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Project-Based RF/Microwave Education

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Abstract -- Immediate application of learned fundamentals to laboratory work is standard practice in Electrical Engineering Education, but student explorations of basic RF/microwave circuits at the transistor-electomagnetics level are particularly challenging. This paper describes an interconnected set of basic electromagnetic and transistor-level RF/Microwave modules that may be assembled into a short range wireless link or modulated scatterer radar system. These Analog/RF/Microwave building blocks are used across the Senior and Graduate level curriculum.

RF Education, Mixers, Receivers, Modulated Scatterer

I. Introduction

The fundamentals of microwave transistor-level circuitry, electromagnetics, analog signal processing and an introduction to basic RF tools such as the Smith Chart and Vector Network Analyzer are well covered in current textbooks. Students are often exposed to hardware in demonstration laboratories with carefully staged experiments. But students learn best when immersed in an environment that encourages exploration and creativity, taking individual projects through the sketch-design-build-measure-repeat cycle [1,2]. Evolution of student designs requires repetition, and implicit in that process is failure of early attempts and long hours at the bench [3]. This process is fundamentally different from the common practice of lab experiments that efficiently and safely expose 40 students to a single fragile and expensive 40 GHz Vector Network Analyzer in a carefully controlled environment. The building blocks and experimental RF/Microwave hardware described in this paper encourage a risk-taking, adventurous atmosphere. The blocks are then immediately assembled into working wireless and modulated scatterer radar systems, to the amazement and delight of students and visitors to the University.

II. A Set of RF/Microwave Building Blocks

Figure 1 is a complete modulated scatterer radar system including RF/microwave signal source, splitters and couplers, antennas, I Q downconverter, analog baseband signal processor, RF and baseband filters, audio amplifier and target. Above 1 GHz the individual blocks may be fabricated using surface mount components on printed microstrip structures. Below 1 GHz a combination of surface mount or through hole components and hand-wound inductors is used. Students are presented with a working benchmark design for a particular block and given the task of modifying it in some significant way--a different frequency range, supply voltage, or reduced current are recent examples. The radar blocks may be easily reconfigured as a low power wireless link.

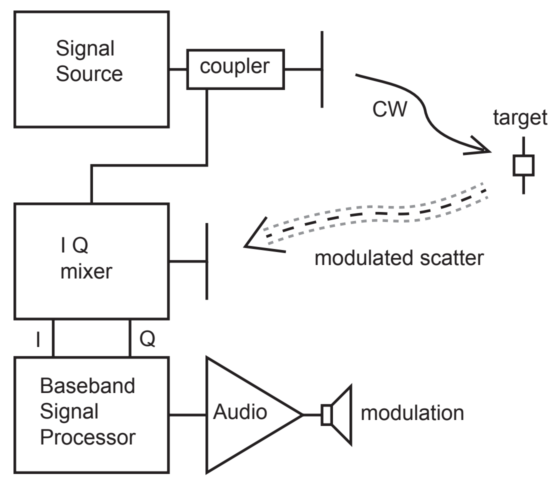

Figure 1. Modulated Scatterer CW Radar

The modulated scatterer radar [4] is an ideal platform for student exploration because the complete system: RF/microwave hardware, targets, baseband signal processing, antennas and electromagnetic path, operate conveniently in a small space and may be easily moved. A benchmark system using a 6 GHz Dielectric Resonator Oscillator is shown in photographs 1 and 2. Output power is 0 dBm, and typical range from a spinning dipole target is a few meters. The baseband signal processor in photo 2 is described in [5], and the IQ mixer in photo 1 was developed for the near-field probe described in [6,7].

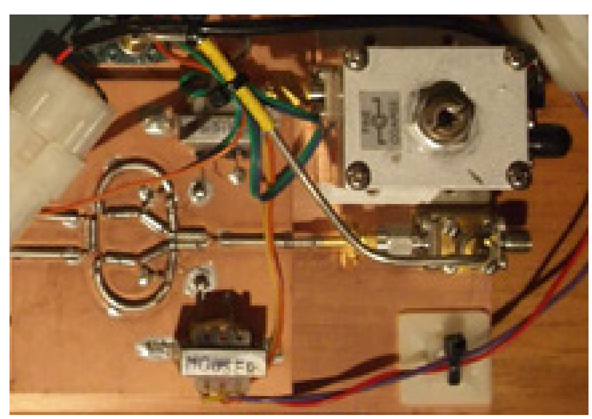

Photo 1. 6 GHz I Q mixer and DRO

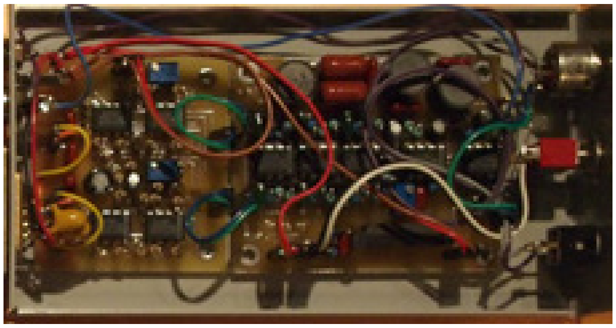

Photo 2. IQ Baseband Analog Signal Processor

III Designing New Blocks

Unlike a simple Doppler radar, the modulated scatterer radar in Figure 1 includes an image-reject downconverter. Doppler from a moving target results in one shifted signal that may be detected as a difference, whether the shift is up or down from the radar oscillator. A more advanced approach is needed with modulated scatterers.

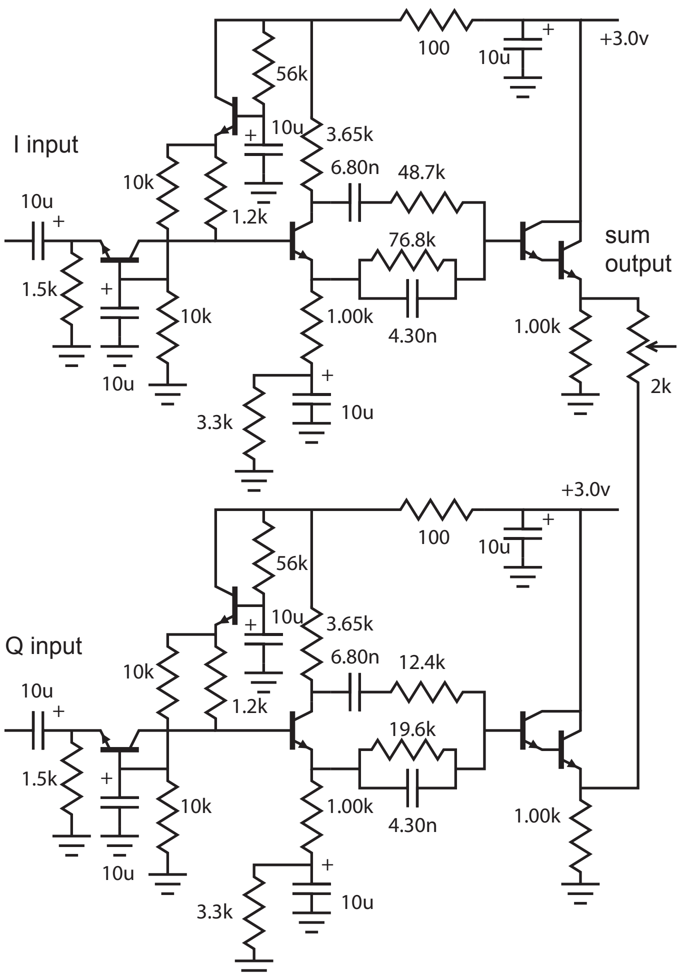

Figure 2. Simplified Baseband Signal Processor

Modulated scatterers generally produce a pair of sidebands above and below the radar frequency, and the downconverted pair of sidebands constructively and destructively interfere at baseband. An I Q mixer and baseband signal processor allow independent recovery of either--or both--sidebands. The basic math for I Q demodulation is fundamental to RF design, and immediate application of basic concepts to working hardware is instructive to students. The general purpose analog baseband signal processor in photograph 2 is highly capable, but overly complex for a student project. Although the baseband signal processing is done at a near-zero IF, the concepts are more familiar to RF than AF designers: 50 ohm LNA ports, precise phase matching between I and Q channels, 90 degree phase difference all-pass networks, and microvolt signal levels. Figure 2 is a recent design for a simple starved-current baseband I Q signal processor that draws 2 mA from a 3v battery. The networks were derived from those presented in [8]. Although deceptively simple, the basic circuit theory represented in figure 2 is rich with opportunities for study. Student exercises include the effect of component tolerances on sideband suppression and the impact of starved current on dynamic range. Photo 4 is a compact variation of the circuit in figure 2 for 4.5v dc supplies. NPN and PNP versions are mirror imaged and connected in series to a 9v battery.

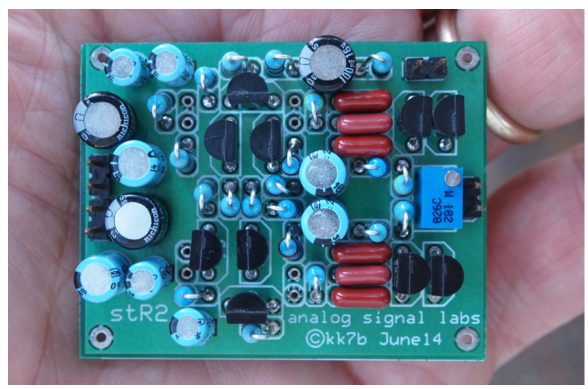

Photo 4. Compact I Q Baseband Signal Processor

The modulated scatterer technique works well from VHF through sub-mm waves, with appropriately scaled hardware. Photo 5 shows a new I Q mixer design being evaluated at 144 MHz [9]. The I and Q baseband outputs of a mixer pair at any RF frequency connect directly to the 50 ohm low noise baseband inputs of the circuit in figure 2.

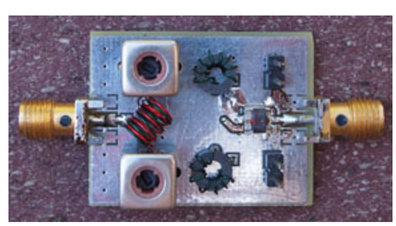

Photo 5. VHF I Q mixer

Students also build low power wireless links and conduct experiments on the Amateur Radio bands. The benchmark VHF signal source design shown in photo 6 for 50 MHz and 144 MHz developed for 2009-2010 classes is now included in the ARRL Handbook for Radio Communications [10].

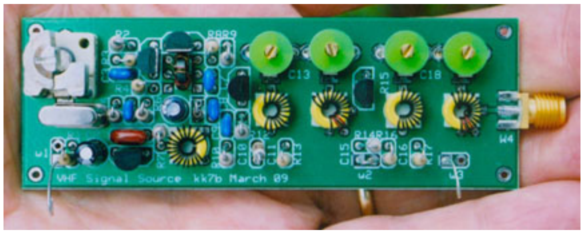

Photo 6. VHF Signal Source

IV. Evaluating the Hardware

A significant advantage of designing and building individual blocks for a working radar or short-range wireless system is that the system itself becomes a complete test laboratory for each block. With blocks designed for power by 9v batteries as in photo 4, there is no need for even bench power supplies. The working hardware system may be evaluated as a complete system outdoors in an appropriate location accessible on foot. Photo 7 shows graduate students Liz Kusel and Bryant Baker deploying a student-designed sonobouy in the Willamette River, a short walk from campus.

Photo 7. Deploying a Student-Designed Sonobouy

A modulated scatterer radar system needs two pieces beyond the RF/microwave hardware: a target, and an output device. Immediate learning takes place with the simplest targets--a spinning dipole on a small electric motor or the switched diode in photo 8--while listening to the radar output. Once the basics are demonstrated, students rapidly produce sketches for clever, more advanced targets. The crossed dipoles fed with different audio tones in photo 9 allow simple polarization studies. A four corner reflector with independently modulated diodes is shown in figure 5. A floating version with four tones has been used to study water wave action.

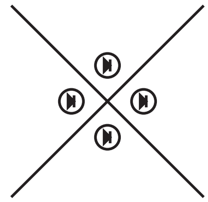

Figure 5. Four Corner Reflector

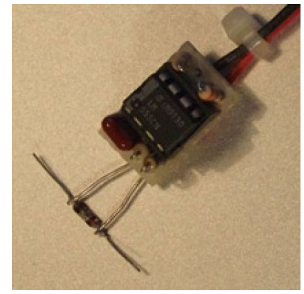

Photo 8. 555 Timer and Diode Target

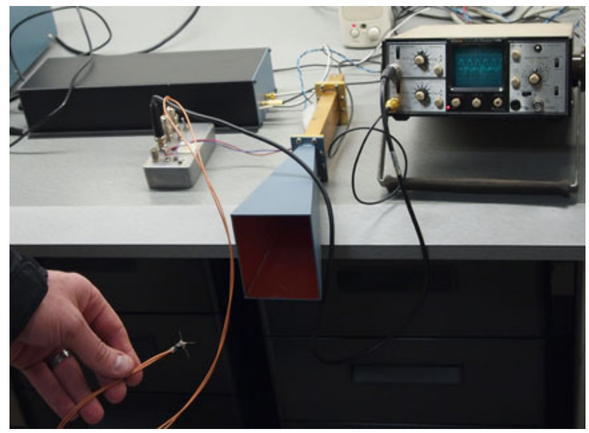

Photo 9. Crossed Dipoles with different audio tones

Sketching, designing, building and deploying basic blocks in simple modulated scatterer and wireless systems provides opportunities and incentive for students to develop advanced laboratory and design skills. Low-cost and high-risk projects encourage multiple design-fabrication cycles, and students learn that catastrophic failures are common while pushing the experimental envelope. Photo 10 shows student Chelsea Throop making emergency repairs at the bench.

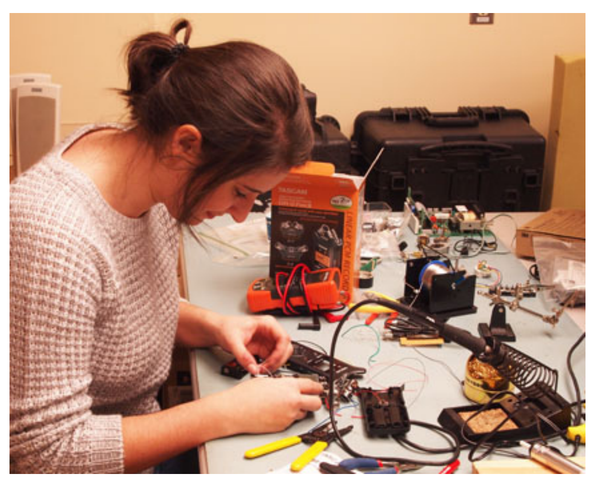

Photo 10. Students quickly become adept with tools

The ear-brain processor is profoundly powerful, but baseband digital signal processing can now literally put a spectrogram in a student's pocket. A spectrogram displayed on an iPhone screen is shown in photo 11. Setting the handset next to the modulated scatterer radar speaker permits identification of many targets with different tones. Such experiments encourage students to explore fundamental signal processing concepts across the curriculum, with applications from millimeter waves through undersea acoustics.

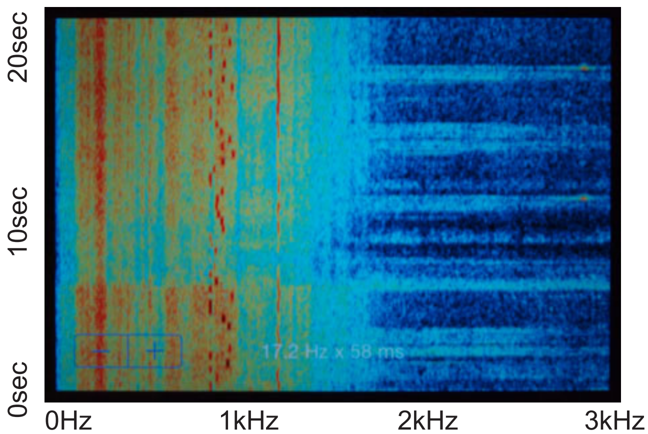

Photo 11. Audio Spectrogram on iPhone

V. Encouraging Design/Construction/Evaluation

A significant advantage of the RF/Microwave field is that engineers typically design individual building blocks with 50 ohm input and output ports. This facilitates both interchanging newly designed student blocks with benchmark blocks in an existing system, and evaluation and comparison of individual blocks in the laboratory using conventional bench supplies, signal generators, spectrum analyzers, oscilloscopes, and vector network analyzers. Students experience the full range of RF/microwave engineering--from sketches of new concepts to design and measurement of circuit blocks in the laboratory and ultimately deployment in the field.

Benchmark building blocks are used for detailed design study and exposure to construction methods during the first weeks of each class. Students then experience a complete working system in the lab, assembled from benchmark blocks and evolved designs by previous year students. While professionally designed benchmark modules may be perceived as representing an advanced skill level, prior art by last year's students is clearly attainable. Each class naturally competes with earlier students, and a challenge of teaching is staying one step ahead. Fabrication is done on campus in the student-run Laboratory for Interconnected Devices, with 3D printing, PC board routing, wave soldering and laser cutting machines, and basic machine tools. Electronic and microwave components are stocked in the IEEE store adjacent to the Prototyping lab. A full range of RF, microwave, and analog test instruments is available in two additional laboratories open to students.

VI. Conclusions

A system of building blocks including signal sources, I Q mixers, baseband analog signal processors, audio amplifiers, antennas and couplers has been evolved over the past decade at Portland State University. Each class assembles existing blocks into a working low power wireless link or modulated scatterer radar, and then performs a detailed study including design, fabrication, and construction of a new block for the system. This approach allows immediate application of learned theory to detailed design, fabrication and test engineering that contributes directly to the performance of a working modulated scatterer radar or wireless link. Each student includes individual contributions in a portfolio of personal work. The recent success of our students in international design competitions supports our belief in the effectiveness of this approach.

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