

## Appendix E: “Daysimeter” Development Report

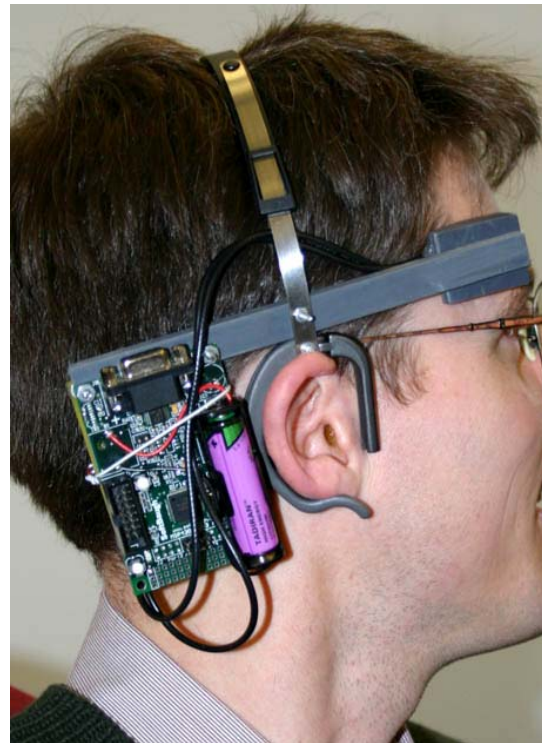
### “DAYSIMETER” DEVELOPMENT REPORT

January 9, 2004

#### Building the Daysimeter prototype

Construction of the Daysimeter prototype occurred in two phases. Phase I entailed developing the overall design of the Daysimeter, assembling the components and testing their functionality. Phase II involved miniaturizing the circuitry and packaging the components into a wearable device that could be easily worn on the head for long periods of time. The result of phase I was a non-miniaturized wire-wrapped circuit that was connected with cables to a rudimentary headset which held light and motion sensors. The circuit board was tethered to a computer that served as a readout device and experimental interface to the device. This apparatus was demonstrated during the Daylight Dividends meeting at the LRC on October 23, 2003.

The Phase II prototype device is pictured below.



## Daysimeter Specifications

### Measurement Functions

- Two channels for light measurement
  - One channel has a photopic spectral response ( $f_1' < 5\%$ )
  - One channel has a circadian response with a peak sensitivity at 460 nm
  - A light level accuracy and/or resolution of 10% or better
  - The range of measurements cover 6 decades (e.g., 1 lux to 1,000,000 lux)
  - Since the resolution is relatively low, a combination of auto-ranging and a moderately high resolution ADC is be used to cover the huge measurement range (e.g., a 10-bit ADC with 3 ranges)
- 1-axis tilt (inclinometer measuring head position,  $\pm 5^\circ$ )
- 2-axis activity sensor for head movement to differentiate resting/sleeping from active/awake behavior
- Date/time stamp (real time clock)
- Ability to enter calibration values in each device so that recorded stored values are appropriately scaled (i.e., calibrated); this is done over the PC interface

### Data recording

- Record measurements of light level, activity and head tilt once every 10 seconds or more frequently
- Record in non-volatile memory continuously for 7-day period
- 2 Megabyte storage capacity
- Upload data to PC
- Battery operated for continuous 7-day operation
- Replaceable batteries
- Status indicator to show that device is functioning

### Physical characteristics

- Small enough to be worn on the head; light weight, low profile, unobtrusive
- On/off and clock controlled over PC interface to avoid accidental switching

### Software

- Embedded source code
  - Written in C with API's for proprietary library function calls that control storage, sampling frequency, filtering, and angle computations
- PC software for data uploads along with program source code
  - Written in LabVIEW with API's for proprietary library function calls that control communication, logging, formatting, and calibration. This software saves the data in collimated text form.
  - Graphical user interface functions
    - Set Device ID
    - Get Device ID

- Get Clock
- Synchronize clock to PC
- Check memory usage
- Check battery life
- Configure sample rates
- Enable/disable data compression (save data and timestamp only if % change is > threshold)
- Enable/disable memory loop back (overwrites oldest data first)
- Start/stop logging
- Read back data
- View data history
- Export data in tab delimited text format
- Clear memory

### **Light measurements**

The spectral response of the photopic light sensor of the Daysimeter is shown in Figure 1. The spectral matching accuracy of this response to the photopic luminous efficiency is on par with laboratory grade photometry instruments. The spatial responses of the Daysimeter's light sensors closely match a cosine response as shown in Figure 2. Therefore, photopic measurements recorded with the Daysimeter are a direct measure of illuminance at the eye and can be compared to measurements taken with standard illuminance meters.

The spectral response of the circadian light sensor is shown in Figure 3. Also shown in Figure 3 is a proposed spectral sensitivity curve of the human circadian system (Rea et al. 2002; Brainard et al. 2001; Thapan et al. 2001). The two curves are a close match, having nearly the same peak wavelength and spectral bandwidth. The Daysimeter achieves this close spectral match by using a gallium phosphide (GaP) solid state detector (Hamamatsu model G1962) with a long pass colored glass filter (type Schott GG19, 2 mm thick). The GaP detector inherently has a long wavelength cutoff at approximately 570 nm which greatly reduces the need to filter the response to match the circadian system resulting in a smaller, less expensive detector assembly with excellent rejection of light outside the circadian measurement band.

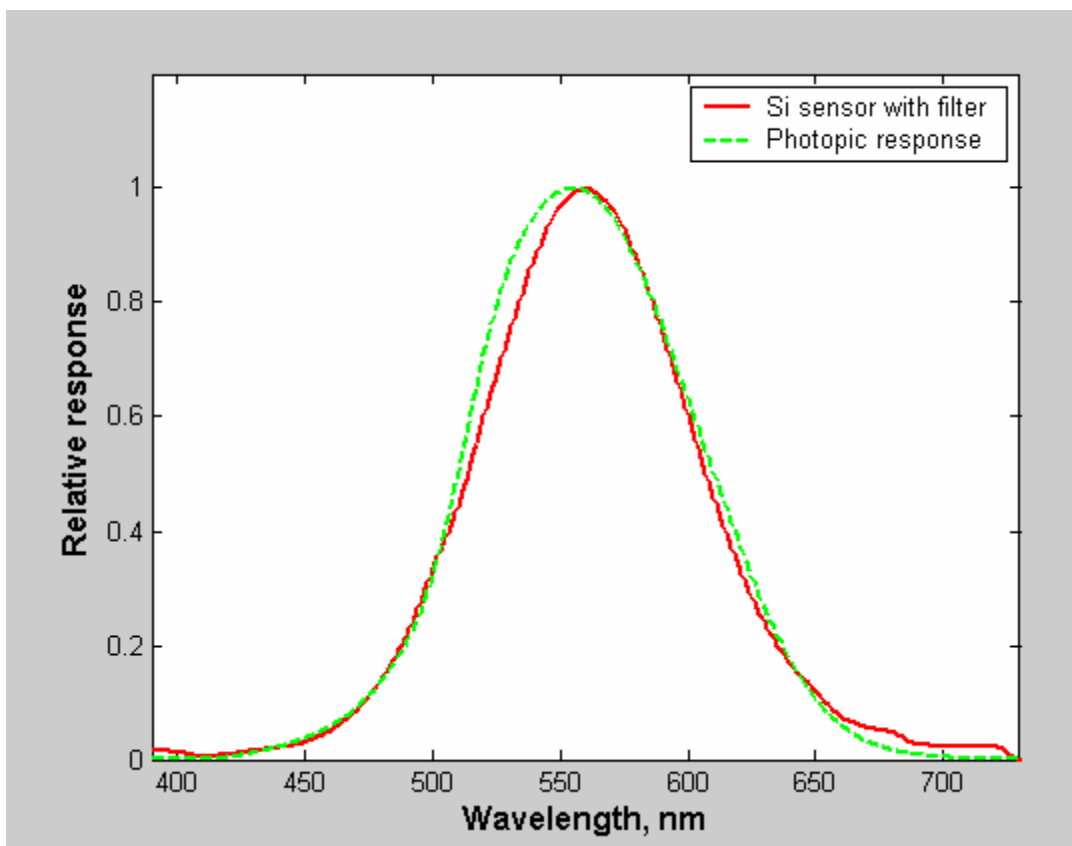
Studies done at the LRC are revealing that the spectral response of the human circadian system might result from a combination of photoreceptors configured in an opponent (subtractive) combination (Figuero et al. 2004). The dual sensor arrangement of the Daysimeter lends itself well to measuring the response from broadband light sources according to an opponent process. The Daysimeter can match the opponent photoreceptor combination response by subtracting a portion of the photopic signal from the short wavelength, circadian signal.

### **Activity measurements**

The Daysimeter uses a two-axis accelerometer to measure and record a person's activity and the inclination, or tilt of their head. The accelerometers are oriented to measure acceleration in the up/down and front/back directions. Activity is quantified as the sum of

the root mean square (rms) deviations of signals from both axes. That is, any change in movement along these two axes contributes to the measurement of activity. Acceleration is sampled at 10 Hz and the rms deviation values are calculated over the recording interval. Figure 4 shows the acceleration signals from the two-axis sensor when attached to a subject's head for periods of walking and stationary behavior. The signals are offset by one volt to separate the signals on the graph.

The tilt of the head is calculated from the mean acceleration values according to formulae that model the change in acceleration due to gravity. The mean acceleration values are determined over an interval of at least several seconds to minimize the effects of movement.



**Figure 1.** Spectral sensitivity of the Daysimeter's photopic sensor

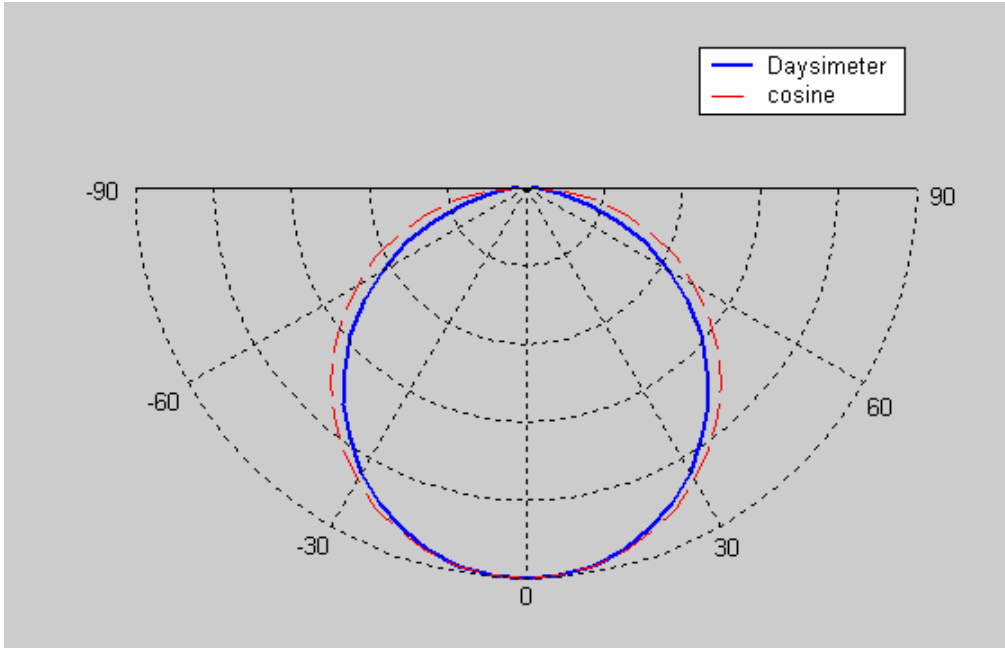


Figure 2. Spatial response of the Daysimeter's light sensors.

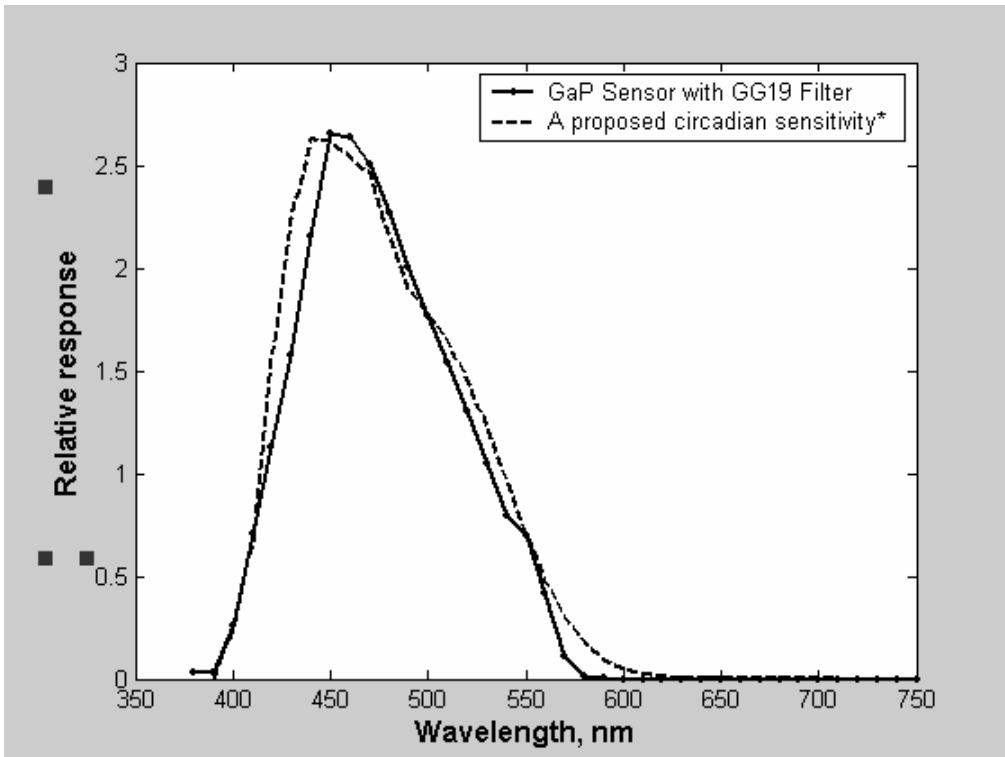
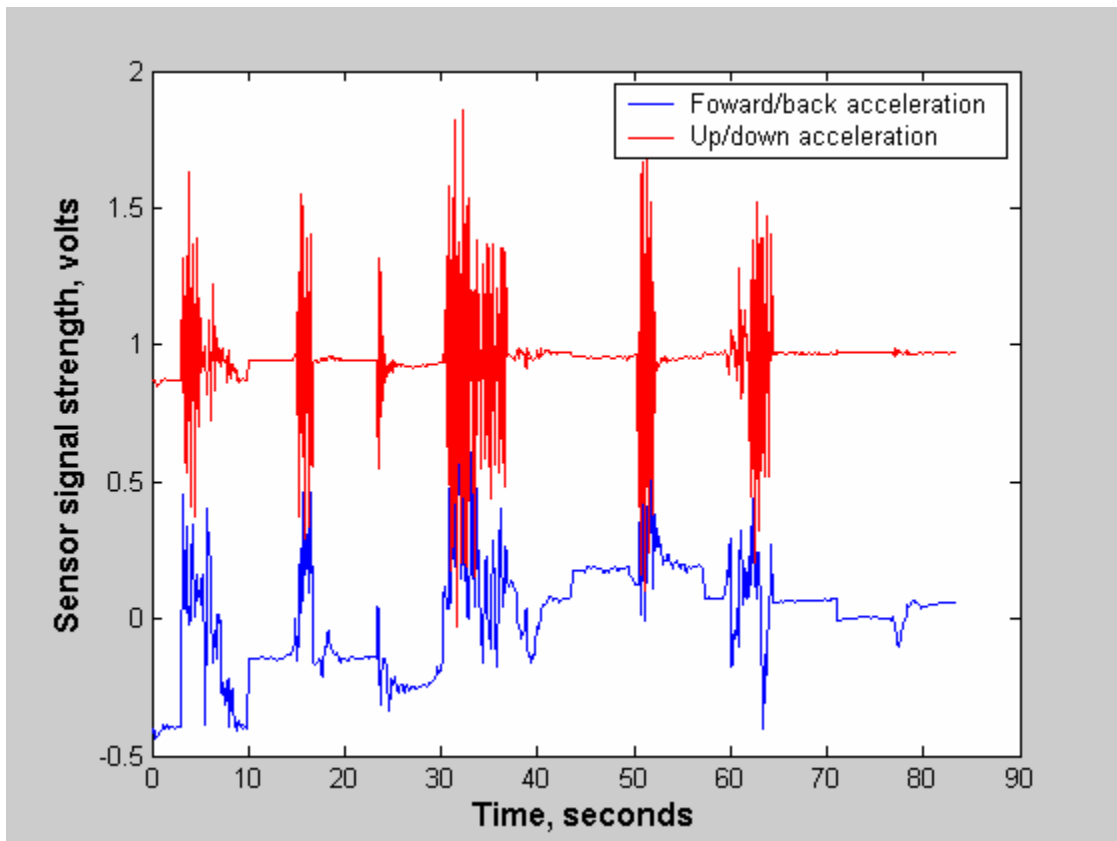


Figure 3. Spectral sensitivity of the Daysimeter's circadian sensor compared to a proposed circadian spectral sensitivity



**Figure 4.** Two-axis acceleration data recorded by the Daysimeter showing sensitivity to movement and the inclination of the subject's head.

## References

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- Figueiro, M. G., J. D. Bullough, R. H. Parsons, and M. S. Rea. 2004. Preliminary evidence for spectral opponency in the suppression of melatonin by light in humans. *NeuroReport* 15 (in press).
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- Thapan, K., J. Arendt, and D. J. Skene. 2001. An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans. *J. Physiol* 535:261-267.