AC 2008-1239: A PSK31 AUDIO BEACON PROJECT PROVIDES A LABORATORY CAPSTONE DESIGN EXPERIENCE IN DIGITAL COMMUNICATIONS

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A PSK31 Audio Beacon Project
Provides a Laboratory Capstone Design Experience
In Digital Communications

Abstract

This paper focuses on combining a 433.92 MHz wireless temperature sensor with a PSK31 Audio Beacon transmitter to provide a laboratory capstone experience for junior students in Electrical and Computer Engineering Technology. The laboratory capstone PSK31 Audio Beacon Project is structured to support course goals and objectives of "Digital Communications" offered at the beginning of the junior year. The paper presents the "project concept" together with its theory of operation and project schematic. Also, students are required to build a prototype audio beacon transmitter using surface mount components, implement a packaging concept, and write a complete project specification. The secondary goals of the project are to introduce students to radio frequency (RF) amplifier concepts, and to prepare students for the upcoming Senior Design Capstone Experience required for a baccalaureate degree in engineering technology. To this end, students are required to maintain a project journal to record ideas, data, test results, and experiences throughout the project. The authors have found that student attitude towards the course and subsequent feedback to be most rewarding, and were very encouraged by the level of student involvement in the project.

Introduction

Over the past four years a phase shift keying (PSK31) Audio Beacon project has been introduced to a group of students in a Digital Communications at the University of Cincinnati. After a couple of iterations of the project, the authors noticed that student comments on the “project evaluation” form tended to center around adding additional capabilities to the project in order to make it more interesting. This paper is a direct result of those student evaluations together with a conscientious attempt on behalf of the authors to utilize projects in the laboratory portion of the course to stimulate student interest in RF communication concepts.

This laboratory capstone project illustrates the integration of a 433.92 MHz wireless temperature sensor into a PSK31 modulated audio beacon transmitter. The temperature sensor is a Dallas Semiconductor DS18S20 integrated with a standard "off-the-shelf" 433.92 MHz RF transmitter module that uses amplitude modulation. The transmission method known as "On-Off Keying (OOK)" transmits the temperature data by simply switching the carrier signal on and off. The RF data-link serial receiver can be located up to 500 feet from the transmitter and interfaces to the PSK31 Audio Beacon via an RS232 interface. The Audio Beacon features PSK31 encoding and audio waveform generation using a single-chip SX28 RISC microcontroller operating at 50 MHz. The beacon has a choice of three base carrier audio frequencies, namely: 500 Hz, 1 kHz, and 2 kHz. As an added bonus, students are introduced to RF amplifier concepts by taking the output from the audio beacon and injecting the audio signal into the microphone input of a five watt single-sideband transmitter. To form a conventional RF Beacon operating on 3.579 MHz (Amateur Radio 80 meter band), the output of the Class AB push-pull RF power amplifier is sequentially reduced by switching in-line a series of 3 dB attenuators until the output power reaches 0.63 watts. The transmit Beacon data string consists of station identification (Amateur

Radio call sign), grid square location of the transmitter (similar to latitude and longitude), return email address, local temperature in °F, and output power level.

In the sections that follow, the PSK31 Audio Beacon concept is described including both the hardware and software. Packaging concepts are introduced and modifications to the original Audio Beacon software are highlighted. Next, the components of the data acquisition system are introduced. A temperature data logger together with a 433.92 MHz wireless transmitter/receiver combination provide the capability to remotely sense environmental parameters such as local temperature at distances up to 500 feet separation. These systems are packaged with the audio beacon to form a working RF data collection subsystem. Finally, a true RF beacon station is established at 3.579 MHz by combining the audio beacon signal with a single sideband transmitter and attenuator.

PSK31 Audio Beacon Concept

As the name implies phase shift keying (PSK) modulates the phase of a carrier, and the number "31" references the actual bandwidth of 31Hz occupied by the signal. The original software for this modulation technique was written and developed by Martinez [1]. Two features that make PSK31 an ideal mode for digital communications are the extremely narrow bandwidth of the transmitted signal, and the high immunity of PSK to background noise. A current use of this technique is keyboard-to-keyboard communication between two or more operators, using a very small portion of the radio frequency spectrum. The signal processing enhancement of PSK31 compared to a continuous wave (CW) signal received and processed through a 500 Hz filter can be easily computed: 10 Log (500/31) = 12 dB. Note that a CW transmitter must transmit 16 times more power than a PSK31 transmitter, just to achieve the same signal-to-noise ratio at the receiving station.

The authors of this paper were in search of a practical "Digital Communications" project for a laboratory course in Digital Communications that did not involve transmission in the RF portion of the radio spectrum. This normally requires a license from the Federal Communications Commission and most students in the laboratory class are unlicensed. Fortunately, G. Heron [2] was successful in translating the software developed by Martinez to a PSK31 assembly language encoding and subsequent audio waveform generation using a single-chip SX28 RISC microcontroller operating at 50 MHz. A schematic of the Audio Beacon [3] is shown in Figure 1. The next two sections describe the hardware and software implementations of the PSK31 Audio Beacon. Subsequently, the additional system components added to the Audio Beacon are described.

PSK31 Audio Beacon Hardware

The PSK31 Audio Beacon is designed to fit into a small stand alone enclosure and includes the following features:

- SX28 RISC microcontroller operating at 50 MHz and used to generate an audio data stream using PSK31 algorithms.
- LM386 audio amplifier that can be used to drive an external speaker.

- Configuration jumpers to select one of three base carrier frequencies (2 kHz,1 kHz, or 500 Hz.)
- An RS232 interface.
- A discrete component digital to analog converter known as R-2R comprised of 16 resistor in a ladder network.

The first generation of the Audio Beacon was built in an Altoids enclosure on a Radio Shack RS 276-15 prototype board. Other components on the board include R-2R ladder network digital to analog converter (DAC) and an LM386 audio amplifier used to broadcast the PSK31 audio tones. The receiver decoder is a laptop computer with and external microphone attached. The PSK de-coding software is an audio spectrum analyzer called Digital Panoramic Tuning (DigiPan) [4] which presents the receive signal in a "waterfall" format. This software is designed for PSK transmission and is freely distributed. The first generation Audio Beacon hardware prototype is shown in Figure 2.

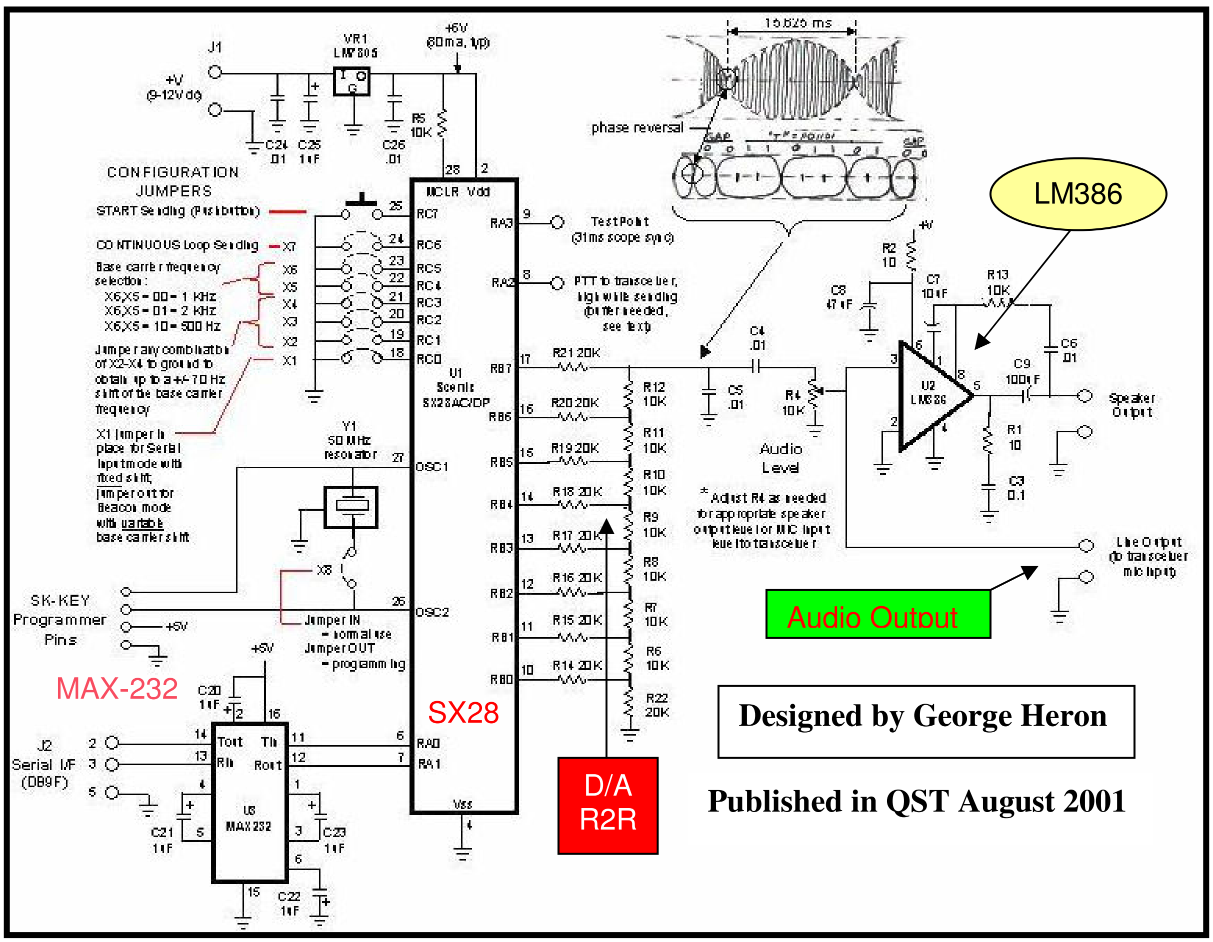

Figure 1-PSK31 Audio Beacon Concept Schematic.

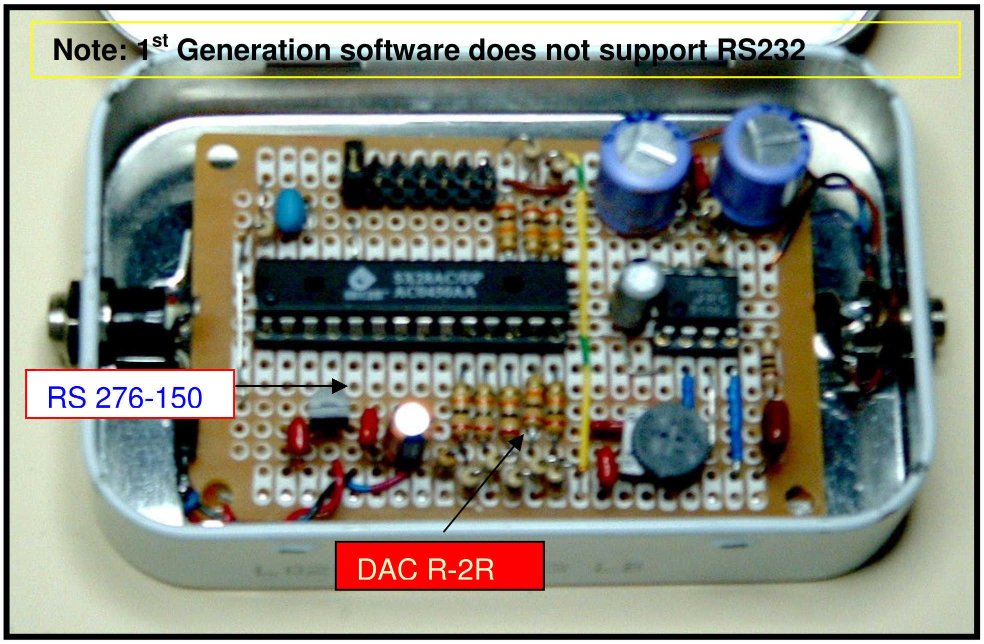

Figure 2-First Generation Audio Beacon Built In An Altoids Enclosure.

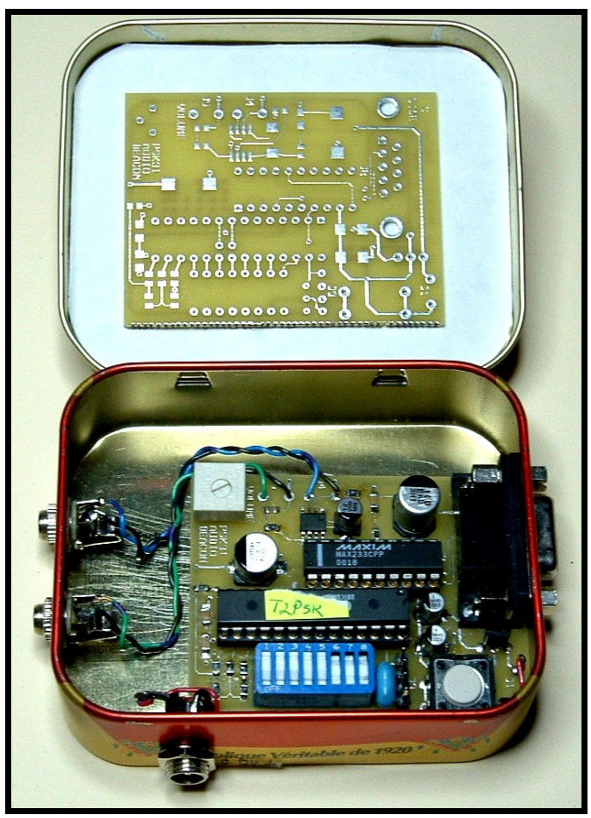

Figure 3-Second Generation Audio Beacon with Rs232 Interface.

A second generation of the Audio Beacon was constructed on a printed circuit board (PCB) utilizing 0805 surface mount parts. Students easily adapted to this prototype and enjoyed the success of assembling their first surface mount project. The second generation beacon includes a RS232 serial interface for interfacing to the outside world. Figure 3 shows the beacon packaged in a Whitman's Sampler enclosure.

Note that an unpopulated Audio Beacon PCB is shown in the lid of the enclosure for comparison purposes. The completed unit represents the stand-alone Audio Beacon that can easily be connected into the microphone jack of a standard single-sideband (SSB) transmitter. This represents the approach that will be taken later when the beacon is established on 3.579 MHz in Amateur Radio portion of the RF spectrum.

PSK31 Software Modifications

The software starting point for this project is Version 2.0 of the PSK31 Audio Beacon transmitter developed by G. Heron. This version of the software supported three different audio carrier frequencies, namely: 500 Hz, 1 kHz, and 2 kHz. Upon power-up, the software awaits a Start input, emits a series of zeroes, and transmits a pre-programmed text message, and then awaits the Start input again. Optionally, through a DIP-switch "continuous" setting, the software could ignore the Start input and repeatedly transmit a simple text message containing up to 60 characters. This version of the software is sufficient for introducing PSK modulation in the laboratory environment and served as the software in the first hardware prototype. However, as indicated in the introduction, student comments on the project quickly centered on "what else can it do?" Hence, the authors embarked on a technical adventure to make the Audio Beacon "more robust" by introducing 433MHz remote sensing of an environmental parameter such as temperature, together with a true RF beacon concept on 3.579MHz.

<u>Software Design Requirements</u>

The software design requirements for the Audio Beacon includes interfacing to a temperature-sensing device, controlling the attenuation of the transmitter, and transmitting a text message that varies based on the temperature and the amount of desired RF attenuation of the transmitted signal. These requirements accomplished two goals:

- The device became useful in that it could collect temperature data from a remote location.
- As a RF Beacon with varying power levels, the unit provides an opportunity to investigate the enhanced signal processing of PSK modulation gained by reducing the spectral occupancy of the transmitted signal to 31Hz.

After some deliberations concerning the construction and the means for optionally inserting the attenuators, the authors decided on four levels produced by adding one, two or three separate 3dB attenuators in series. Starting with five-watts of transmitted power, the attenuators produce four useful levels for RF Beacon transmitted power, namely: 5W, 2.5W, 1.25W and 0.63W.

Interfacing a Temperature Sensor to the Beacon

The Dallas Semiconductor DS18S20 temperature sensor outputs its data as text in serial format at 2400 baud. The selection of this temperature sensor necessitated the inclusion of the receive portion of a universal asynchronous receiver/transmitter (UART). The SX28 microcontroller does not have a built-in UART. The choices were to either add a UART chip to the circuit or implement the UART in software as a virtual peripheral. The authors chose the later path because adding a UART in hardware would not only add parts and cost, but the parallel nature of the data would require the use of more I/O pins on SX28 than the virtual peripheral approach. However, the virtual peripheral approach for the UART, while great from a hardware point of view, had a huge impact on the software and is detailed in the next sections.

Software Control of RF Power Attenuator

To select one of four choices, two bits suffice, and the initial design provided for two output pins to control the 3dB RF attenuators. However, upon further investigation the authors discovered that the RF attenuators are placed in series (not a binary combination), and the solution involving the least hardware turned out to be controlling each of the three relays with a separate output pin. To provide enough I/O pins to support the attenuation circuit, the authors eliminated the flexibility to select and fine-tune the audio carrier frequency at runtime, and chose 2 kHz as the “hard-coded” audio carrier frequency. The next section provides a brief overview of the sequence of software "flow" for the Audio Beacon.

Audio Beacon Software Flow

Figure 4 illustrates the software flow of the beacon control program. First, the program awaits a temperature value from the temperature sensor. The sensors transmits ASCII data, and it is stored "as-is" in memory. Second, turn OFF all attenuation relays, which causes all of the attenuation circuits to be bypassed, and full power reaches the antenna. Third, emit a series of zeroes. This sequence of zeroes provides a longer message and gives the PSK receiver an opportunity to adjust.

Form and transmit the message 'N' times, where N is a hard-coded value in the program. Then, check the attenuation DIP-switch. This switch allows the program to skip the attenuation sequence. If the user desires to skip the sequence, the program awaits another temperature value. If the user desires attenuation, the program turns on the first relay, which inserts the first attenuation circuit and cuts the power in half. A new message is formed that indicates the reduced power level, and it is transmitted N times. Then, the program energizes the second attenuation relay, which inserts a second attenuator again cutting the power in half. A message indicating the new power level is transmitted N times. Finally, the program turns ON the third attenuation relay. This cuts the power level in half again. The program forms a new message, transmits it N times, and then awaits a new temperature value.

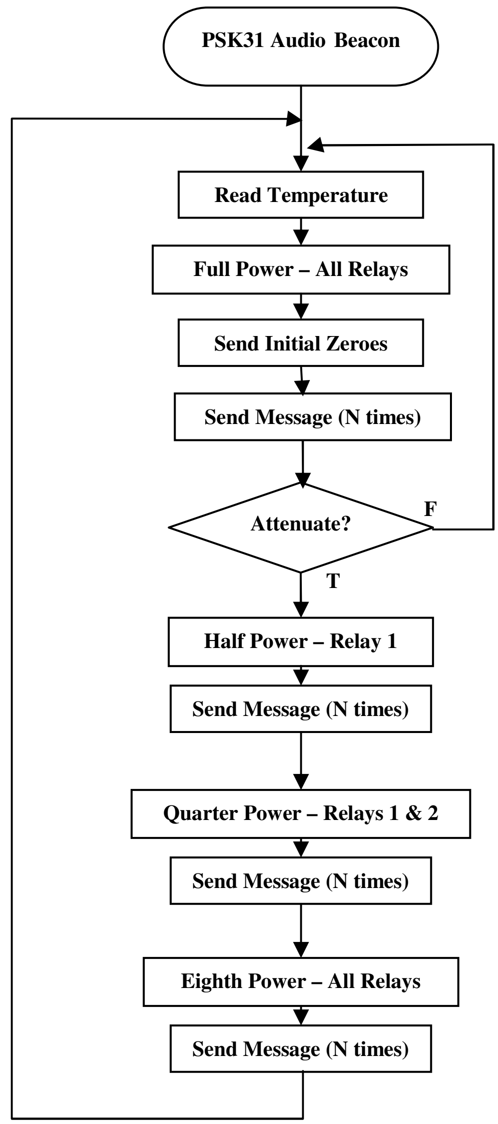

Figure 4-Program Flow Diagram

Note that the program reads the temperature *before* it creates the PSK31 signal. While there is no practical reason to read temperatures during the PSK31 signal, the decision not to do so, allowed for a much easier modification of the original program software because the UART virtual peripheral does not have to operate simultaneously with the PSK31 generation of the PSK signal.

Having eliminated the runtime selection of the audio carrier frequency, the interrupt could now have a fixed periodicity. The program generates the 2 kHz carrier signal with 64 stair-step values, and holds each value for 7.8125 µs. Using a 50-MHz resonator, the closest interval that could be obtain was about half that period, so we designed the interrupt software to ignore every other interrupt. The resulting interrupt timing, based on the capabilities of the SX28, was 7.88 μs which represents approximately a 1% error.

A flag was added to the interrupt service routine to indicate which function to service: virtual UART peripheral or PSK31 signal generation. When servicing PSK31 generation, the program is very similar to the original except for the addition of a state machine to control the dynamic generation of the message.

When serving as virtual UART, the 7.88 μs interrupt provides ample resolution for detecting 2400-baud serial data from the temperature sensor – approximately 53 interrupts occur during the period of a single bit. When the virtual peripheral software is in operation, it first waits for the serial data input to be idle for a period of 9 bit-durations. This assures that the signal from the temperature sensor is between messages, so that the program detects the beginning of the message. Once this is satisfied, it waits for the input to indicate the lead-edge of what should be the Start Bit of a data byte. Under the presumption that this is the beginning of a character, it ignores the next 80 (53 times 1.5) interrupts and then examines the input signal. Theoretically, it is sampling the input in the middle of the least significant bit (Bit #0) of the data byte. Then, it ignores the next 53 interrupts, and takes a sample in the middle of Bit #1. This is repeated for all eight data bits and the Stop Bit.

The program shifts received characters into a six-byte shift-register. The format of the data from the temperature sensor includes the temperature as "XXX.XX", where the X's are digits. When the decimal point appears in the appropriate slot of the shift-register, the reading of the temperature value is complete; the flag is set to indicate PSK31 operation.

The addition of the state-machine allows the text message to have several parts. There are fixed-text portions for each power level. The state-machine uses the six-byte shift-register as the text for temperature value.

Teaching the Software

The approach taken in this course was is to view the software from a high level – to see the software as a collection of components that work together. Next, we take a "top-down" approach looking at each component using pseudo code and flowcharts for the logic, and block diagrams of the devices. We view the data flow through the program and the devices. For those accelerated students who are prepared to understand the assembly language, we provide the actual code, and for cross reference purposes, we use the same naming scheme within our pseudo code and flowcharts as that used in the code.

433 MHz Data Acquisition System

The industrial, scientific and medical (ISM) radio band is a small section of the RF spectrum set aside or reserved internationally for the use of RF electromagnetic fields for industrial, scientific and medical purposes other than normal communication purposes in which channels are often designated. Sensors operating in the ISM Band are used to collect temperature remotely for re-broadcast as an RF Radio Beacon on 3.579 MHz. The ISM Band components of the system consist of a data logger, and RF transmitter and receiver. An RS232 signal serves as a common serial interface between these modules.

Temperature Data Logger

The temperature data logger provides real-time data for up to four Dallas Semiconductor DS18S20 temperature sensors. The sensors can be configured to read either in degrees Celsius or Fahrenheit with a basic resolution of 0.5 ºC. The heart of the data logger is a 12C509 8-Bit CMOS Microcontroller from Microchip Technology, Inc. Sensor data is transmitted serially via an RS232 serial interface set to 2400 baud, 8 bits, no parity, and one stop bit. Also, the data logger is powered from pin four of the serial interface and does not require an external power source. The data logger selected for this project is marketed as kit CK110 [5] and is easy to assemble at the beginner level. Since the temperature data is transmitted serially the data logger is easily interfaced with an RF transmitter module to provide a wireless connection to the PSK31 Audio Beacon.

RF Data-Link Transmitter

The RF transmitter for this project is low power and occupies the frequency range from 433.05–434.79 MHz with a center frequency 433.92 MHz. The advantage of using the ISM Band is that no FCC license is required in order to operate the transmitter. This transmitter is available "off-the-shelf" as a 433.92 MHz RF transmitter module and uses a modulation method known as "On-Off Keying (OOK)" which transmits the temperature data by simply switching the carrier signal on and off. The RF data-link serial receiver can be located up to 500 feet from the transmitter. A four pin RF module designated as TWS-BS3 is manufactured off-shore and is available at very low cost. The module is designed to operate into a $\lambda/4$ wire antenna approximately 17.3 cm in length. The stand-alone module is very useful but when integrated with AT89C2052 microcontroller and MAX 232 interface the composite module is easy to interface with the selected data logger. The module selected is shown in Figure 5 and is available in kit form (K173) and retails for $39.95. This module is easy to integrate into projects where fast prototyping and concept verification are required. Much of the interfacing is redundant and can be easily eliminated by developing a project specific printed circuit board (PCB). Figure 7 illustrates the packaging concept for the temperature data logger and transmitter modules. This assembly is mounted underneath a $\lambda/2$ aluminum ground plane with the $\lambda/4$ vertical mounted at the center of the ground plane. The transmitter is operated from a 9-volt battery and is easily placed at a remote location for data collection.

RF Data-Link Receiver

At the heart of the data-link receiver is the RWS 374-6 receiver module operating at 433.92 MHz. The modulation mode is amplitude shift keying and the unit supports data rates up to 4800 bps. The receiver selectivity is -108 dB and the channel spacing is 500 kHz. This module can be used separately or integrated into a package that supports a RS232 serial interface. The module selected for prototyping is shown in Figure 6 and is available in kit form (K174) and retails for $44.95. This unit supports receiver addressing and two selectable baud rates, namely: 2400 bps or 4800 bps. Communication synchronization is controlled by an AT89C2052 microcontroller. The kit contains a MAX232 interface chip and a 78L05 voltage-regulator.

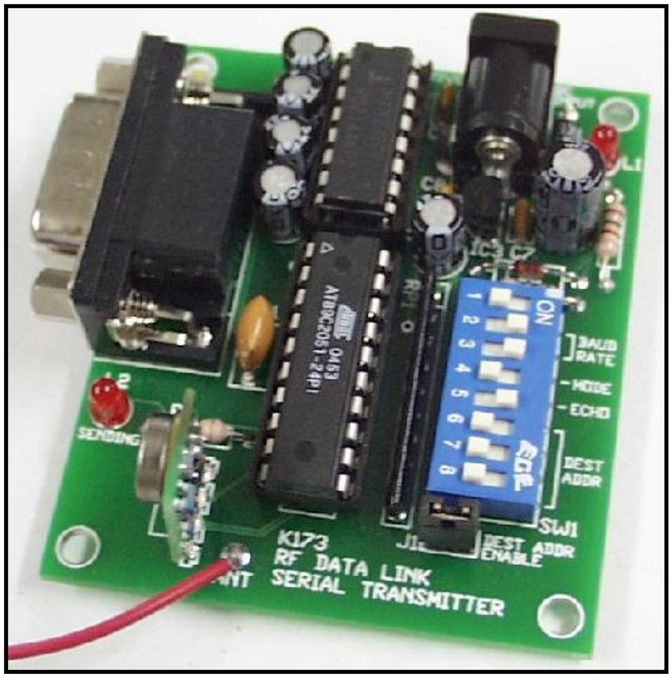

Figure 5- RF Data-Link Transmitter Module

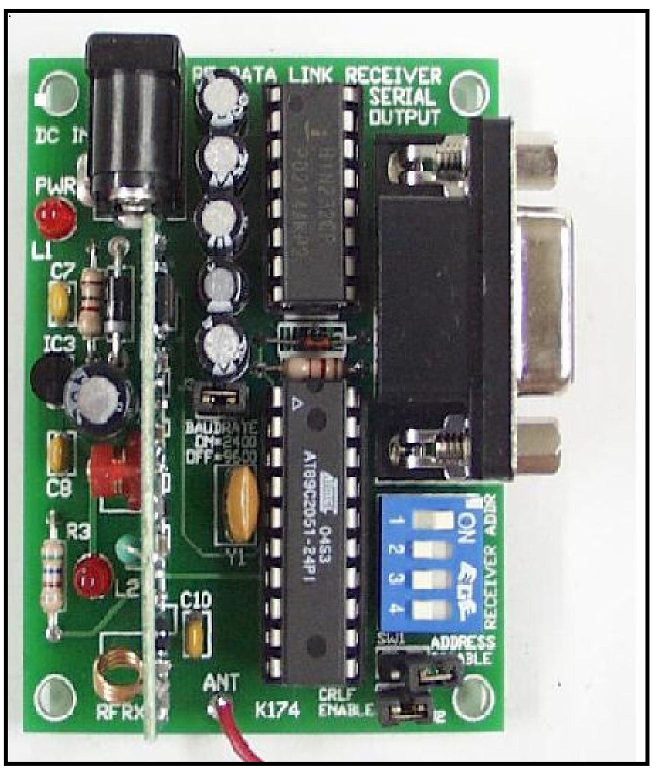

Figure 6- RF Data-Link Receiver Module

The composite cost of the modules comprising the data-logger and RF receiver/transmitter modules is summarized in Table 1. While not inexpensive, the total cost is not prohibitive especially considering that the modules can all be interconnected via an RS232 serial interface and that individual components are all mounted on high quality printed circuit boards.

Table 1- Cost of ISM Data-Link Components

Kit	Device	Cost
CK-110	Data Logger	$29.95
K-173	Transmitter	$39.95
K-174	Receiver	$44.95
	Total Cost =	**$114.85**

Project Sub-System Packaging Concept

The ISM Band modules together with Audio Beacon PCB are grouped together to form a functional sub-system. Notice that data is easily transferred between modules via an RS232 interface. A single 9-volt battery powers the combined Data-Logger and RF Transmitter sub-system. The Data-Logger only employs a single Dallas Semiconductor DS18S20 temperature sensor which can be seen protruding through the enclosure in the lower left corner of the cabinet.

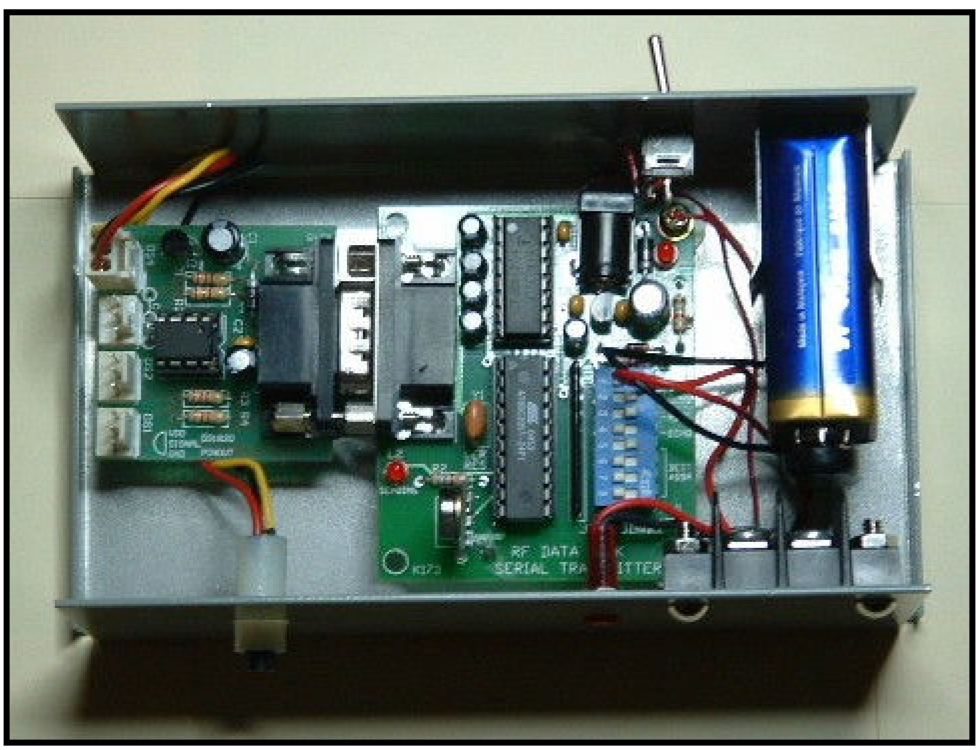

Figure 7-Packaging Concept for Data Logger and RF Transmitter.

The data-link receiver and the Audio Beacon transmitter are also packaged together to form a sub-system. Each of these packages is mounted underneath a 12 inch square λ/2 aluminum ground plane containing a λ/4 monopole antenna. The entire unit can be oriented to demonstrate either horizontal of vertical antenna polarization.

Figure 8 shows the second sub-system packaging concept. On the right side is the data-link receiver and it connects to the Audio Beacon transmitter on the left side. Again, an RS232 interface is used to connect to the data-link receiver. Observe that a RG174A coaxial cable is used for a transmission line connecting the monopole antenna to the data-link receiving antenna. In the lower left-hand corner of the enclosure are two DB9 connectors which are to send control information to the RF attenuator and the High Frequency (HF) single-sideband transmitter operating on 3.579 MHz.

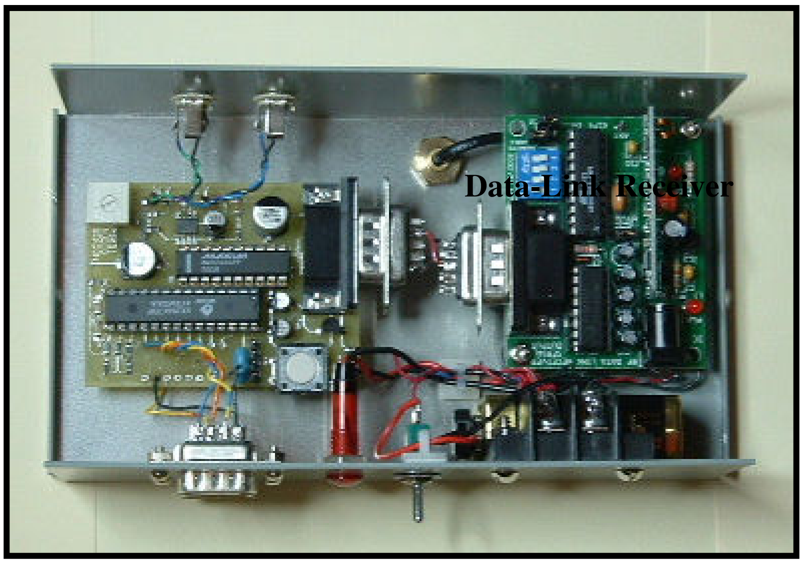

Figure 8- Data-Link Receiver and PSK31 Audio Beacon

The next section describes how the PSK audio signal from the beacon is converted to a radio frequency signal via a simple single sideband transmitter. To form a conventional RF Beacon operating on 3.579 MHz (Amateur Radio 80 meter band), the output of the class AB push-pull RF power amplifier is sequentially reduced by switching in-line a series of 3 dB attenuators until the output power reaches 0.5 watts. The transmit Beacon data string consists of station identification (Amateur Radio call sign), grid square location of the transmitter, return email address, local temperature in °F, and output power level.

Single Sideband Transmitter

The schematic diagram of the process of converting an audio signal into an RF signal at 3.579 MHz is shown in Figure 9. The PSK audio signal enters the circuit on the left side of the schematic and the signal is amplifier by a Class A transistor amplifier. The signal is then converted to a double-sideband suppressed carrier signal at 3.579 MHz via an SA-612 doubly balanced modulator. The upper-sideband is removed by a two-pole crystal filter. An RF amplifier stage further amplifies the single sideband signal. In order to increase the output to the 4-5 watt level a Class AB push-pull amplifier is used. An advantage of this type of amplifier is that the second harmonic of the transmitted signal is cancelled which in turn improves spectral purity of the transmitted signal and reduces the requirement for a sophisticated output low-pass filter. The circuit shown in Figure 9 was designed by Benson [6].

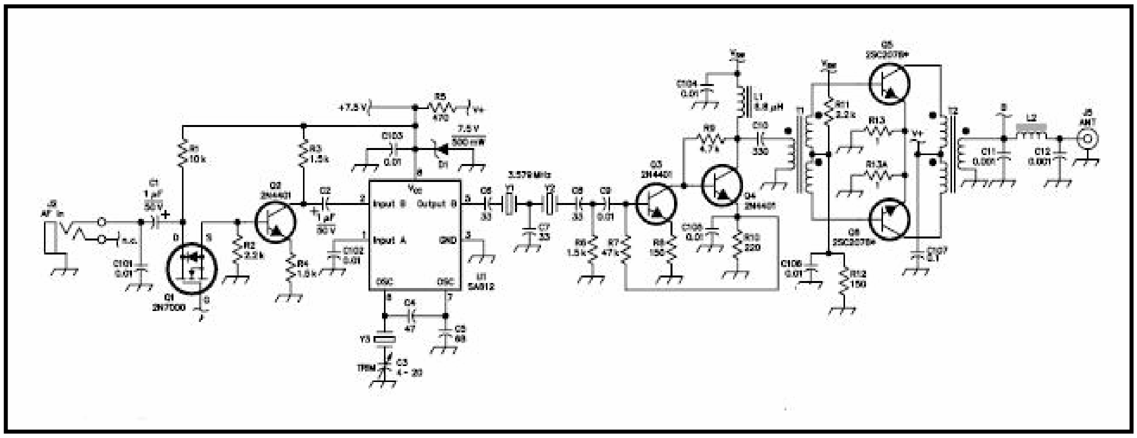

Figure 9- Schematic Of The SSB Transmit Unit Designed By Benson.

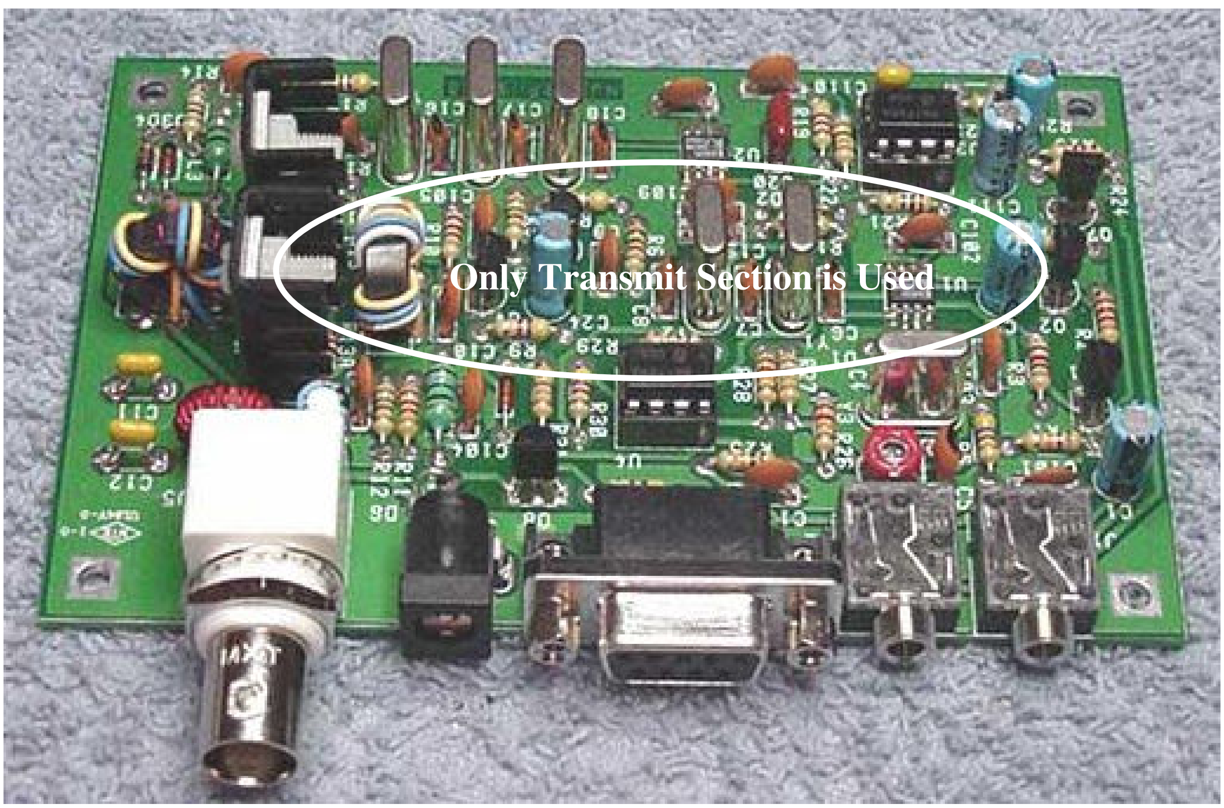

Figure 10- PSK31 RF Transceiver Designed By Benson and Built By the Authors.

The completed PSK31 transceiver is shown in Figure 10. Only the transmit section is used as illustrated in the schematic diagram shown in Figure 9. Note the heat-sinks on the push-pull final amplifier transistors and the white BNC connector used for the SSB radio frequency output.

The RF output from this transmitter is approximately 4-5 watts and needs to be attenuated and needs to be attenuated in order to turn the system into an RF beacon. To form a conventional RF Beacon operating on 3.579 MHz (Amateur Radio 80 meter band), the output of the class AB push-pull RF power amplifier is sequentially reduced by switching in-line a series of 3 dB attenuators until the output power reaches 0.5 watts. The transmit Beacon data string consists of station identification (Amateur Radio call sign), grid square location of the transmitter, return email address, local temperature in °F, and output power level. The he next section describes the attenuator built for this purpose.

RF Attenuator Unit

The RF attenuator shown in Figure 11 is constructed via a technique known as "Manhattan Style." This technique consists of gluing isolated pads of printed circuit board material to a base copper-clad printed circuit board which serves as an electrical ground plane for the project. The isolated pads are arranged to accommodate the requirements of the schematic diagram. These pads form isolated islands which serve as "tie points" for circuits components which are soldered to the strips.

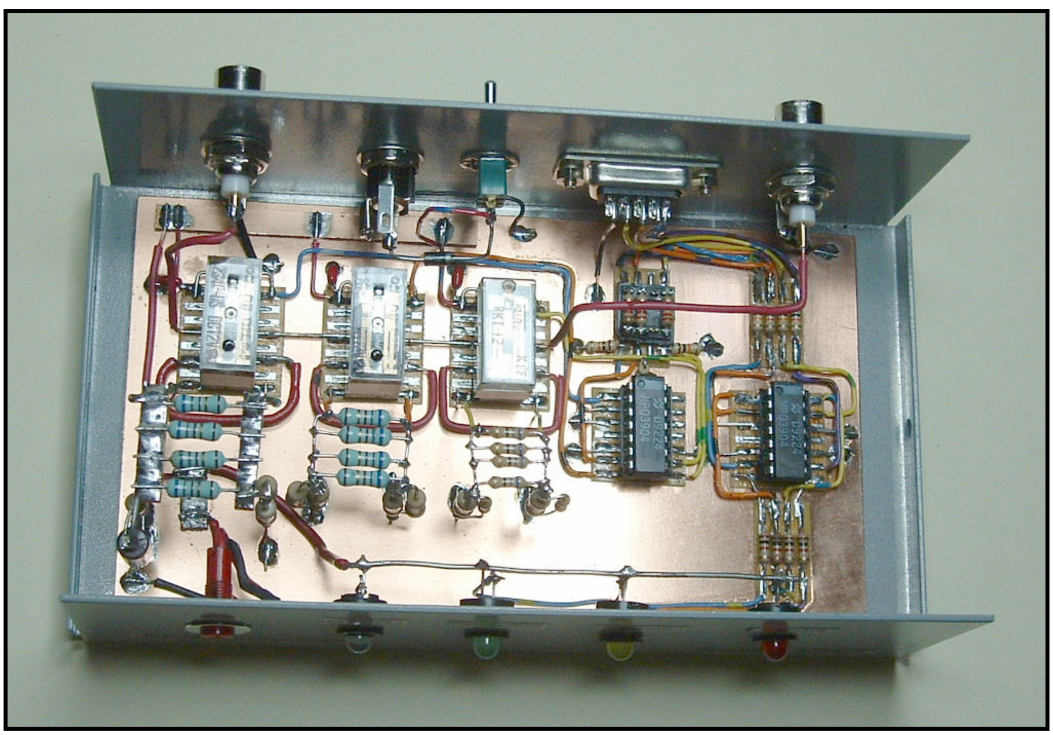

Figure 11- RF Beacon RF Attenuator Unit

The result is a functional circuit which offers an alternative to the standard plastic prototyping board used for laboratory experiments. An additional advantage of this technique is that it provides insight to the layout of the printed circuit board.

Figure 12- Front View Of RF Attenuator.

The unit consists of three twelve-volt "dc" DPDT relays controlled by the SX28 microcontroller is the audio beacon. Radio frequency power is absorbed using 3 dB pads configured in the form of a "**π**" network. Each 3dB pad reduces the available RF power by 50%. Initially, no power is absorbed by the attenuator and the beacon signal is transmitted at 5 watts. Sequentially the power is reduced in the following sequence: 5W, 2.5W, 1.25W, and finally 0.625W. At each power level the beacon sequence is transmitted and then the power is sequentially reduced and the signal re-transmitted at successively lower power levels. The BNC connector for power output to the dipole antenna a 3.579MHz is shown in the upper right corner. Note the IC chips are actually an array of 2N3904 transistors used to control each relay. Different color LED's are turned on for each power level. The unit can achieve a total of 9 dB of signal attenuation

Project Notebook

Each student is required to maintain a project notebook in the laboratory to record the student's journey through the course with emphasis being placed on recording events and ideas as the prototype concept develops. Many students also use the notebook as a journal and often record their frustrations as well as their successes. Laboratory time is used to form discussion groups which deal with problems encountered during the building and testing phase of the project. The final packaging concept is often discussed and students share ideas during group discussions. Each student is required to develop a "Gantt Chart" to show project progress during the project. A handout is given in lecture that describes the Gantt Chart technique for implementing the project schedule, but the actual development and updating of the chart occurs during the laboratory period. The chart must be included in the student notebook.

Student Assessment

To date, qualitative and quantitative student feedback on the course structure and project has been very positive and representative selections of student comments are presented in the following student assessments.

The following comments are extracted from course assessment forms developed by the authors. Four questions were presented to the students during the last class of Digital Communications during Winter Quarter of 2007. Overall, the comments are very encouraging:

1.0 Did the class project illustrate the concepts presented in the course?

> "This project covered just about all of the concepts presented in the course. We explored design considerations, in testing circuits to find current draw, so that overall power consumption could be considered. We developed testing procedures for step-by-step project assembly. We learned troubleshooting skills for a complex multi-component circuit and redesigned aspects of the circuit for improved performance."

2.0 Was the class project effective in enhancing your technical skills?

> "The project introduced the soldering of surface mount components onto a printed circuit board, which I had no prior experience with in the past. In addition this project allowed us to work on design improvements for the project to overcome some small problems in interfacing to the attenuator unit. Also, it was necessary to use a wide range of test equipment to accomplish the tasks that were outlined in the project, and troubleshooting skills were a must. I feel that the project provided an excellent review that spread across concepts which had been presented in several different courses. It was interesting to see a practical application of all of the concepts that were covered in the course. This was also my first experience with soldering surface mount components to a PCB, so a lot was gained from going through the design and build process."

3.0 Was the class project rewarding?

> "I feel that this class project was very rewarding and I enjoyed seeing the subsystem components coming together to form a complete system. The project walked us through a complete system which emulated concepts that I will need in the senior design process, and in addition to the material I learned about RF systems the course provided a review of earlier coursework. I feel that I am well prepared to start senior design next year. I also would have liked to learn about Microsoft Project beyond the simple Gantt chart because I plan to use project management software for senior design."

4.0 Rate this course overall, based on its effectiveness and helpfulness in utilizing your past coursework experiences and preparing you for senior design.

> "This course proved to be quite enjoyable. Introducing ExpressPCB and printed circuit board design together with soldering surface mount components was a high point of the class. Also this was the first large scale project system project that I have encountered, outside a previous Honors project that I completed. One of the nice things about the course is that once it is all said and done you are able to walk away with a completed circuit/project that has a certain level of professionalism that cannot be achieved in labs where simple breadboards and jumpers are used. Also, I feel that this course provided a solid foundation that can be taken into Senior Design."

Conclusion

This junior level laboratory course capstone design project relies heavily on knowledge and skills previously learned in both the analog and digital electronic sequences at the University of Cincinnati. In addition, the Audio Beacon Project provided a vehicle to introduce Digital Communication concepts, construction techniques, printed circuit board layout techniques, and packaging concepts. Only a modest amount of construction, testing, and calibration skills are required for successful completion of the project. The authors found the student attitude towards the course and subsequent feedback to be most rewarding, and were very encouraged by the level of student involvement in the project. In addition, the effort expended in hardware and software development yielded a more robust Beacon Concept and offered Electrical and Computer Engineer Technology students an opportunity to gain a "broader technical view" of the radio frequency communication process.

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