Application Note

PowerSage Integration into a Motorola XPR4500 Mobile Radio

Energy Savings with On-Demand Power®

Executive Summary

Packet Digital has developed and patented On-Demand Power®, a dynamic power management technology that provides real-time, system-wide energy savings for military radios, computers, and other portable electronics. Using Packet Digital's PowerSage® power management integrated circuits, designers can shorten their design cycle and reduce the non-recurring engineering costs to integrate dynamic power savings. Systems using PowerSage benefit from lower energy usage, extended battery life, reduced heat, and in certain designs, lighter/smaller systems.

Packet Digital researched the potential for energy savings in C4I electronic systems representative of devices carried by Marines on foot patrol. Selecting a Motorola XPR4500 radio as a surrogate, Packet Digital demonstrated a 34.5% energy reduction in the radio during normal operation, equating to a 53% battery life improvement. Based on data provided by the Office of Naval Research, the calculated reduction of battery weight for a foot patrol on a 96 hour mission (without resupply) exceeds 12 pounds per Marine, and the cost reduction based on the reduced battery expenditures exceeds $20,000 per mission.

Figure 1: Packet Digital Portable Demonstration of On-Demand Power for Military Radios

1 Summary

Power management within complex electronic designs is, by itself, extremely complex. The state-of-the-art implementation includes characterizing and projecting the system operation and functions with usage models of operation, and then creating and verifying software to execute various standby and sleep states for components. This software effort usually occurs at the completion of the software development for normal operation, and may be jettisoned due to schedule, cost, or resource limitations.

Additionally, there are fundamental flaws with this state-of-the art approach. Usage models are extremely difficult to create accurately and are rendered ineffective if additional applications are loaded or situational conditions alter the usage of the system. Placing circuits in standby or sleep states effectively shuts off the capability of the functions, and there may be circuits (such as radio receivers) that are not allowed to completely lose operation. Finally, power management through software control has little effect on the battery life, since large portions of the system may not have any dynamic power management.

Packet Digital has developed a new paradigm in dynamic power management. On-Demand Power addresses the shortcomings of software based power management by moving the control out of the microprocessor and placing the intelligence inside the power management integrated circuits (PMICs). Packet Digital's PowerSage PMICs provide high efficiency power distribution with integrated load management, resulting in "just in time/just enough" system wide power management.

The hardware-based power management of the PowerSage PMICs is based on the following approach:

- PowerSage PMICs will unobtrusively monitor activity within the system, by analog and digital detection of control signals;
- PowerSage PMICs will calculate the energy demand of the electronics, based on correlation of the measured activity;
- PowerSage will dynamically adjust the supply voltage to the electronics without halting the system.

This innovative approach scales to electronic systems from simple wireless sensors to complex multi-band/multi-mode radios and tactical computers. Packet Digital has demonstrated battery life improvements of 400% in unattended ground sensors with PowerSage power management integrated circuits.

In this research, Packet Digital targeted the battery life improvements in a military radio, targeting devices such as the AN/PRC-148, AN/PRC-153, or the AN/PRC-117F. Due to expense and lack of readily available design documentation, Packet Digital chose to demonstrate power savings on a commercial radio with similar operating characteristics in transmit power, receive sensitivity, digital signal processing, software defined radio protocols, and user interface. All analysis and measurements were conducted on a Motorola XPR4500 radio.

Packet Digital analyzed the operation of the system and defined three states for user-control:

- Transmitting – where the radio is actively sending data or voice wirelessly. During this mode, the system should be configured to provide the maximum amount of power defined by the user settings.
- Receiving – where the radio is receiving, decoding, storing, and providing data or voice to the user that has been wirelessly captured. During this mode, the system should be configured to provide the maximum amount of power defined by the user settings.
- Idle – where the radio is scanning the communications channels and the user settings for incoming data or commands. During this mode, the system should be configured to use the minimal amount of energy while being 100% responsive to incoming commands or communications.

It is expected that the Idle state dominates the usage profile, with the Receive and Transmit states occurring less than 10% of the time. Therefore, the Idle state was targeted for the reduction of energy usage to improve battery life.

A power management controller was designed and debugged to implement PowerSage hardware based power management. By modulating the supply voltage during the Idle state, Packet Digital demonstrated battery life improvement while not affecting the user perspective of radio operation. With the dynamic power management, there was no noticeable change in operation in terms of delay, functionality, control, or performance. However, when using the PowerSage circuitry,

- The total energy of the radio during the Idle state decreased from a nominal value of 5.8 Watts to 3.8 Watts, representing a decrease of 34.5%.
- The battery life of the radio, which is dependent on the energy consumption, is calculated to increase by 53%. Actual battery life improvements are likely to exceed the calculated value, as battery capacity is known to increase with decreased discharge rates.
- Increased capacity of batteries will improve battery life of rechargeable cells, and allow for a greater number of recharge cycles.
- The heat fins on the rear of the radio measured a 16° F temperature decrease, since the reduction in energy consumption corresponds to a reduction in heat generation. The reduction of heat is particularly important for covert systems that may be compromised due to thermal signatures.
- The improvement of battery life is calculated to reduce the number of batteries carried on foot patrol by Marines. Based on numbers provided by the Office of Naval Research, Packet Digital projects the reduction of 12 pounds of batteries per Marine and a cost reduction of $20,000 per mission for a 96 hour patrol without resupply.

2 Introduction

The overload of electronic systems presents a liability for warfighters on missions. Battery weight represents a major component of the warfighter equipment payload, at certain times totaling up to 100 pounds. Making the problem worse is the requirement for warfighters to bring back depleted batteries to leave no positional evidence. Current battery technologies have reached a performance plateau. Although the energy density has improved, dead batteries continue to cause warfighters' electronics equipment to shut down without warning. In addition, most of the batteries deployed cannot be recharged.

As we look to the future, we can assume the problem will only get worse. Multiple programs are in development that will add sensor networks to the warfighters' communication suite. Feature enhancements to Blue Force radios will drive higher demands for battery power. In all cases, the trends are for increased battery demand, which is already a critical point of failure for warfighters' electronic weaponry. The demand for energy has historically increased at a faster rate than the ability to supply it. Therefore, power management in electronics must be changed to determine the exact amount of energy that is needed by the application and deliver that amount where needed, as needed.

This is precisely the approach used by Packet Digital, which is relevant to laptops, radios, sensors, and control systems. Using our patented On-Demand Power technology (ODP), Packet Digital has tripled the life of wireless sensors, reduced the size of asset tags by 40%, and improved the performance of RF receivers by 10 dBm. While these devices have different architectures, applications and complexities, they all benefit from Packet Digital's clear vision of just-in-time/just-enough power management.

Packet Digital developed ODP technologies to drive high-efficiency power management for electronic systems, independent of application, architecture, or packaging. By continually monitoring the application's demand for energy, ODP technology dynamically adjusts clock frequencies, supply voltages, and circuit impedances for maximum battery life, increased miniaturization, and improved performance. The dynamic control may be commanded by a user or a microprocessor, or be completely autonomous, allowing the user to concentrate on his/her mission while the system is continually retuning itself for maximum efficiency and performance. The autonomous mode of ODP circuitry will adjust the system parameters as needed without operator intervention, and does not require complete characterization of all load profiles prior to deployment.

3 Methods, Assumptions, and Procedures

In this research, Packet Digital leverages the successful demonstrations and technology developments for previous commercial and defense programs. The primary objectives of this effort are to:

- Analyze the architecture for recommended C4I electronic systems, determining the most critical system that would benefit from extended battery life and a reduction in batteries for deployment
- Develop a PowerSage demonstrator to analyze energy savings, weight and cost reduction, and performance improvements
- Develop the chip architecture for selected C4I PowerSage device

Packet Digital's advanced power management provides battery life extension, energy conservation and equipment miniaturization. Smaller, lighter, and less expensive power sources benefit the warfighter by providing more covert technology, lighter loads, longer lasting equipment and putting more tools in the tool box. Packet Digital has created the solution that can be integrated into Department of Defense C4I electronics to benefit the warfighter.

Packet Digital has completed research and development programs for the Battle Command Battle Laboratory, Marine Corps Systems Command and the Defense Microelectronics Activity. Packet Digital was given the highest scores for customer satisfaction by the Battle Command Battle Laboratory for the on-time delivery and quality of design and manufacturing. In research for the Defense Microelectronics Activity, Packet Digital exceeded program objectives of 50% system weight reduction of a wireless sensor system by using On-Demand Power technology to extend battery life by 400%. With Packet Digital's technologies, the weight of a fielded system for a 60-day deployment was decreased by 63% from the state-of-the-art reference design. In the research for the Marine Corps Systems Command, Packet Digital demonstrated 25% energy savings in the Panasonic Toughbook. For this program, Packet Digital used the proven design methodologies and program management as used in our previous, highly successful research programs.

A list of C4I devices typically carried by a PM-MERS team was provided to Packet Digital by the Office of Naval Research prior to the start of the research. Several devices of the squad inventory were selected as candidates for advanced power management, specifically the communication systems. However, these systems are not available to Packet Digital, nor are their engineering schematics or layouts, which are necessary for the modifications and measurements that Packet Digital requires as part of the research.

With approval from ONR, Packet Digital purchased commercial radios from Motorola normally intended for business applications. The XPR4500 two-way radio has integrated global positioning satellite (GPS) reception, 160 operating channels, 45 Watt transmitting power in the VHF communication range, and integrated voice/data transmission capabilities. These characteristics have similarities to the AN/PRC-117F, although the AN/PRC-117F have additional features to provide secure communications. Since Packet Digital's demonstration of On-Demand Power is based on system activity and not dependent on actual data on the communications channel, using the Motorola XPR4500 as the demonstration vehicle would be sufficient to predict operation on the military radios. A full specification of the Motorola radio is found at their web site (www.motorola.com).

Packet Digital was able to receive the complete documentation package for operation and repair from a local Motorola radio reseller and repair center. With this information, Packet Digital made power measurements of circuit functions, and defined operational states that were used for the power management logic and control. Figure 2 below shows the power distribution and major subsection architecture of the XPR-4500.

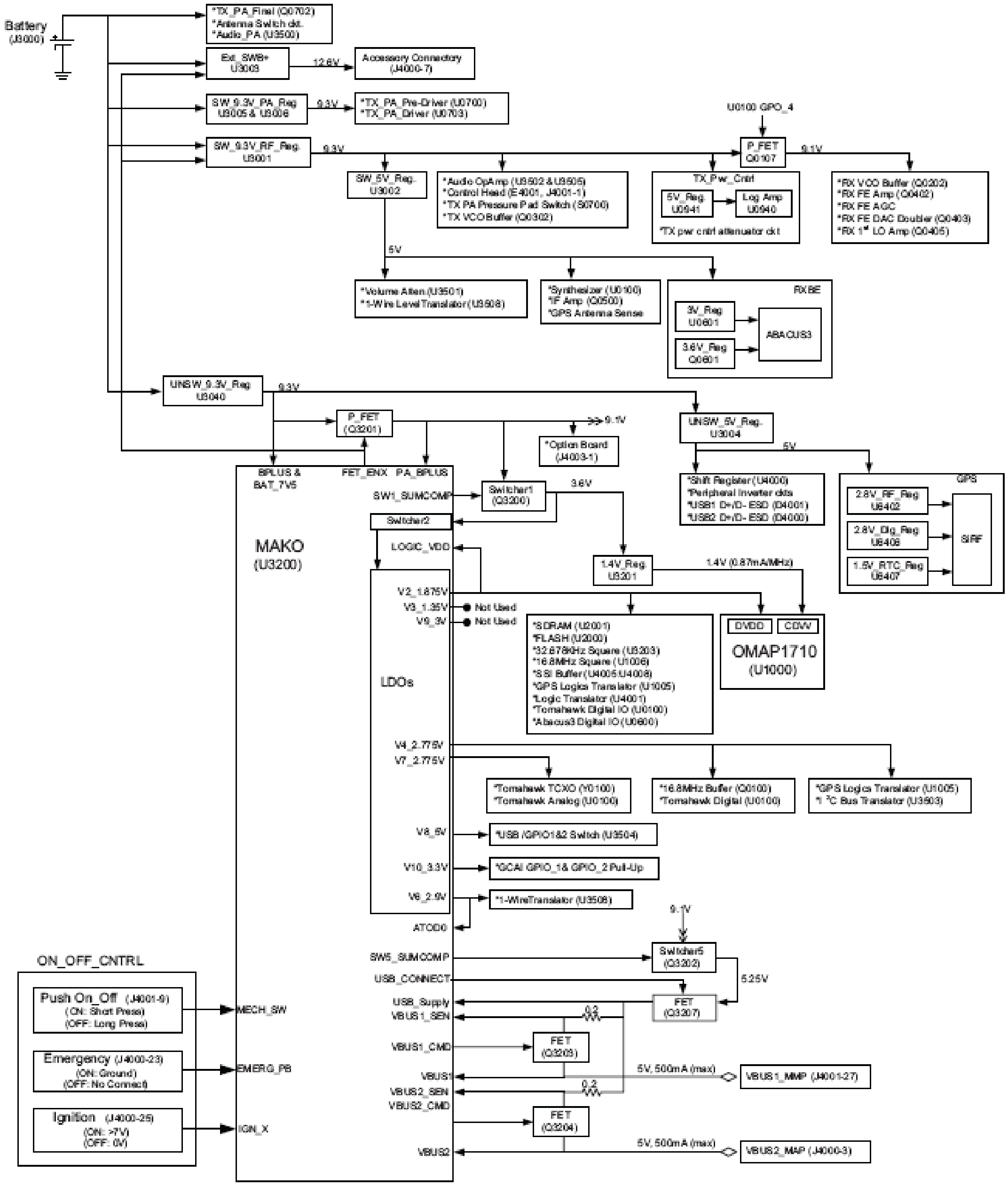

Figure 2: Architecture and power distribution of the Motorola XPR4500

A review of the XPR4500 architecture shows greater than 15 supply voltage domains. Since the target is to replace a standard power management integrated circuit with Packet Digital's PowerSage power management integrated circuit, a power distribution map needed to be generated. The purpose of the power distribution map is to understand where the energy is consumed during different modes of operation, which allows the specific targeting of devices that have the greatest impact on improving battery life. Figure 3 illustrates the power distribution of the XPR4500 while in idle state, defined as when the radio is listening to the communications channel but not transmitting or actively receiving voice or data.

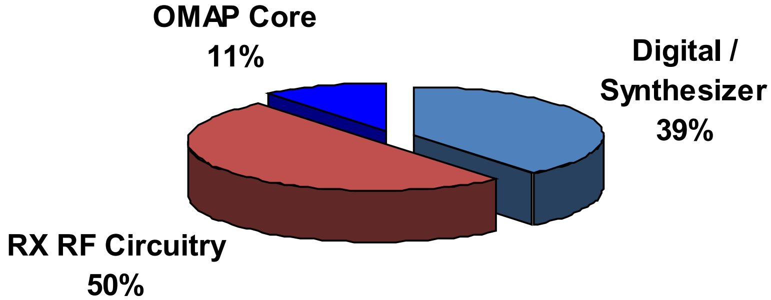

Figure 3: Power Distribution of the XPR4500

Packet Digital chose to provide autonomous power management to the receive circuitry of the radio, shown in Figure 3 as RX RF. Since this circuitry consumes 50% of the power (approximately 2.9W), savings in this function would have significant impact on the overall energy consumption. No changes would be made to the power distribution during Receive modes (when the radio is actively decoding voice and/or data), or the Transmit mode.

4 Results and Discussion

By providing dynamic power management with Packet Digital's patented On-Demand Power technology, the receive circuitry used considerable less energy during the Idle mode. With the power management, there was no detectable loss of operation, no discernable latency introduced with the power management, and no noticeable change in system functionality. Packet Digital demonstrated the results to program management at the Office of Naval Research during a debrief in Arlington, VA on March 23, 2010. Figure 4 shows the portable demonstration system created during this research program. The radio on the right side of the unit is unmodified, and the radio on the left has Packet Digital's power management for reducing energy. The laptop shown on the left shows energy usage in real-time, as the On-Demand Power circuitry is enabled.

Figure 4: Packet Digital Portable Demonstration of On-Demand Power for Military Radios

In normal operation, the radio will switch between the Idle states and the Receive states, using a nominal 5.8 watts. When transmitting, the radio will turn on the power amplifiers of the transmitters and power consumption will jump to approximately 65 watts. However, when the Packet Digital power management is engaged, the power consumption for normal operation drops to 3.8 watts, representing a 34.5% reduction. The demonstration system was presented during the debrief, with a software defined button on the laptop screen that allowed the enable or disable of the On-Demand Power technology.

An added benefit of the energy savings is the thermal management. Reducing the energy consumed directly reduces the heat that is generated by the electronics. At steady-state, the Motorola XPR4500 running with On-Demand Power had a reduction of 16 degrees Fahrenheit as measured at the rear heat fins, compared to operating without On-Demand Power. The reduction in generated heat may lead to thermal management solutions such as lighter/less expensive heat spreaders, smaller fans, and the opportunity for further miniaturization without excessive heat issues. On-Demand Power is a valuable addition to the tools used for thermal management of electronic systems.

Figure 5 shows the vast difference in power consumption observed between the original radio configuration as compared to the PowerSage improved version in our lab.

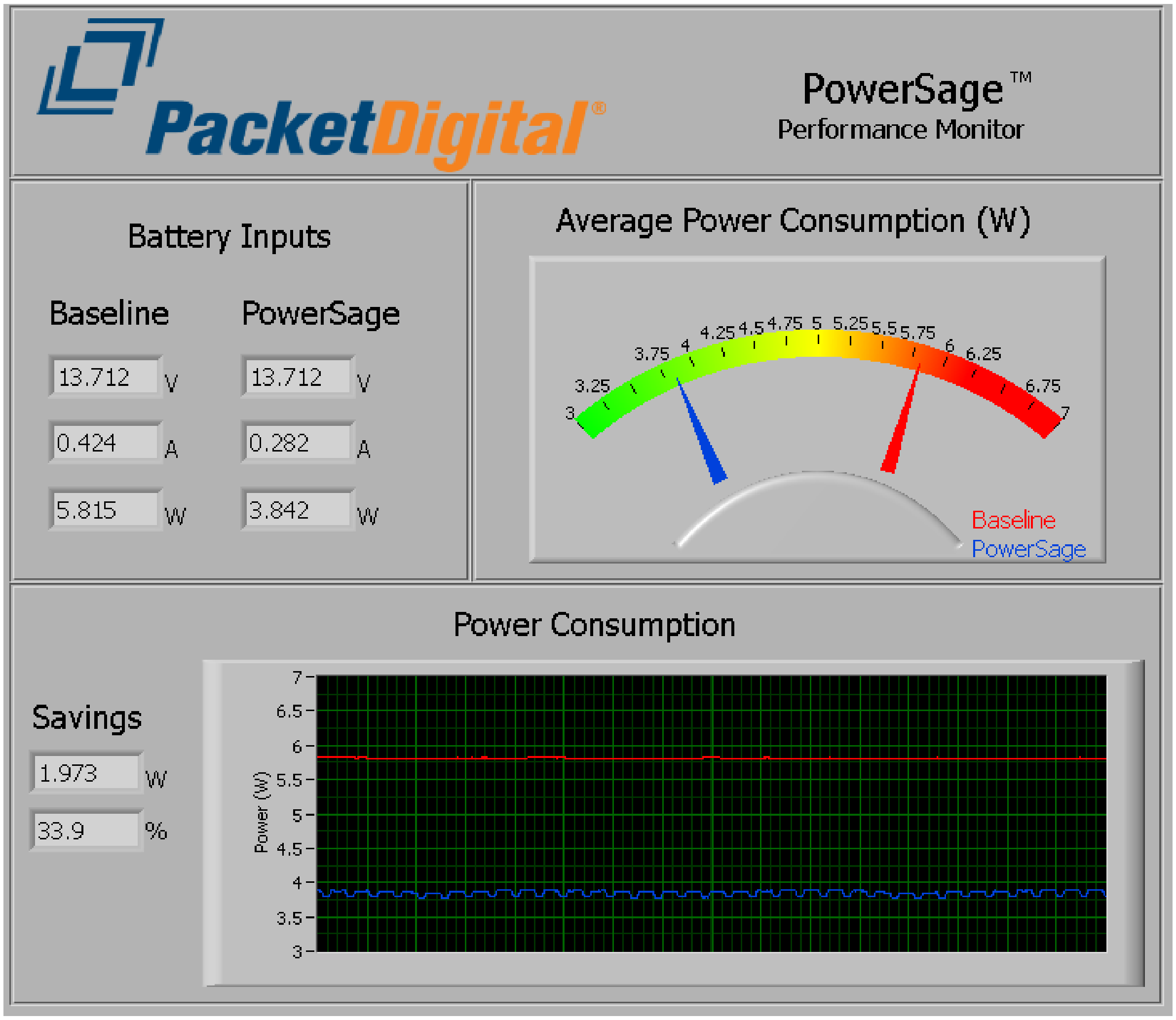

Figure 5: Radio Power Consumption Comparison showing instantaneous 33.9% power savings

Table 1 displays the power savings achieved and demonstrated on the Motorola-XPR 4500 UHF Mobile Radio.

Table 1: PowerSage Radio Power Savings Test Results

Type of Power	Measured Power Savings (mW)
Analog	1557
Digital	409
Total	1966

The analysis of this energy savings, based on the data provided by ONR, is shown in Table 2.

Table 2: Savings for a 96 Hour Patrol (without resupply)

Device	Battery	Batteries Savings per Mission	Batteries Weight Savings Per Mission (pounds)	Battery $ Savings Per Mission
AN/PRC-117F	BA-5590A/U	7	16	$1,034
AN/PRC-153 IISR	Rechargeable Lithium	91	51	N/A
AN/PRC-148(V)	1600515-7	63	63	$18,964
AN/PSN-13	BA3058U	56	30	$45
Totals		**217**	**160**	**$20,043**

5 Conclusions

The objective of the program was to analyze the characteristics of C4I electronic systems with the goal of adapting proven On-Demand Power technologies to complex military radios and handheld systems. Although the specific military systems were not available and used as part of the study, commercial systems were selected based on similarities to military devices. Since Packet Digital's technologies are not predicated on the actual data that is passed within a system but rather on the activity that would be detected on a communications bus, the energy savings realized on the commercial system is indicative of the savings projected on military systems.

Packet Digital characterized a commercial 45W radio by Motorola and mapped the power usage during multiple modes of operation. The Idle mode, where the radio is scanning communication channels for voice or data communications, is likely to be the mode of operation that dominates normal usage models. During this mode, Packet Digital demonstrated the means to save 34.5% of the energy at no discernable loss of functionality or performance. The user is unlikely to notice any change in radio operation, but will notice the significant extension of battery life and the reduction in the conducted and radiated heat from the electronics.

An energy reduction of 34.5% correlates to a battery life extension of 53%. In practice, the battery life may be greater, since the capacity of batteries are sensitive to the discharge rate of the electronics, and the reduction of the discharge rate will increase the battery capacity to further extend battery life. With additional research and design integration, Packet Digital has the potential to nearly double the battery life of military radios and handheld devices.

6 Contact info

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