Physiologist's Friend Chip User and Demonstration Guide

The **Physiologist's Friend Chip (**http://www.ini.unizh.ch/~tobi/friend/chip**)** is a neuromorphic analog VLSI chip that models cells in the early visual system. It has audible spiking cell responses to visual stimuli. You can use it in the lab or the lecture hall.

In the lab it acts as a fake animal. You can use it to train students and to test data collection and analysis software. It sits in your toolbox like any other tool.

In the lecture hall, you can use it with an overhead projector to do live demonstrations of fundamental principles of the visual system while interactively plotting the receptive fields of several types of cells.

This user guide shows the features of the chip and how to use it for classroom demonstrations and in a physiology lab.

Guide to the chip

Cautions

The Physiologist's Friend Chip is between an experimental and production device—it is more like an engineering sample. In fact only about 20 of these chips exist in the world. As such it has not gone through the qualifications that high volume products must pass. We have done the best job we could, but remember that this device has not gone through a billion-dollar evolutionary process like a cell-phone.

The transistors on the chip can be damaged by electrostatic discharge (ESD). Before handling the chip, discharge yourself on a grounded surface like the chassis of the overhead projector. Handle the board by the edges. **Damage due to ESD is not covered under the warranty.** Use common sense—if you have just walked across a carpet in the middle of the winter high in the Swiss Alps and feel a shock when you touch the doorknob, then this is a situation where the chip could really be damaged. We have never damaged one of these chips by ESD so far, but I'm sure that it could happen. **Store the chip in the pink antistatic bag when not in use.**

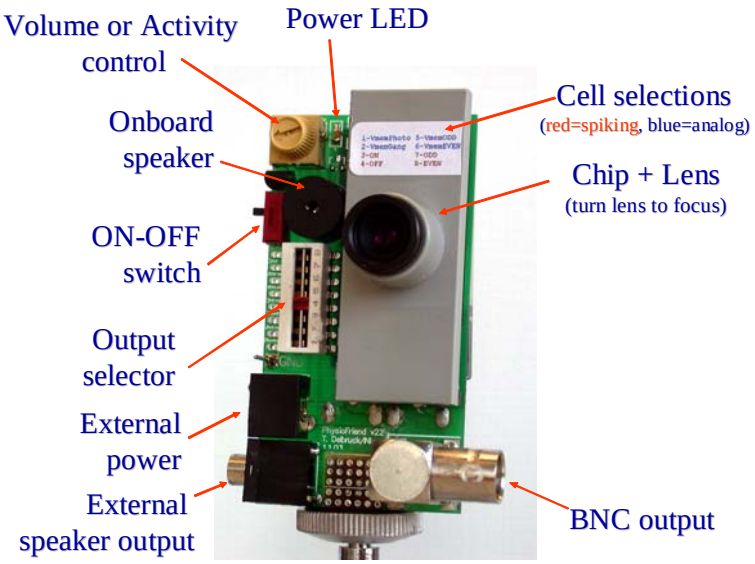
Attach the battery or external power supply with the correct polarity. **Damage due to incorrect battery or external power supply polarity is not covered by warranty.**

Unpacking and assembly

To assemble the system, remove the board from the antistatic bag, attach the battery, and screw on the minitripod. Save the packing materials and antistatic bag for traveling.

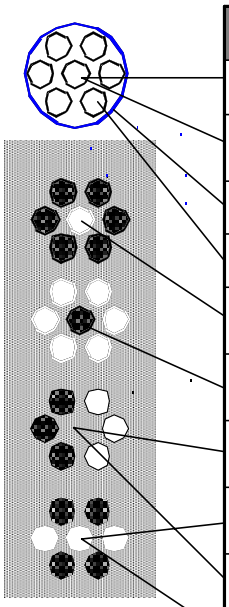
Controls and outputs

The photo below shows the controls and outputs from the chip. Board versions up to "friend22a" use the knob for on-board speaker volume; version friend23 uses this knob to control overall neural activity.



The figure below shows the cells. The numbers in the table below refer to the slider switch positions on the board. Slide the switch to select the cell type to monitor. (You may find it helpful to use the tip of a pen to slide the switch.) The cell outputs are available on the external speaker jack (stereo 3.5mm plug) or on the BNC connector. The receptive fields of the cells are shown schematically on the left. For example, the ON center ganglion cell is best stimulated by a light center and dark surround.

Some of the cells are spiking cells that can be clearly heard on the on-board speaker, while others are analog cell potentials that you may not be able to hear—at least on the on-board speaker--because the frequencies or amplitudes of the signals are too small. The spiking cells are shown **in bold face**.



Name	#	Type	Characteristics
VmemPhoto	1	Analog	The central photoreceptor
ad	*	Analog	Photoreceptor adaptation state: log(Intensity)
HCell	*	Analog	The average photoreceptor
VmemGang	2	Analog	Membrane potential of one ganglion cell
ON	**3**	**Digital**	**Spikes from the central ON-center ganglion cell**
OFF	**4**	**Digital**	**Spikes from the central OFF-center ganglion cell**
VmemODD	5	Analog	Membrane potential of ODD-type simple cell
VmemEVEN	6	Analog	Membrane potential of EVEN-type simple cell
ODD	**7**	**Digital**	**Spikes from ODD-type simple cell**
EVEN	**8**	**Digital**	**Spikes from EVEN-type simple cell**

* Available at probe point on board

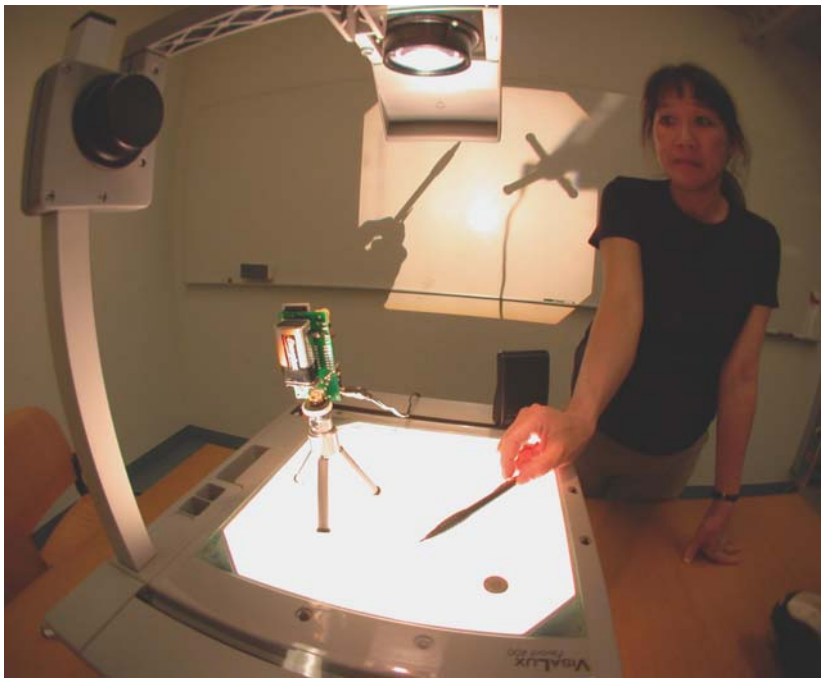
On-board and external speakers: The on-board speaker lets you listen to the spiking cells. To really hear them well, and to listen to the membrane potentials, you need to use an external speaker like the ones you use with your PC. The external speaker must be self-powered. The Sony SRS-A37 (for example) are battery-powered speakers that works well.

Using the Physiologist's Friend chip for demonstrations of principles of the visual system

You can use the chip to demonstrate the following fundamental properties of the visual system:

Receptive Field
Spike coding
Complementary signaling by ON and OFF pathways
Adaptation
Temporal coding of changes
Orientation selectivity

When you use the chip for classroom demonstrations, place it on or near the overhead project so that it faces the projection screen. The chip sees the same scene as the audience. The projection screen is like a tangent screen. In the photo to the right the chip sits on top of the overhead projector aimed at the screen. Shih-Chii Liu is using a pen as a stimulus for the chip. A coin nearby the pen is the optimum stimulus for the OFF center ganglion cell that she is demonstrating.



You may find that if the room lights are on, the contrast is insufficient on the projection screen to provoke a really clear response.

I emphasize that the chip is looking up at the tangent screen just like an animal would look at one. (If you don't point this out, then people sometimes don't realize that the chip is aimed up at the screen.)

I start the demonstration by showing the architecture of the chip and how the circuits emulate the layered processing of the visual system. (You can use the slides at http://www.ini.unizh.ch/~tobi/friend/chip.) I emphasize that this is just a little patch of the visual system that has just 7 photoreceptors. All the subsequent processing is laid out linearly below the patch of photodiodes and emulates with analog circuits a very basic feedforward model of visual processing by the visual system. I continue by demonstrating the different cells.

Finding the receptive field

The receptive field sizes and optics have been optimized for use with an overhead projector. If you place the chip looking up at the screen at the location of the overhead projector, it won't matter how far away you are from the screen. The angular size of the receptive field is constant, so no matter how large the image is projected, it will always be the same size on the bed of the overhead projector. The receptive field center width is approximately the diameter of a fat pen or a medium-sized coin.

I use a pen or cardboard bar as a stimulus on the overhead projector. Sometimes it takes a little while to find the receptive field. It is better to use a stimulus like a line or edge, because a small spot doesn't sweep enough area. Let's assume you use a pen as the stimulus. Sweep the pen around first horizontally and then vertically. Eventually you will get a response. If not, try changing the aim of the chip. When you get a response, now try the other orientation. Alternate to localize center of the receptive field.

Demonstrating the OFF and ON cells.

I usually start with the OFF ganglion cell (#4) because with an overhead projector it is easier to make a small dark stimulus than a small light stimulus. As far as functionality is concerned, the ON and OFF cells are identical except that they have complementary response to brightness. Here are the points I emphasize along with their demonstrations:

1. *The receptive field is localized.* At this early stage of the visual system, a cell responds to a particular location. Demonstrate by showing how the receptive field is localized spatially.

2. *The response doesn't depend on absolute intensity.* Demonstrate by making the whole field black or white and showing that the resting spike rate doesn't change.

3. *The response only depends on local contrast.* Demonstrate by using a small black stimulus. Grab a coin out of your pocket to make the optimum stimulus. The cell should really go! Compare with #2.

4. *Adaptation makes the visual system forget about stuff it has seen for a while, so that it can respond to novel stuff.* Demonstrate by showing how the response dies away if you leave the stimulus on the receptive field for a while. (This adaptation can take many seconds.) Point out that this time scale of adaptation is much slower than usually seen in the visual system.

5. *Complementary signaling.* Ask your audience, how do you represent a negative stimulus with spikes? Demonstrate by first showing the OFF cell, then switching to the ON cell and showing how it responds to the complement of the brightness.

6. *Inhibitory surrounds are a manifestation of the encoding of local contrast.* Demonstrate how a dark stimulus in the surround of the OFF cell inhibits the cell.

7. *The cell response also encodes* ***changes*** *in brightness.* Demonstrate by showing the transient OFF excitation caused by sudden darkening of the whole field of view. Show the complement: how sudden brightening momentarily inhibits the OFF cell.

Demonstrating a cortical simple cell

I usually use the ODD simple cell because the receptive field is simpler and the orientation response and polarity are unambiguous. There is just a single ON and OFF subfield and the response to the null orientation is just that—null. Here are the points I emphasize:

1. Cortical simple cells are orientation tuned.

2. Cortical simple cells receive push-pull input. The cell is not only excited by the optimum stimulus, but is also actively inhibited by the opposing stimulus.

3. Cortical cells are noisier than retinal cells. The response of the cortical cell sounds more random than the predictable firing of the retinal ganglion cells. You can attribute this to the quantal nature of the small number of synaptic inputs to the cell.

For showing the orientation response of the simple cells, a grating stimulus is very helpful because it makes it easy to produce modulation of the response that is very salient. You can print the last page of this user guide on a transparency as a grating stimulus.

If you choose one of the analog membrane potentials from a simple cell (outputs 5 or 6), then you can hear the synaptic input to the simple cell. (You need to use an external speaker for this because the onboard speaker is too wimpy). The membrane potential sounds like a noisy hiss. The hiss is from the volleys of synaptic input to the simple cell membrane. They push the voltage up and down, sometimes resulting in spikes that sound more like pops.

You can use this hiss to demonstrate the push-pull input to the simple cells. For a stimulus that has the complementary contrast to the preferred stimulus, the cell will be maximally inhibited. In fact the membrane potential is clamped to the negative reversal potential (ground) and the hiss goes away. For the null stimulus (a horizontal bar for the ODD simple cell), the hiss increases, because the bar excites both excitatory and inhibitory inputs to the simple cell. On the average these balance out, but sometimes the pseudo-random walk that the membrane potential takes will exceed the spike threshold and the neuron will spike.

Using the chip in a physiology lab

When you use the chip in a physiology lab as a fake animal you may want to consider the following points:

1. The chip's photoreceptors do not have as steep a high-temporal-frequency roll-off as biological photoreceptors. They are more sensitive to screen flicker. That is the reason for the neutral density filter that sits just under the lens, on top of the chip. This filter dims the light falling on the silicon photoreceptors, to slow them down so that the flicker caused by the scanning of a monitor does not dominate their responses.

2. The analog outputs of the chip (e.g., the photoreceptor, the membrane potentials) have a voltage range of volts, compared with the much smaller range of mV seen in biology.

3. Plugging a 3.5mm stereo jack into the external speaker output disables the onboard speaker, which unloads the chip output and increases the signal amplitude. If you are using the BNC connector and not using an external speaker, then you can maximize the amplitude of the analog signals by turning the onboard speaker volume to a minimum.

4. A normal alkaline 9V battery should run the chip for several days. You can also power the chip from an external power supply that outputs 7-9VDC. **If you use the wrong polarity then you could damage or destroy the chip.** The correct polarity has the negative on the center plug.

Improving this guide

That's it. You may think of other experiments to try yourself. If so, please let me know (tobi@ini.phys.ethz.ch) so that I can incorporate them into this user and demonstration guide.

If you use the chip for classroom demonstrations, you may want to have a look at the companion simulation program (http://www.ini.unizh.ch/~tobi/friend/program), which can be used for student exploration.

Contact information

Tobi Delbruck (tobi@ini.phys.ethz.ch)
Inst. of Neuroinformatics
Univ. Zurich, ETH Zurich
Winterthurerstr. 190
CH-8057 Zurich
Switzerland
tel. +41 44 635 30 38 fax +41 44 635 30 53

Troubleshooting

Symptom	Things to check
Chip doesn't respond, or doesn't make spike sounds	Is the battery worn down? The power LED should be on. Is the speaker volume turned down too low? Have you selected one of the spiking outputs? (#3,4,7,8) Is the metal case of the battery shorting out pins on the back of the board?
Response of chip to stimulus is weak	Are you using a high contrast black and white stimulus? If you are using an overhead projector, are the room lights on? This background light could be reducing the stimulus contrast. If you have printed a stimulus, is it really high contrast for the chip? The chip's photoreceptors have a different spectral response than our eyes. For example, a black and white stimulus printed on an Epson Stylus 800 ink-jet printer is a very poor stimulus for the chip. When the same stimulus is made a black permanent marker, it works much better.
Analog outputs of membrane potentials are very small (outputs #1,2,5,6)	If you are using the BNC connector to measure these voltages on an oscilloscope, turn down the on-board speaker volume to unload the analog output drivers on the chip, or plug in an external speaker to the external speaker jack (this will disable the onboard speaker and will unload the outputs.) The analog outputs are only driven by approximately 10uA on-chip biases—they can only drive high-impedance loads. With an oscilloscope, you should see a photoreceptor voltage of between 1 to 3 volts on output #1, responding with amplitude of about 500mV to high contrast stimulus.

Support policy and warranty

Please call or email me if you need help using the chip.

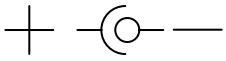
Because the supply of chips is extremely limited, we may not have a replacement part if your device is damaged.

We warrant that the chip will be functional for 90 days after delivery.

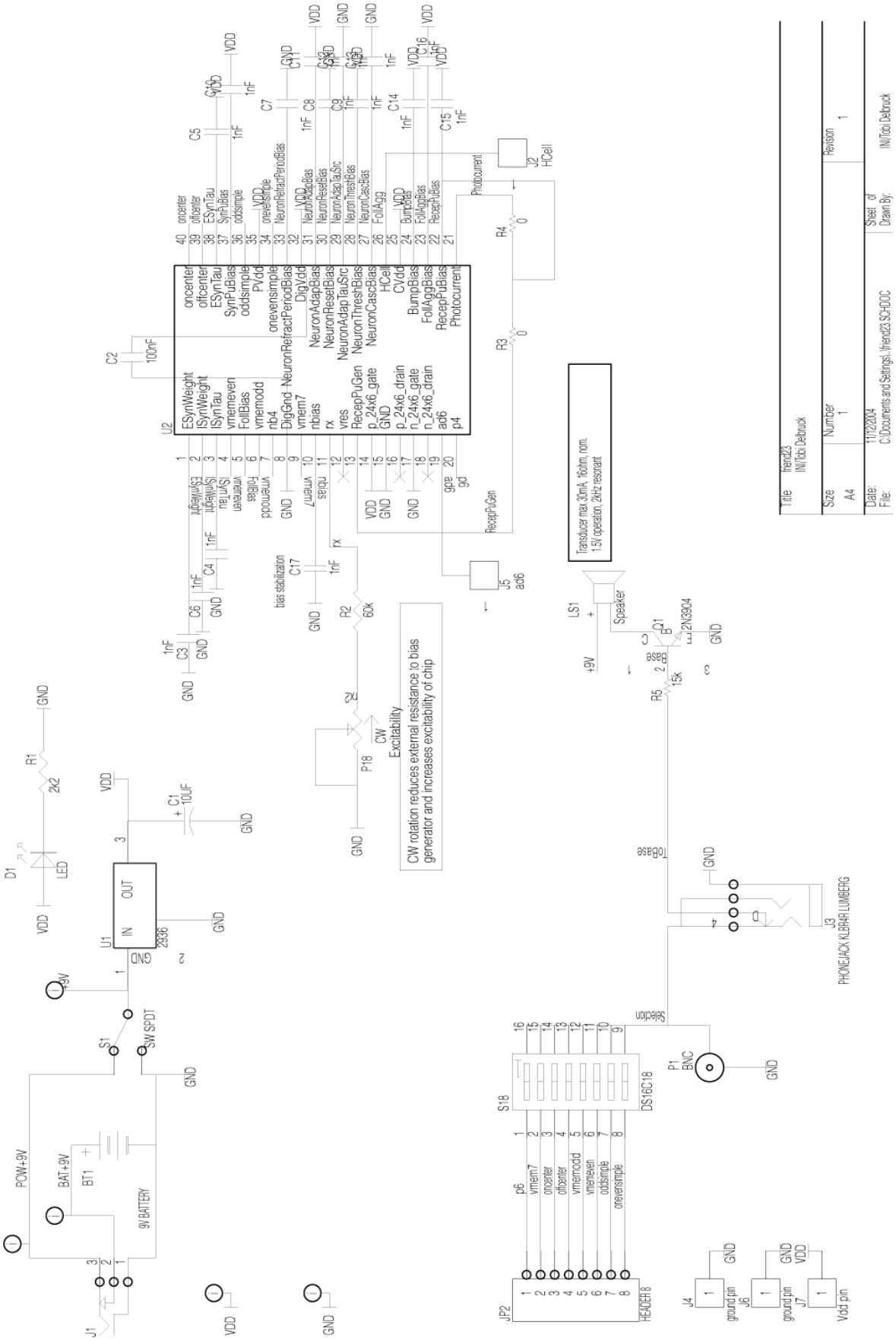
We do not cover damage due to mishandling (breakage, electrostatic discharge, incorrect external supply voltage polarity or excessive voltage, or incorrect battery polarity). If your system fails due to mishandling, we will repair your system for a charge of 400 euro.

If the shipped product is defective, we will replace it or refund you.

Specifications

System power supply	On-board 9V battery External supply 7-9VDC, negative inside (incorrect polarity could damage or destroy chip) 
System power consumption	External speaker: 2.5mA Internal Speaker: 5-20mA
Chip power consumption	1mA with all functionality. With analog output pads disabled, 100uA.
Battery lifetime	Based on alkaline 9V battery with 450mAh capacity, 24-180 hours depending on speaker volume. (Rechargeable NiMH 9V batteries have only 150mAh capacity.)
Temperature range	15-45°C. Firing rate decreases about 30% over this range at higher temperature.
Tripod mount	Standard ¼"x20 thread
Lens	8mm focal length. (CES VPC-465, www.cesag.com)
Neutral density filter	2 decade, under lens to reduce flicker responses caused by raster scan with cathode-ray tube monitors. For use under very low light conditions, remove this filter.
External speaker output	3.5mm stereo plug (signal is mono driven onto both channels)
External speaker	Self powered PC speaker (10kΩ input impedance). E.g. Sony SRS-A47 or Intersound LS-78A are battery powered.
Chip fabrication	MOSIS (AMI 1.6um technology)
Chip size	2.2x2.2 mm^2
Chip power supply	5V
Pixel size	On chip, photodiodes are 160um by 160um squares arranged as center pixel surrounded hexagonally by 6 more (row of 2, row of 3, row of 2).
Pixel angle	(With 8mm lens) Each pixel of the 7-pixel array subtends 1.14 deg horizontally and vertically. 2 pixels 2.29 deg, Total horizontal or vertical extent of sensitive area: 3.42 deg. The center of the receptive field (one pixel) is 6mm on the object plane at a distance of 30cm from the chip.
Pixel spacing	Same as pixel size (no dead area)
Spike amplitude	5V (depending on volume of on-board speaker, which loads the output)
Spike width	Approximately 2ms
Spike rate	Adjustable over about 3X range using activity control knob. With middle setting, Retinal ganglion cells: approx. 20Hz quiescent (viewing blank image). Cortical cells: approx 6 Hz quiescent.
Analog outputs	Can only drive high-impedance loads. (Output drivers are supplied by approx 10uA.)

Schematic of board



Stimuli

The following pages can be printed onto paper or transparency and are good stimuli for demonstrating the behaviors of the cells.

Because the chip's photoreceptors have a different spectral response than our eyes (they are more sensitive to near IR), a printed pattern may appear to have high contrast but will not effectively stimulate the chip. We suggest that you use a laser printer rather than an inkjet printer to print these patterns.