# MicroPaq

# Duty Cycle Analysis

# 1 Introduction

The Micropaq 402 and 404 patient monitors contain a Symbol LA-3021-100 transceiver that operates in the 2.4 GHz ISM band. The duty cycle of the transceiver is algorithmically controlled and is normally less than 0.7 percent when transmitting at 2 Mb/s and less than 1.4 percent when transmitting at 1 Mb/s. This exhibit contains two sections. The first is a description of the algorithmic controls and the second is a set of empirical measurements that show the duty cycle is 0.7% at a 2 Mb/s transmission rate and 1.4% at a 1 Mb/s transmission rate. The data below are from a Micropaq 404, which has a slightly higher data bandwidth than the Micropaq 402. In the test configuration, Micropaq 404 transmits ECG and $S_PO_2$ waveform data while the 402 would only transmit ECG data. The same antenna is used for both the Micropaq 402 and Micropaq 404 and the antenna position is the same for both models.

# 2 Algorithmic control limits for data transmission

Several layers of algorithms control the radio transmission and each is described briefly below.

## *2.1* Controls provided by the Symbol Host Adapter interface:

The PSP (Power Save Polling) interval is settable once during card initialization to the desired activity interval. We have chosen to use every tenth beacon as the desired Beacon Listen Algorithm. This means that once every second, the radio interface awakens to transmit and/or receive data.

## *2.2* Controls provided by Welch Allyn Protocol developed code:

There are three threads of execution involved in the outgoing data transmission: the *PSICP Object*, which packages the data for the TCP/IP stack, the *S24 Process*, which handles the sequencing of the wakeup, transmit and sleep mode controls, and the *Wake Resume* process, which performs direct control of the wakeup and sleep mode processing.

In addition to these threads, which keep the nominal duty cycle at or below 1.4% for the slowest transmission rate, the Welch Allyn Protocol code tracks the following statistics, uses them to compute the duty cycle by evaluating Equation 1, and shuts the unit down if the computed duty cycle exceeds eight percent:

- *N*, the number of radio packets transmitted
- *NR*, the number of times radio packets are re-transmitted

The duty cycle calculation is a 6-minute moving average, updated every 30 seconds[1]. In addition, if in any two sequential 30-second periods, the duty cycle exceeds 8%, then the unit is shut down. The maximum packet size is 512 Bytes (4096 bits), and the duty cycle is calculated assuming all packets are the maximum packet size and minimum bit rate (1 Mb/s). The actual transmitter on-times of 4.8 ms (1 Mb/s rate) or 2.4 ms (2 Mb/s rate) per 512-byte packet are detailed in Section 3.2.3[2]. Since transmitting for 1 ms out of every second represents a 0.1% duty cycle, the duty cycle, D, is computed:

**Equation 1**

$$D(percent) = 0.48 * (N + NR)$$

A typical transmission (see Figure 3 and Figure 4 below) consists of three radio packets per second. At a 1 Mb/s data rate, D evaluates to 0.48 * 3 = 1.44 percent. If we were to evaluate the duty cycle for a 2 Mb/s data rate, the result would be 0.24 * 3 = 0.72 percent. These numbers are slightly higher than Figure 3 and Figure 4 indicate because the final packet transmitted in these cases is less than 512 bytes.

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[1] Title 47 of the CFR specifies IEEE Std. C95.3-1991 for specification of measuring and/or computing SAR values. IEEE C95.3-1991 specifies a 6-minute averaging time in Section 3.2.2.

[2] We note that transmitter on-time exceeds (Number of bits)/(Data Rate) by approximately 20 percent and use the *measured*, more conservative value in our calculations.

### 2.2.1 PSICP Object Control Limits:

Once each second, PSICP will send out a packet of data to be wrapped with the TCP/IP layers and sent to the Symbol LA-3021-100 radio card. This packet has a maximum size of 2048 bytes and is less than 1200 bytes in normal operation. Watch dog timers and various software and hardware checks prevent any abnormal operation.

### 2.2.2 S24 Process Control Limits:

The S24 Process checks once every 100 milliseconds for the arrival of data from the TCP/IP stack to be transmitted, and when data are available, signals for the wakeup of the Symbol PCMCIA Card Host Interface. Recall, the PSICP object control limits ensure that data arrives from the TCP/IP stack no more than once per second.

The S24 process then waits until either the card has been successfully awakened or the wake-up timeout period of 12 milliseconds has expired.

If the card has awakened, then the process transmits as much data as is ready out the interface, then requests the interface be put into sleep mode again.

If the card was not successfully awakened, then the system error handler is called, which shuts off the power supply to the PCMCIA card (Note that the power supply switch is external to the radio card). After performing some post-processing for the system, the S24 process waits until either a successful sleep mode resume indication is received or the go-to-sleep timeout has expired.

### 2.2.3 Wake Resume process control limits:

The wake resume process waits with the Symbol PCMCIA card in the sleep mode until a request to wakeup is received. When the signal to wake up the Symbol PCMCIA card has been received, it performs the required processing to put the adapter in the awake mode.

When the card has indicated a successful wakeup, the wake resume process signals to the S24 Process that this has occurred. There is a 12-millisecond limit on waking up the Symbol PCMCIA card, otherwise a system error will shut down the power to the card. This same sequence and timeouts are used within the wake resume process control thread for putting the Symbol PCMCIA card back into sleep mode.

## *2.3* Controls provided by the Symbol LA-3021 radio card:

Since only one PSICP packet is generated per second, only one TCP/IP packet is generated per second. Large TCP/IP packets are fragmented into multiple 512-Byte radio packets. The radio card automatically re-transmits a radio packet when it fails to receive a valid acknowledge signal from the system's receiver after the Micropaq transmitter has sent a packet. A maximum of 15 attempts are made by the radio card to transmit the entire set of radio packets that comprise the TCP/IP packet, even if the TCP/IP packet is fragmented into multiple radio packets. With the 4.8 ms duration of a maximum-size, 512-Byte radio packet, and a maximum of 15 radio packets transmitted (or re-transmitted) per second, the maximum duty cycle is 15*0.48% = 7.2%.

# 3 Empirical Data

This section consists of two data sets. The first are long-duration measurements taken over approximately 90 minutes using software methods. The second set is several short snapshots of current and rectified RF output that show actual transmission time.

## *3.1* Software-derived data

The software logs the amount of time that the radio interface is enabled, which *over estimates the transmit time*. The over estimation occurs because the measurement of radio on-time includes not only the transmit time, but also time for receiving data and overhead time for radio initialization and waiting between transmit and receive cycles. The software-generated data are included to show that the long-term duty cycle is controlled; the *actual* transmitter duty cycle was measured directly and is outlined below.

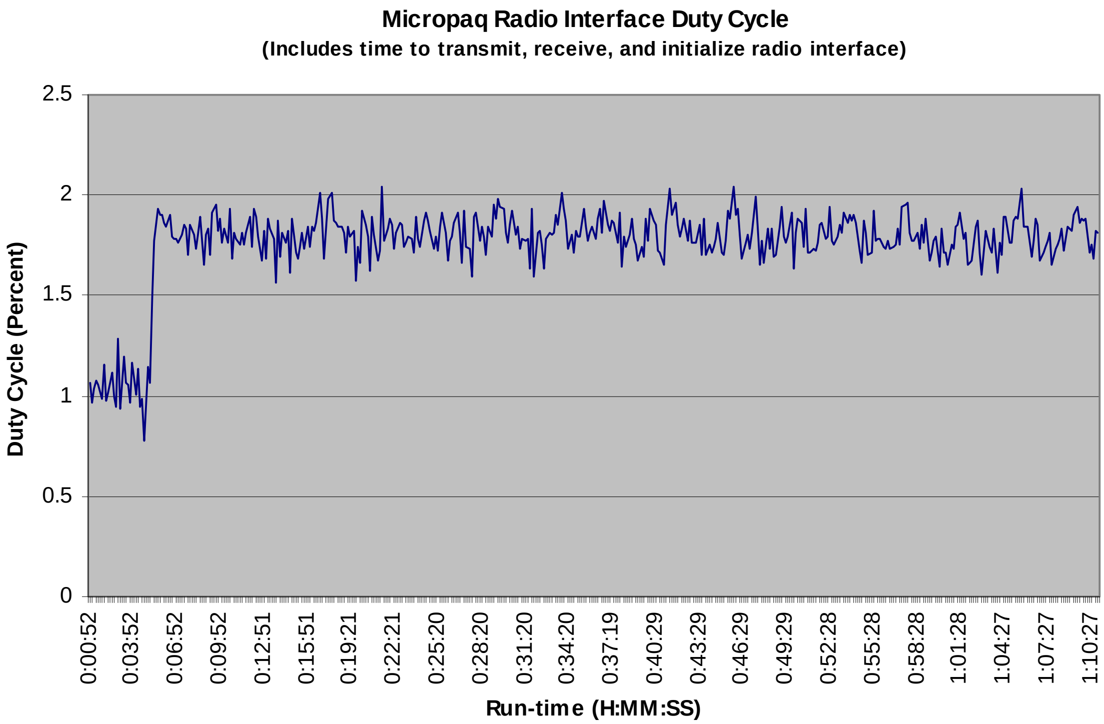


**Figure 1 Software-derived data showing the radio on-time is relatively constant. A six-minute moving average has a maximum value of 1.82 percent. These data were taken with a 2 Mb/s data rate. The low percent on-time at the left edge of the plot represents the time before PSICP data transmission began, but while the system is being initialized. Note that the increase in radio-on duty cycle that occurred when PSICP transmissions began is about 0.7%, which correlates well with the 0.69% transmit duty cycle reported in Figure 3.**

## *3.2* Oscilloscope-derived transmission duty cycle data

These measurements show the actual transmit time for the maximum-length 512-Byte packets at both 1 and 2 Mb/s data rates. A typical 2-second interval plot shows the radio transmissions occur in bursts once per second.

### 3.2.1 Test Set-up

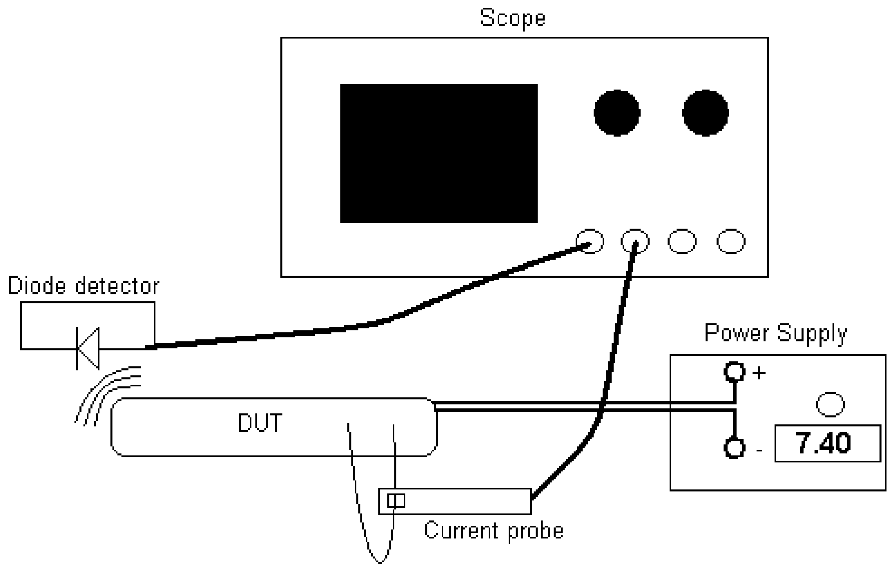


**Figure 2 Diagram illustrating how the two independent measurements of transmitter duty cycle were obtained.**

**Equipment List:**

| Equipment Description | Serial Number | Revision |
|---|---|---|
| Micropaq 404 | 00266016 | HW: Rev A<br>SW: Q3 Rev 3 |
| Micropaq Radio, LA-3021 | MAC Address<br>00 A0 F8 95 46 FD | FW: Rev 4.52 |
| Laptop, IBM Thinkpad | 78-AY599 97/11 | Microsoft Windows 95 |
| Laptop Radio, LA-3021 | MAC Address<br>00 A0 F8 8A 5A CC | FW: Rev 4.52 |
| Tektronix TDS 744A Oscilloscope | 01364 | N/A |
| Tektronix TCP202 Current Probe | B010247 | N/A |
| Power Supply Kikusui PAB 25-1TR | 30101965 | N/A |

A Micropaq 404 loaded with Q5REV3.S19 software, Rev A main board (031-0098-00), Rev C. Antenna Flex (660-0157-00), and standard 404 hardware was connected as shown in Figure 2. The current probe (Tek TCP202) is attached around a loop of wire in series with the Micropaq power to the Symbol card (LA-3021-100) and brought out of the closed Micropaq case. A diode detector (Tek P6193A oscilloscope probe across a Germanium diode) is placed near the antenna to detect directly the RF emission from the unit. The amplitude of this signal is dependent on the position of the diode relative to the antenna, and some variations are seen in the following figures.

Communication is with a MicroAP-configured card (LA-3020-100) running on a laptop computer platform (not shown). The MicroAP/Laptop is running PSITOOL software. Note: PSITOOL software data demands and formatting are the same as a standard installed AP/Acuity based system used by the customers of this product.

### 3.2.2 Procedure

The DUT is powered up and allowed to establish communications with the MicoAP/Laptop. The scope is triggered on both the diode detector voltage pulses and current probe readings exceeding 400mA. To correspond to normal operation of the device, an ECG simulator is attached to the ECG input of the DUT as well as an $S_PO_2$ sensor to the $S_PO_2$ input. Communication of data is confirmed by observation of physiological data on the MicroAP/Laptop. The following data were acquired and then plotted using Microsoft Excel.

- Figure 3: One of the once-per-second PSICP packet transmissions was recorded at a 2 Mb/s transmission rate.
- Figure 4: One of the once-per-second PSICP packet transmissions was recorded at a 1 Mb/s transmission rate.
- Figure 5: A 2-second window, triggered on a transmit pulse was recorded.

### 3.2.3 Data

For each of the tests, the oscilloscope-derived data are displayed below with a brief explanation of each test result in the figure caption.

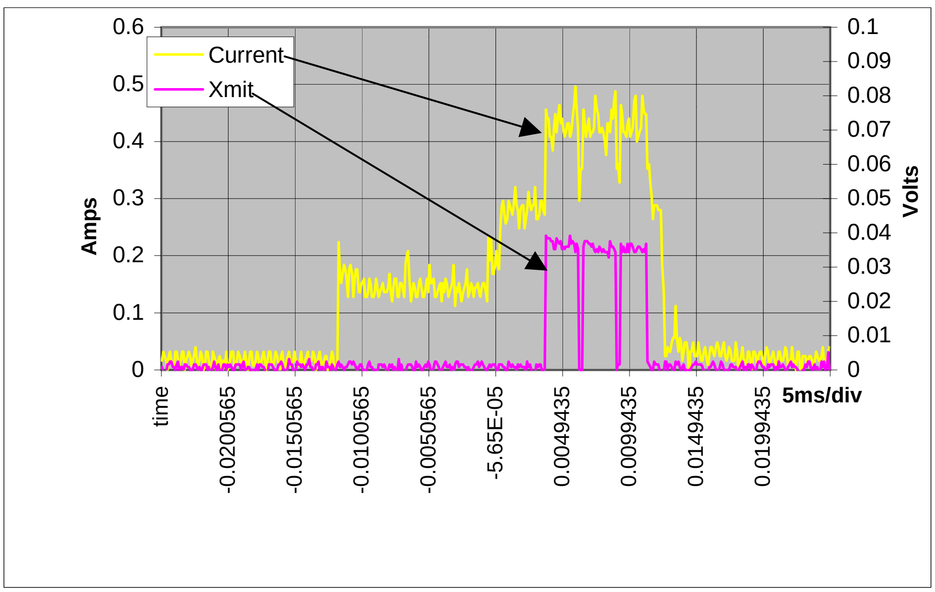


**Figure 3 Shows data from the current probe (yellow) and the diode transmit-detector (pink) are well correlated. Current above approximately 400 mA indicates the transmitter is active. The first transmit pulse begins at about t=3 ms. The duration of each of the first two pulses is 2.4 ms. The third pulse has less data and lasts approximately 2.1 ms. This is a 0.69% duty cycle as these pulses occur once per second. We note that transmitter on-time exceeds (Number of bits)/(Data Rate) by approximately 20 percent.**

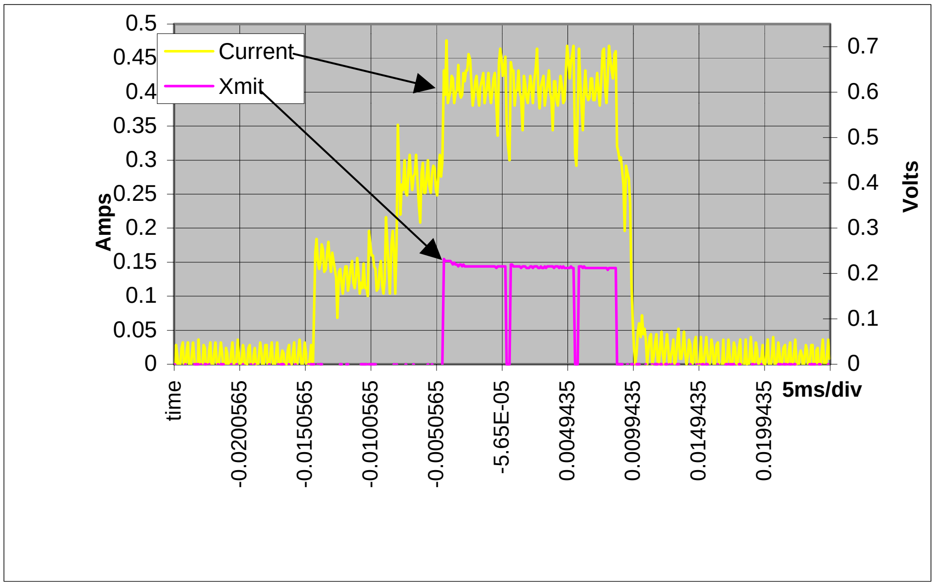


**Figure 4 Shows Data from the current probe (yellow) and the diode transmit-detector (pink) are well correlated. Current above approximately 400 mA indicates the transmitter is active. The first transmit pulse begins at about t=-5.5 ms. The duration of each of the first two pulses is 4.8 ms. The third pulse has less data and lasts approximately 2.9 ms. This is a 1.25% duty cycle as these pulses occur once per second. Xmit amplitude differs from Figure 3 as the position of the diode changed.**

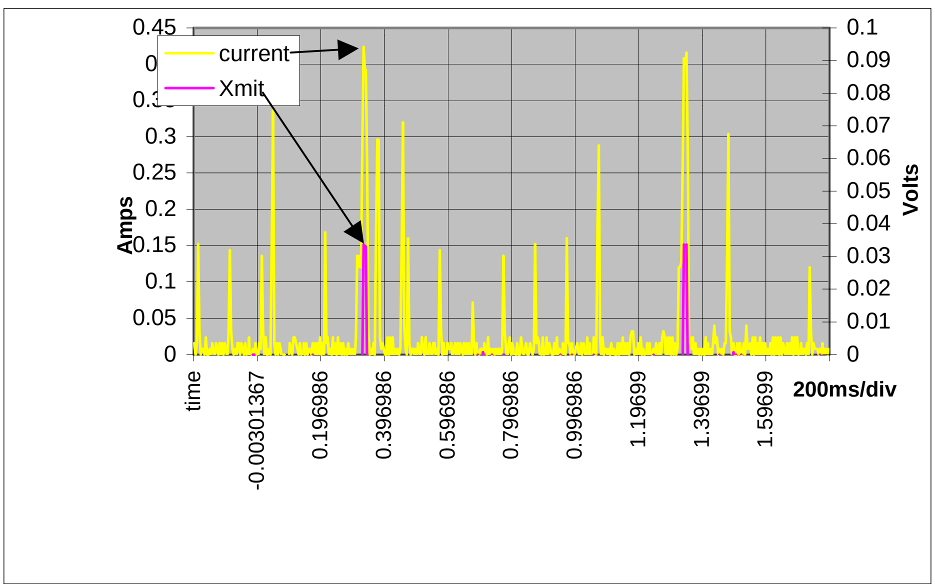


**Figure 5 Shows two seconds of current probe data (yellow) and transmission detector data (pink) for the Micropaq 404. There are two bursts of transmissions that begin at times t=0.310 S and 1.310 S. The three discrete radio packet transmissions for each PSICP data packet are not visible at this sampling resolution.**

# 4 Contributors

This document was assembled by Steve Baker. Glenn Kustka compiled the data and wrote the accompanying text in Section 3.2. Bill Howell supplied the algorithmic control description and the data for Figure 1.