

Typical measurement requirements include acceleration, strain, air pressure, and temperature. Because established sensors are expensive within the context of this program, and important element of the program is exploring the use of low cost commercial sensors. The program studies have discovered new generation Micro Electromechanical Systems (MEMS) and integrated sensors are available for prices that are much less than established mil-spec components. Data acquisition bandwidths that read the sensors are typically from tens of Hz to a few kHz. Since any telemetry system is a data pipe with a fixed upper limit on the throughput, a data acquisition system that allows flexible trading of the number of data channels, sample rate, and resolution is the ideal solution to getting the most operational use out of the link.

The protocol for data transmission will be TDMA with an “ack/nak” handshake. The planned frame structure is shown in Figure 2 with the data packets as they would be spaced in time, with simultaneous packets aligned vertically. After each packet of any kind, the receiving end acknowledges correct receipt, or not, with the ack/nak/command. Incorrectly received packets are stored for retransmit during the assigned retransmit interval. Each ITU has 276 wireless sensor channels, or 18 wired sensors in the case of a Wireless Sensor capable ITU that can also access multiple Wireless Sensors.

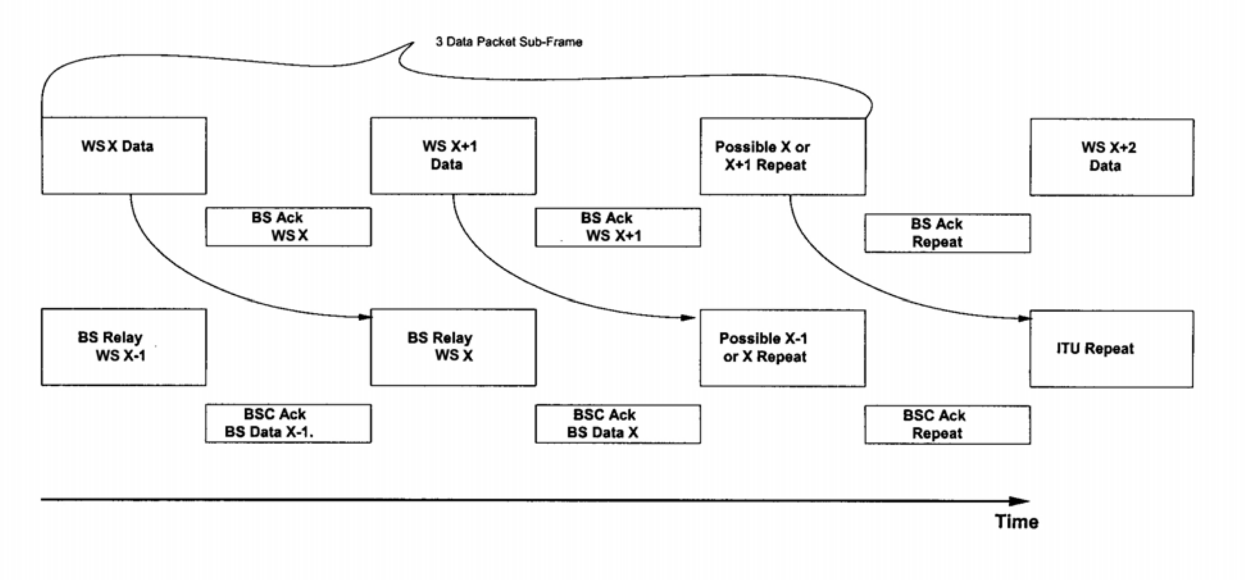


Figure 2: ASMT TDMA Packet Timing Example

Each packet is approximately 11.6 msec long and each 3 packet “sub frame” with overhead is approximately 44 msec long (including turnaround time between packets). The sub frame is adopted because a mobile (Wireless Sensor or ITU) does not have to use a slot on each sub frame, and thus larger numbers of mobile can be multiplexed in if their data rates allow.

SYSTEM HARDWARE CONFIGURATION

As stated earlier, the system is designed for maximum flexibility to allow for many different configurations. The most probable system configuration consists of three separate sections, a Wireless Sensor, an ITU, and a base station. The wireless sensor has been described earlier and the base station is a bank of up to 4, 2.4 GHz transceivers. The configuration of the ITU station has a 6 connector Inter Board (IB) bus that can accept any combination of transceivers (900 MHz or 2.4 GHz) or data acquisition cards.

The system control of the data flow is performed by the ground station for the ground to ITU link and by a 2.4 GHz transceiver in the ITU aircraft for the ITU to Wireless Sensor link. Both structures are the same and the basis for data flow is as follows. The master on the link controls the data collection order, the overall system timing, and the frequency allocation. Once the system has been configured, all users identified, and basic control established, the flow of data from sensors to the end users is as follows. Wireless Sensor sensors gather and buffer data and wait for their turn to send. They will receive that order from a 900 MHz transceiver in the ITU aircraft. The data is then sent to the ITU aircraft where it is decoded by the 900 MHz transceiver and if the packet is found to have no errors, an acknowledge is sent back to the wireless sensor. The entire packet is then made available to the IB bus for collection by the master. The data is then passed on from the master to the ground station over a 2.4 GHz radio link when the ground station requests it. The master in the ITU aircraft can also collect data from a DAQ card on the ITU aircraft IB bus.

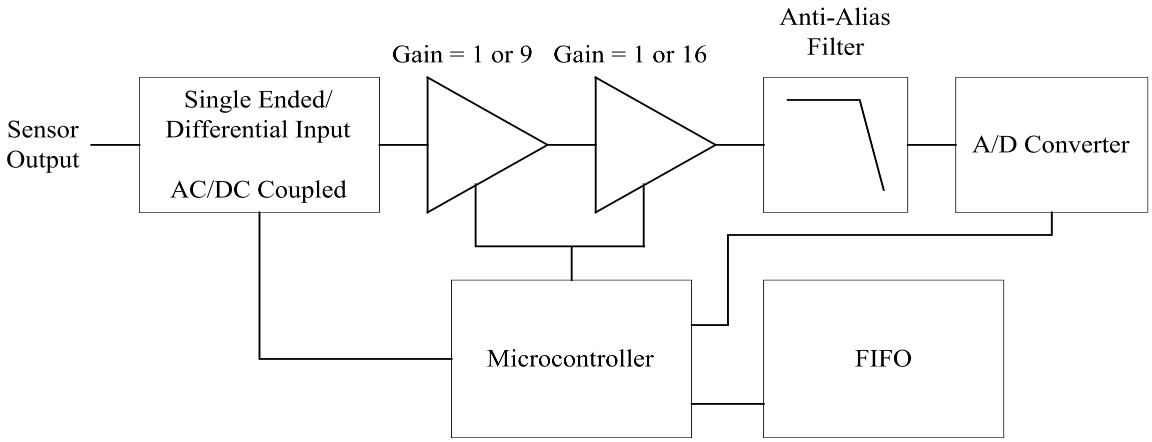
The Wireless Sensor and ITU units are attached with electro-cleavable adhesive, are battery powered, and are good for one 4 hour test mission. More detail about overall system capability is available from the Seek Eagle office or Cleveland Medical Devices.

HARDWARE DESCRIPTIONS

The following discussion details the components available in the ITU section of the ASMT system. The Wireless Sensor transceiver and the Base Station hardware implementations are similar to the design of the ITU components.

Data Acquisition Board (DAQ)

The DAQ board consists of eighteen independent analog channels that accept signals ranging from 1 uV to 1.25 V covering the frequency range of DC to 5kHz. There is also one channel that will collect already digitized data and form it into a system data packet. A “part” of the DAQ board is a separate connector board that supplies power to, and gathers analog input from, the external sensors. The output from the DAQ board is a multi-plexed encoded data stream that is passed onto either the 900 MHz or 2.4 GHz transceivers over the IB bus. The block diagram for the board is below:



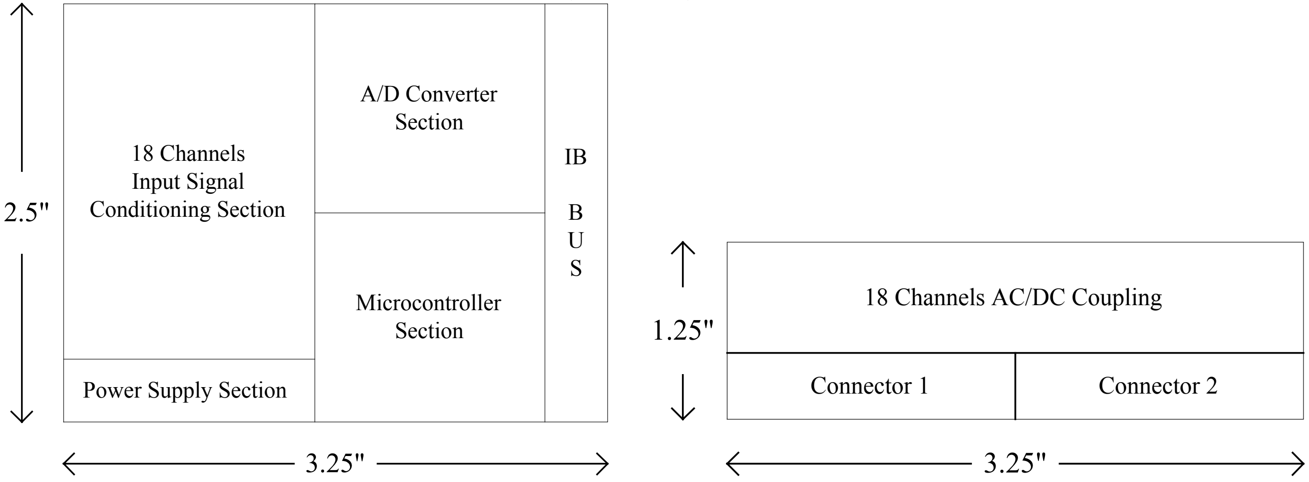
DAQ Board Channel Block Diagram

The variable gain amplifiers have a gain that is selectable from 1, 9, 16, and 144. The gain is selectable independently for each channel and is controlled by the microcontroller. The amplifiers can either be AC coupled or DC, and single ended or differential input and that is also microcontroller controlled. Following the amplifier is a filter to prevent aliasing in the Analog to Digital conversion process (A/D). The A/D has selectable gains that are powers of two up to a maximum of 256. The A/D output is selectable from 8, 12, or 16 bits depending upon the signal resolution desired. The A/D is clocked at a frequency determined by the microcontroller and all channels are clocked at the fastest channel rate. The highest clock rate for one channel is 10,000 samples per second and low pass filtering of the data is performed by decimation in the microcontroller. This makes the maximum bandwidth achievable for one channel of 5000 Hz. After conversion, the data is formed into packets with minimal overhead and made available to the IB or placed in memory. The packet can contain data from 1 channel or all 18 channels to reach the data structure defined earlier.

The DAQ card is capable of running by itself from a single battery source. On board circuits generate all the required voltages to operate the card from a single battery source.

The DAQ board's physical size is approximately 3.25 inches by 2.5 inches, is a 6 layer PCB and uses all commercially available components. The connector board is 3.25 inches by 1.25 inches, is a 4 layer PCB and uses all commercially available parts. The distribution of each section is shown below:

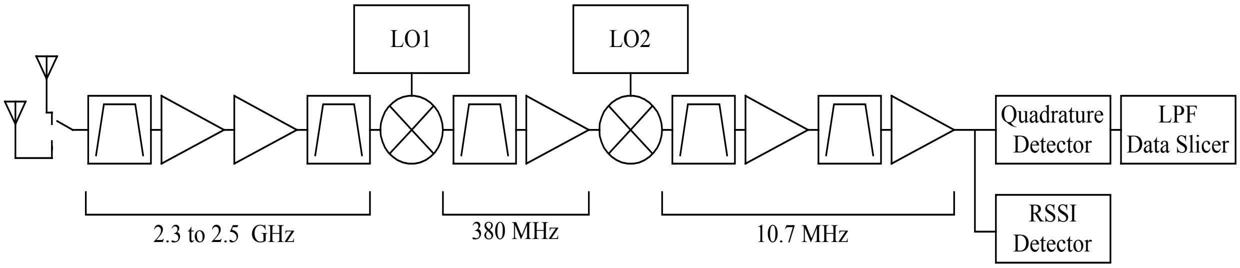
DAQ Board Physical Layout



2.4 GHz Transceiver

The 2.4 GHz board consists of a 2.3-2.5 GHz radio receiver and transmitter, a microcontroller for unit control and signal processing, and an interface for passing data to end user terminals (the same board that is in the ITU aircraft is in the ground station).

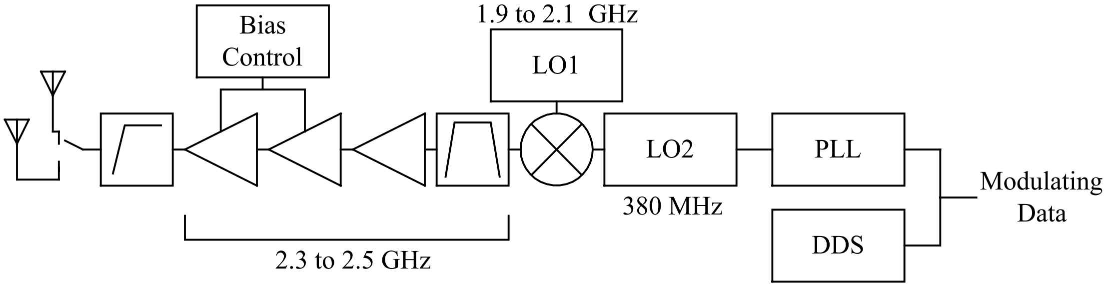
The input to the receiver is one of 2 antennas, the antenna selection is made for maximum input level and can be switched in the event of signal fade. The receiver is capable of demodulating signals in the 2.3 to 2.5 GHz frequency range with BER capability, without correction, of 10E-5 for signals as low as -96 dBm and as high as -20 dBm. . The error rates improve between these limits with the –96 dBm as a result of the thermal noise floor and the –20 dBm as a result of hardware non-linearities. A block diagram of the receiver is below:



2.4 GHz Transceiver Receiver Block Diagram

The receiver is a dual conversion superhetrodyne configuration with a Noise Figure (NF) no higher than 10 dB, and a Resolution Bandwidth (RBW) of 230 kHz. Dual frequency conversion is required to ensure proper performance over the 200 MHz frequency range of operation. The tuning of the receiver is accomplished by changing the frequency of the higher frequency Local Oscillator LO1. LO1 covers the range of 1.9 GHz to 2.1 GHz to produce a fixed Intermediate Frequency (IF) of 380 MHz. LO2 then converts the signal down to 10.7 MHz where the resolution bandwidth is set, and the signal is detected. The demodulation circuitry is a non-coherent, quadrature detector, whose voltage output is proportional to the frequency input. The quadrature detector output is followed by a Low Pass Filter (LPF) and a data slicer that prepares the demodulated data for decoding. There is also a Receive Signal Strength Indicator (RSSI) whose output is proportional to the signal level at the antenna and is used to adjust the radio link to the minimum power levels required to maintain error free communications (error free includes FEC).

The transmitter takes advantage of the circuits designed for the receiver section to create the desired signal at the proper frequency required during the transmit operation. Below is the block diagram of the transmitter:



2.4 GHz Transceiver Transmitter Block Diagram

The transmitter output signal is created by upconverting (mixing) the two LO's used in the receiver down conversion process and adding modulation to the low frequency oscillator circuitry. This approach also has the advantage that by adding modulation to the fixed, lower frequency oscillator, the transmitted signal will have the exact same modulation characteristics regardless of the output frequency. The data is added via FM, in a manner similar to GMSK, by a 2 point system where the data modulates the Voltage Controlled Oscillator (VCO) in LO1 and the Direct Digital Synthesizer (DDS) reference for the Phase Locked Loop (PLL). The VCO input controls the maximum deviation, as well as maximum modulation frequency component of the data, while the DDS input allows for low frequency content of the data to modulate the carrier. The output power of the transceiver will cover the range of -30 dBm to + 30 dBm in 3 dB steps. The control of the output power will be performed by a factory calibration to ensure accurate output level control.

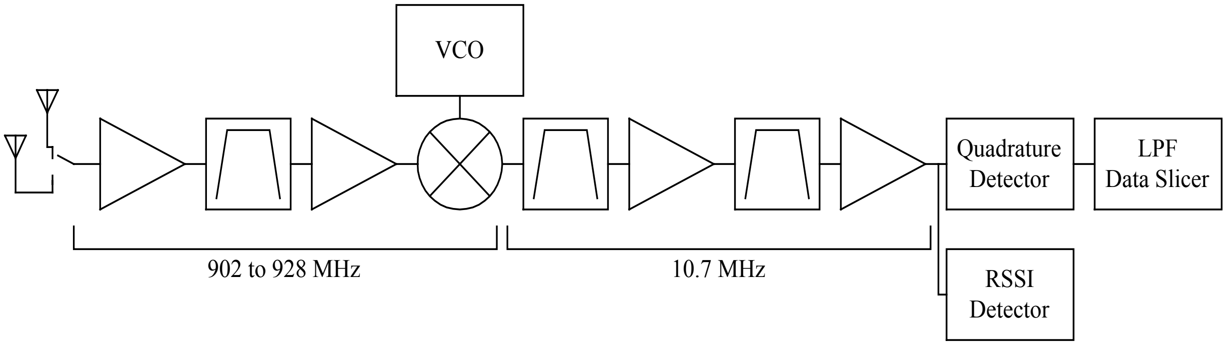
The microcontroller section, in addition to controlling the unit, also performs the data encoding and decoding, places the data in memory, and interfaces to several end user interfaces. The encoding and decoding capability is a significant benefit because it eliminates the need for a stand-alone modem. Circuits typically used for this purpose takes a lot of space and a lot of power. The interface to the FIFO memory is to ensure that no data is lost and it is available for transmit to the ground station when requested. The microcontroller is also capable of controlling where the data output of the 2.4 GHz transceiver will be routed. The port controller circuits are capable of routing the data to the IB bus, a serial port, or a USB port.

The 2.4 GHz transceiver is capable of running by itself from a single battery source. On board circuits generate all the required voltages to operate the card from a single battery source.

900 MHz Transceiver

The 900 MHz board consists of a 900-928 MHz radio receiver and transmitter, microcontroller for unit control and signal processing.

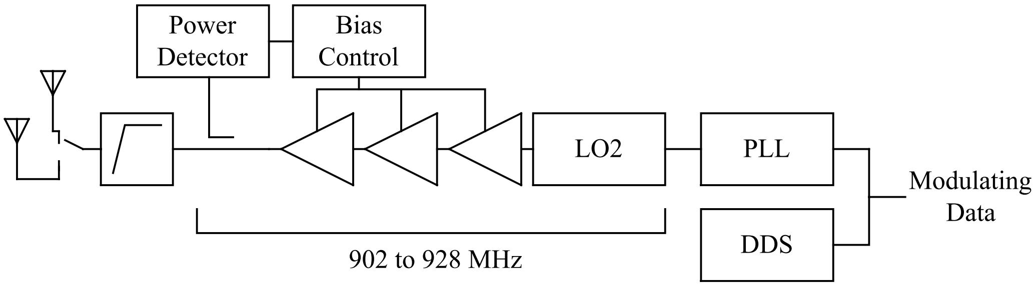
The input to the receiver is one of 2 antennas, the antenna selection is made for maximum input level and can be switched in the event of signal fade. The receiver is capable of Bit Error Rates (BER), without correction, of 10E-5 for signals as low as -96 dBm and as high as -20 dBm. The error rates improve between these limits with the –96 dBm as a result of the thermal noise floor and the –20 dBm as a result of hardware non-linearities. A block diagram of the receiver is shown below:



900 MHz Transceiver Receiver Block Diagram

The receiver is a single conversion superhetrodyne configuration with a Noise Figure (NF) no higher than 10 dB, and a Resolution Bandwidth (RBW) of 230 kHz. Single conversion is possible because of the more narrow bandwidth of the 900 MHz receiver (26 MHz for the 900 MHz receiver and 200 MHz for the 2.4 GHz receiver). The demodulation circuitry is a non-coherent, quadrature detector whose voltage output is proportional to the frequency input. The quadrature detector output is followed by a Low Pass Filter (LPF) and a data slicer that prepares the demodulated data for the decoding. There is also a Receive Signal Strength Indicator (RSSI) whose output is proportional to the signal level at the antenna and is used to adjust the radio link to the minimum power levels required to maintain error free communications (error free includes FEC).

The block diagram of the transmitter is shown below:



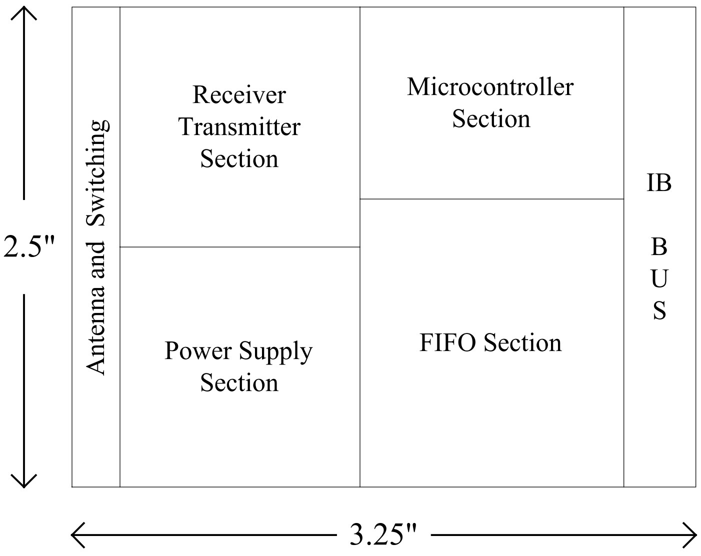
900 MHz Transceiver Transmitter Block Diagram

The transmitter is capable of producing any output level in the range of -30 to 0 dBm, in 3 dB increments, over the entire 902 to 928 MHz range. Power control is maintained by sampling the output power of the transmitter and adjusting the amplifier gain accordingly. The final amplifier is capable of 55% efficiency to minimize the drain on the battery under maximum output conditions. The data is added to the carrier via FM, in a manner similar to GMSK, by a 2 point system where the data modulates the VCO and the DDS reference for the Phase Locked Loop. The VCO input controls the maximum deviation, as well as maximum modulation frequency component of the data, while the DDS input allows for low frequency content of the data to modulate the carrier.

The microcontroller section, in addition to controlling the unit, also performs the data encoding and decoding, places the data in memory, and interfaces to the IB bus. The encoding and decoding capability is a significant benefit as described above. The interface to the FIFO is to ensure that no data from a Wireless Sensor is lost, and is available to the IB bus when requested. The FIFO can also be used to store data that will be passed on from an ITU to a Wireless Sensor.

The 900 MHz transceiver is capable of running by itself from a single battery source. On board circuits generate all the required voltages to operate the card from a single battery source.

The 900 MHz transceiver physical size is approximately 3.25 inches by 2.5 inches (the same size as the DAQ board) is a 6 layer PCB, and uses all commercially available components. The distribution of each section is shown below:



900 MHz Transceiver Physical Layout

CONCLUSION

This paper has delved into the more specific implementation of the ASMT system being developed by CMDI for the Air Force. The overall system design has been reviewed, as well as a general description of the individual boards that comprise the system. At the time of this writing, the individual boards have been 80% tested, but the complete system integration still has to be performed. CMDI has developed a specific and comprehensive test plan, which has been approved by the Air Force to have a system with basic operational capabilities in October 2002.