Chapter 1

Introduction

The retina is a thin layer of neural tissue that lines the back wall inside the eye. Some of these cells act to receive light, while others interpret the information and send messages to the brain through the optic nerve. This is part of the process that enables us to see. In damaged or dysfunctional retina, the photoreceptors stop working, causing blindness. By some estimates, there are more than 10 million people worldwide affected by retinal diseases that lead to loss of vision.

The absence of effective therapeutic remedies for retinitis pigmentosa (RP) and age-related macular degeneration (AMD) has motivated the development of experimental strategies to restore some degree of visual function to affected patients. Because the remaining retinal layers are anatomically spared, several approaches have been designed to artificially activate this residual retina and thereby the visual system.

At present, two general strategies have been pursued. The “Epiretinal” approach involves a semiconductor-based device placed above the retina, close to or in contact with the nerve fiber layer retinal ganglion cells. The information in this approach must be captured by a camera system before transmitting data and energy to the implant. The “Sub retinal” approach involves the electrical stimulation of the inner retina from the sub retinal space by implantation of a semiconductor-based micro photodiode array (MPA) into this location. The concept of the sub retinal approach is that electrical charge generated by the MPA in response to a light stimulus may be used to artificially alter the membrane potential of neurons in the remaining retinal layers in a manner to produce formed images.

Some researchers have developed an implant system where a video camera captures images, a chip processes the images, and an electrode array transmits the images to the brain. It’s called Cortical Implants.
The human visual system is remarkable instrument. It features two mobile acquisition units each has formidable preprocessing circuitry placed at a remote location from the central processing system (brain). Its primary task include transmitting images with a viewing angle of at least 140deg and resolution of 1 arc min over a limited capacity carrier, the million or so fibers in each optic nerve through these fibers the signals are passed to the so called higher visual cortex of the brain.

FIG 2.1 BLOCK DIAGRAM OF VISUAL SYSTEM

The nerve system can achieve this type of high volume data transfer by confining such capability to just part of the retina surface, whereas the center of the retina has a 1:1 ration between the photoreceptors and the transmitting elements, the far periphery has a ratio of 300:1. This results in gradual shift in resolution and other system parameters.

At the brain’s highest level the visual cortex an impressive array of feature extraction mechanisms can rapidly adjust the eye’s position to sudden movements in the peripherals filed of objects too small to se when stationary. The visual system can resolve spatial depth differences by combining signals from both eyes with a precision less than one tenth the size of a single photoreceptor.
### 2.1 THE EYE

The main part in our visual system is the eye. Our ability to see is the result of a process very similar to that of a camera. A camera needs a lens and a film to produce an image. In the same way, the eyeball needs a lens (cornea, crystalline lens, vitreous) to refract, or focus the light and a film (retina) on which to focus the rays. The retina represents the film in our camera. It captures the image and sends it to the brain to be developed.

![Eye-Camera Similarity Diagram](image)

**FIG 2.2 EYE-CAMERA SIMILARITY**

The macula is the highly sensitive area of the retina. The macula is responsible for our critical focusing vision. It is the part of the retina most used. We use our macula to read or to stare intently at an object. About 130 million photoreceptors in the outermost layer (as seen from the center of the eye) of the transparent retina transform local intensity and color patterns into chemical and electrical signals which trigger activity of the many different retinal cells: horizontal cells, bipolar cells, amacrine cells, and ganglion cells.
The information is processed by astonishing amounts of serial and parallel pathways by in parts still unknown mechanisms. The information of these 130 million photoreceptors is compressed to the level of 1 million highly specialized GC-fibers. These 1 million fibers in the retina then form the optic nerve and transmit visual information to the visual cortex and its various areas in the back of the brain.

The area of the retina that receives and processes the detailed images—and then sends them via the optic nerve to the brain—is referred to as the macula. The macula is of significant importance in that this area provides the highest resolution for the images we see. The macula is comprised of multiple layers of cells which process the initial “analog” light energy entering the eye into “digital” electro-chemical impulses. The retina is the innermost layer of the wall of the eyeball. Millions of light-sensitive cells there absorb light rays and convert them to electrical signals. The signals are sent through the optic nerve to the brain, where they are interpreted as vision.

2.2 RETINA
Light first enters the optic (or nerve) fiber layer and the ganglion cell layer, under which most of the nourishing blood vessels of the retina are located. This is where the nerves begin, picking up the impulses from the retina and transmitting them to the brain.

**FIG 2.4 THE RETINAL LAYERS**

The light is received by photoreceptor cells called rods (responsible for peripheral and dim light vision) and cones (providing central, bright light, fine detail, and color vision). The photoreceptors convert light into nerve impulses, which are then processed by the retina and sent through nerve fibers to the brain. The nerve fibers exit the eyeball at the optic disk and reach the brain through the optic nerve. Directly beneath the photoreceptor cells is a single layer of retinal pigment epithelium (RPE) cells, which nourish the photoreceptors. These cells are fed by the blood vessels in the choroids.

### 2.3 Retinal Diseases
There are two important types of retinal degenerative disease:

- Retinitis pigmentosa (RP), and
- Age-related macular degeneration (AMD)

They are detailed below.

RETINITIS PIGMENTOSA (RP) is a general term for a number of diseases that predominately affect the photoreceptor layer or “light sensing” cells of the retina. These diseases are usually hereditary and affect individuals earlier in life. Injury to the photoreceptor cell layer, in particular, reduces the retina’s ability to sense an initial light signal. Despite this damage, however, the remainder of the retinal processing cells in other layers usually continues to function. RP affects the mid-peripheral vision first and sometimes progresses to affect the far-periphery and the central areas of vision. The narrowing of the field of vision into “tunnel vision” can sometimes result in complete blindness.

AGE-RELATED MACULAR DEGENERATION (AMD) refers to a degenerative condition that occurs most frequently in the elderly. AMD is a disease that progressively decreases the function of specific cellular layers of the retina’s macula. The affected areas within the macula are the outer retina and inner retina photoreceptor layer.

Patients with macular degeneration experience a loss of their central vision, which affects their ability to read and perform visually demanding tasks. Although macular degeneration is associated with aging, the exact cause is still unknown.

Together, AMD and RP affect at least 30 million people in the world. They are the most common causes of untreatable blindness in developed countries and, currently, there is no effective means of restoring vision.
Ocular implants are those which are placed inside the retina. It aims at the electrical excitation of two dimensional layers of neurons within partly degenerated retinas for restoring vision in blind people. The implantation can be done using standard techniques from ophthalmic surgery. Neural signals farther down the pathway are processed and modified in ways not really understood therefore the earlier the electronic input is fed into the nerves the better.

There are two types of ocular implants are there epi-retinal implants and sub retinal implants.

Fig 3.1 shows the major difference between epi-retinal & sub retinal approach

3.1 EPI-RETINAL IMPLANTS.
In the EPI-RET approach scientists had developed a micro contact array which is mounted onto the retinal surface to stimulate retinal ganglion cells. The information in this approach must be captured by a camera system before transmitting data and energy to the implant.

A tiny video camera is mounted on eyeglasses and it sends images via radio waves to the chip. The actual visual world is captured by a highly miniaturized CMOS camera embedded into regular spectacles. The camera signal is analyzed and processed using receptive field algorithms to calculate electric pulse trains which are necessary to adequately stimulate ganglion cells in the retina.

This signal together with the energy supply is transmitted wireless into a device which is implanted into the eye of the blind subject. The implant consists of a receiver for data and energy, a decoder and array microelectrodes placed on the inner surface of the retina. This micro chip will stimulate viable retinal cells. Electrodes on microchip will then create a pixel of light on the retina, which can be sent to the brain for processing.

The main advantage of this is that it consists of only a simple spectacle frame with camera and external electronics Communicates wirelessly with microchip implanted on retina programmed with stimulation pattern.
The issues involved in the design of the retinal encoder are:

- CHIP DEVELOPMENT
- BIOCOMPATIBILITY
- RF TELEMETRY AND POWER SYSTEMS
3.1.1 CHIP DEVELOPMENT

EPI RETINAL ENCODER

The design of an epiretinal encoder is more complicated than the sub retinal encoder, because it has to feed the ganglion cells. Here, a retina encoder (RE) outside the eye replaces the information processing of the retina. A retina stimulator (RS), implanted adjacent to the retinal ganglion cell layer at the retinal 'output', contacts a sufficient number of retinal ganglion cells/fibers for electrical stimulation. A wireless (Radio Frequency) signal- and energy transmission system provides the communication between RE and RS. The RE, then, maps visual patterns onto impulse sequences for a number of contacted ganglion cells by means of adaptive dynamic spatial filters. This is done by a digital signal processor, which, handles the incoming light stimuli with the master processor, implements various adaptive, antagonistic, receptive field filters with the other four parallel processors, and generates asynchronous pulse trains for each simulated ganglion cell output individually. These spatial filters as biology-inspired neural networks can be 'tuned' to various spatial and temporal receptive field properties of ganglion cells in the primate retina.

3.1.2 BIOCOMPATIBILITY

The material used for the chips and stimulating electrodes should satisfy a variety of criteria’s. They must be corrosion-proof, i.e. bio stable.

- The electrodes must establish a good contact to the nerve cells within fluids, so that the stimulating electric current can pass from the photo elements into the tissue.

- It must be possible to manufacture these materials with micro technical methods and.
They must be biologically compatible with the nervous system.

### 3.1.3 RF TELEMETRY

In case of the epiretinal encoder, a wireless RF telemetry system acts as a channel between the Retinal Encoder and the retinal stimulator. Standard semiconductor technology is used to fabricate a power and signum receiving chip, which drives current through an electrode array and stimulate the retinal neurons. The intraocular transceiver processing unit is separated from the stimulator in order to take into account the heat dissipation of the rectification and power transfer processes. Care is taken to avoid direct contact of heat dissipating devices with the retina.

Fig 3.1.2 shows the only one system which uses the current technology and it is the Low Vision Enhancement System (LVES) developed at Johns Hopkins. LVES- a video magnification system for people with low vision. This Can zoom from 2 inches to infinity. Can magnify 9x at distance and 25x near.

Visually impaired people must have a system customized to their own visual deficiencies. But it will be available only after 2010. Low vision described was no better vision than 20/40 when corrected.
3.2 SUB RETINAL IMPLANTATION

The subretinal approach is based on the fact that for instance of retinitis pigmentosa; the neuronal network in the inner retina is preserved with a relatively intact morphology. Thus, it is appropriate for excitation by extrinsically applied electrical current instead of intrinsically delivered photoelectric excitation via photoreceptors. This option requires that basic features of visual scenes such as points, bars, edges, etc. can be fed into the retinal network by electrical stimulation of individual sites of the distal retina with a set of individual electrodes.

Subretinal approach is aiming at a direct physical replacement of degenerated photoreceptors in the human eye, the basic function of which is very similar to that of solar cells, namely delivering slow potential changes upon illumination. The quantum efficiency of photoreceptor action, however, is 1000 times larger than that of the corresponding technical devices. Therefore the intriguingly simple approach of replacing degenerated photoreceptors by artificial solar cell arrays has to overcome some difficulties, especially the energy supply for successful retina stimulation.

On the ‘back’ side of the retina, photoreceptors (rods and cones) are excited by the incoming light and deliver gradual potential changes to the inner retina layers. The path of the electrical signals is then opposite to that of the incoming light. The main problem in diseases like retinitis pigmentosa or macula degeneration is the loss of photoreceptors or photoreceptor function, whereas the signal processing path in the inner retina is remaining intact. This gives us the chance to place a micro photo diode array (MPDA) in the subretinal space, which may then electrically stimulate remaining photoreceptor or bipolar cells. Appropriate surgical techniques have recently been developed and tested.

It’s believed that the so evoked retinal activity leads to useful sensations if the retinal output reveals the topography of the image feature and is projected retinotopically correct to the visual cortex.
In addition, the sampling density of a sub retinal device could be designed to match that of the remaining photoreceptor or bipolar cell matrix, thereby providing a potentially high-resolution input to the retina.

Implant chips have been tested both in vitro and in vivo to assess their biostability. In vitro stability (in buffered saline solution) is excellent even for periods as long as 2 years. In vivo, however, the passivation layer could withstand the biological environment for up to about six months only. In contrast, the electrodes made of titanium nitride showed excellent biostability over more than 18 months in vivo. These are the results of vitro and vivo tests conducted by the scientists in Retinal Implant Research centre.

3.2.1 IN VITRO-TESTS

In order to evaluate parameters for subretinal electrical stimulation scientists established new in-vitro methods for electrical multisite stimulation of explanted retinas and multichannel recording of retinal activity. The aim of the study, which is still carried out at the NMI is to find stimulation paradigms that are suitable to evoke spatially structured ganglion...
cell activity within a safe operational range of the electrodes and the tissue and with an adequate dynamic range of the retinal output.

![Diagram of functional electrical retina stimulation](image)

**Fig 3.2.2 Functional electrical retina stimulation in vitro.**

(A) Monofocal distal current injection: Pieces of whole mount retinas are attached to a microelectrode array (MEA) with the ganglion cell side facing the transparent glass plate and its embedded planar electrodes (asterisks). A tungsten electrode is lowered into the distal side of the retina. Monopolar charge balanced current pulses are applied (bundle of arrows from top). Fig B Shows Multisite charge injection: With the ganglion cell side up, multifocal stimulation of the distal retina side is obtained by applying voltage pulses to a variable number of electrodes of the MEA (bundle of arrows from bottom). The retinal response is recorded from ganglion cell bodies with a glass pipette. Fig (C) Sandwich preparation technique: A MPDA prototype chip is placed onto the distal retina side and is illuminated with flashes of light (arrow from bottom). Multi-unit ganglion cell activity evoked by the light generated photodiode current (bundle of arrows from top) is recorded with several MEA electrodes in parallel.

Retina segments from chicken or blind RCS rats were adhered to a microelectrode array (MEA) with 60 substrate integrated planar electrodes (diameter 10 µm,
spacing 100 µm) either for distal stimulation or proximal recording. In the preparation where
the photoreceptor side faces the MEA, retinal activity was evoked by stimulation with different
geometrically defined voltage patterns. With this method, we were able to investigate the
dependence of the retinal network response on the strength, shape and location of distally
injected spatial charge patterns. This arrangement well imitates the in-vivo situation of a
subretinal implant with embedded stimulation electrodes.

They found that application of different spatio-temporal voltage pattern via the
electrode array resulted in well ordered spatio-temporal activity pattern in the retinal network.
Median charge delivery at threshold was 0.4 nC/pulse/electrode (charge density 500 µC/cm²).
The operational range for modulating the spike activity with distally injected charge covers
about one to two orders of magnitude (charge in nC). The spatial resolution was 100 - 200 µm.
The results also indicate that ganglion cells respond to charge injection within a circumscribed
area with center and surround.

**Threshold and operational range for subretinal stimulation:**
Evoked retinal response related to the amount of injected charge. (A) Raster plot (40 trials) and cumulative response histogram (bin width 1 ms) to a single voltage pulse with 0.5 ms duration and increasing amplitude, applied via a platinized gold electrode to a chicken retina sample. In the histograms the number of spikes from 40 trials is given. (B) Relative ganglion cell response in a 40 ms window after pulse onset plotted against charge injected per pulse and electrode. At the upper axis the related voltage level and peak current are given. The error bars indicate the standard deviation of the number of spikes per trial within the analyzing window. The colored triangle indicates the operational range between the 10% and 90% response level. (C) Scatter diagram showing the charge thresholds for spot stimulation (n = 10). The line represents the median value (0.43 nC).

The experiments revealed that in a partly degenerated neuronal network information processing capabilities are present and can be activated by artificial inputs. This open up promising perspectives not only for the development of subretinally implanted stimulation devices as visual prostheses but also for the entire field of neurobionics and neurotechnology.

3.2.2 IN VIVO TESTS

ELECTRICAL SIGNALS FROM THE BRAIN - VEP

A special part of the brain, the visual cortex, is believed to be the entrance structure to visual perception and cognition. Activity of nerve cells within the brain's surface (the cortex) produce electrical fields that can be picked up at some distance with electrodes (like ceiling microphones pick up sound from instruments in an orchestra during a concert). In humans these electrodes are simply "glued" on the scalp with a sticky paste on the back of the head. In the pig model special arrays of electrodes fixed on a silicone-carrier (Fig.1 B) are placed under the scull bone above the duration by neurosurgeons (Fig.1 A) and can be left there for several months.
When a visual stimulus (e.g. a blinking spot or a reversing checkerboard pattern) is presented within the visual field the electrical fields arising from the visual cortex change over time in a characteristic manner. These changes are measurable as voltage changes across the electrodes. They are referred to as "visually evoked potentials" or VEP.

**VEP as an objective measure for visual function**

VEPs are very informative about the visual system and its function. Each time a VEP can be recorded most probably a visual sensation has occurred. In humans VEP-curves vary in amplitude and time, dependent on the intensity, the location and the type of visual stimulus that is used to evoke the VEP. VEPs are an objective measure for central visual function. Since its anatomy and size is very close to the human eye, the pig is an ideal model to develop implantation techniques for subretinal devices or to test long-term stability and biocompatibility.
Fig 3.2.3 Mini-Pig VEP

White light flashes of varying intensity were repeatedly presented to the anaesthetized pig. Electrical fields arising from the visual cortex in response to the stimulation were recorded with special amplifiers and further analyzed by computer. A) At high light intensities response amplitudes of up to 200 µV of voltage could be recorded. B) Following electrical stimulation with a subretinal device evoked brain activity in the visual cortex.

In the last years scientists could prove that stimulation via a subretinal implant indeed led to a activation of the visual cortex both in pigs and rabbits. These electrically evoked "VEP" signals from the brain were similar in time course and amplitude to the VEP obtained by light stimulation (white flashes) of an equivalent retinal area.
Fig. 3.2.4: Focal white light flashes (approx. 10-15° visual angle) were repeatedly presented to the anaesthetized rabbit. Interleaved to the light stimulation series of electrical stimuli of varying amplitude and duration were applied to the retina (via a subretinal implant) during complete darkness.

Stimulus amplitudes of 600 mV (trace at 600 mV) evoked brain activity clearly above noise level (trace at 0 mV). The response amplitude further increased on increasing stimulation amplitudes. In comparison, the lowermost trace reflects the brain's response to a white light flash. Although the shape of the responses to electrical stimulation and to light stimulation matches closely, with the subretinal implant there is a much lower implicit time (~time from onset of the stimulus green line to the onset of a recordable response in the brain). This is probably due to the much faster propagation of the "light signal" through the subretinal prosthesis and the connected retinal cells.
The Chows originally tested their chip in blind animals and successfully produced visual sensations. Their device displays only black and white images and works best in well-lit rooms, but they hope that the addition of more solar cells on the chip will eventually improve the results. Much of this technology hinges upon the ability of the human eye to accept silicon chip implants, and six retinitis pigmentosa patients have undergone the procedure during the past year. Dr. Chow reports that, as yet, there has been no sign of rejection, infection, inflammation, or detachment, and that the patients (all affected by retinitis pigmentosa) are reporting improved vision.

A recent press release from Optobionics (May 2002) reported these positive results, and also that the chips seem to be stimulating remaining healthy cells. Initial expectations were to gain some light perception at the site of the implant, but improvement outside the implant areas is also being seen: something Dr. Chow calls a "rescue effect." His report was also presented at the 2002 meeting of the Association for Research in Vision and Ophthalmology (ARVO) in Ft. Lauderdale, Florida.

In addition to continuing to follow up on these six patients, the Optobionics company is planning more implants in the near future. This work by the Chows is for the purpose of determining the safety of the procedure in humans under FDA guidelines, and it will be several years before large-scale clinical trials will prove the efficacy of their approach.

The micro chip which should be designed for sub retinal implantation should small enough to be implanted in eye, supplied with continuous source of power, and it should be biocompatible with the eye tissues. To meet these requirements scientists in optobionic research centre have developed a device called artificial silicon retina.
3.2.3 STRUCTURE AND WORKING OF ASR

The ASR™ microchip is a silicon chip 2mm in diameter and 25 microns thick, less than the thickness of a human hair. It contains approximately 5,000 microscopic solar cells called “microphotodiodes,” each with its own stimulating electrode. These microphotodiodes are designed to convert the light energy from images into electrical chemical impulses that stimulate the remaining functional cells of the retina in patients and rp type or devices.

The ASR microchip is powered solely by incident light and does not require the use of external wires or batteries. When surgically implanted under the retina—in a location known as the “subretinal space”—the ASR chip is designed to produce visual signals similar to those produced by the photoreceptor layer. From their sub retinal location, these artificial “photoelectric” signals from the ASR microchip are in a position to induce biological visual signals in the remaining functional retinal cells which may be processed and sent via the optic nerve to the brain.

In preclinical laboratory testing, animal models implanted with the ASRs responded to light stimuli with retinal electrical signals (ERGs) and sometimes brain-wave signals (VEPs). The induction of these biological signals by the ASR chip indicated
When a diode is reverse biased the electrons & holes move away from PN junction. If the photo diode is exposed to a series of light pulses the photon generated minority carriers must diffuse to the junction & should be swept across to the other side in a very short time. Therefore its decided that he width of the depletion region is be large enough that most of the photons are absorbed within the depletion region rather than in the neutral PN junction region. Photodiode can work in two modes. One in which the external circuit delivers power to the device other in which device gives power to the external circuit. Therefore it can be called as a solar cell.

The ASR is powered solely by the incident light & does not require the use of external wires or batteries. When surgically implanted under the retina in a location known as subretinal space the ASR is designed to produce visual signals similar to those produced by the photoreceptor layer. Thus a photodiode produces a voltage corresponding to the light energy incident on it. Solar cells in the device's microchip are supposed to replace the function of the retina's light-sensing cells that have been damaged by disease.

The ASR microchip relies on the ability to stimulate the remaining functional cells within a partially degenerated inner or neuro retina. As a result, the ASR chip will not be able to assist patients with conditions where the retina or visual pathway is more substantially damaged.

3.2.4 IMPLANT DESIGN AND FABRICATION

The current micro photodiode array (MPA) is comprised of a regular array of individual photodiode subunits, each approximately 20×20-µm square and separated by 10-µm channel stops. Across the different generations examined, the implants have decreased in thickness, from ~250 µm for the earlier devices, to approximately 50 µm for the devices that are currently being used. Because implants are designed to be powered solely by incident light, there are no connections to an external power supply or other device. In their final form, devices generate current in response to a wavelength range of 500 to 1100 nm.
Implants are comprised of a doped and ion-implanted silicon substrate disk to produce a PiN (positive-intrinsic-negative) junction. Fabrication begins with a 7.6-cm diameter semiconductor grade N-type silicon wafer. For the MPA device, a photo mask is used to ion-implant shallow P+ doped wells into the front surface of the wafer, separated by channel stops in a pattern of individual micro photodiodes. An intrinsic layer automatically forms at the boundary between the P+-doped wells and the N-type substrate of the wafer. The back of the wafer is then ion-implanted to produce a N+ surface.

Thereafter, an insulating layer of silicon nitrate is deposited on the front of the wafer, covering the entire surface except for the well openings. A thin adhesion layer, of chromium or titanium, is then deposited over the P+ and N+ layers. A transparent electrode layer of gold, iridium/iridium oxide, or platinum, is deposited on the front well side, and on the back ground side. In its simplest form, the photodiode and electrode layers are the same size. However, the current density available at each individual micro photodiode subunit can be increased by increasing the photodiode collector to electrode area ratio.

Implant finishing involves several steps. Smaller square devices are produced by diamond sawing, affixed to a spindle using optical pitch, ground, and then polished to produce the final round devices for implantation. The diameter of these devices has ranged from 2-3 mm (for implantation into the rabbit or cat sub retinal space) to ~0.8 mm (for implantation into the smaller eye of the rat).
fig 3.2.5 Schematic cross section through a micro-photodiode (left) and micrograph of surface obtained by scanning electron microscopy. The micro-photodiodes convert light impinging on the surface of the chip to electric current which is delivered to the tissue via micro-electrodes.

Fig 3.2.6: Titanium is sputtered at high pressure in a nitrogen atmosphere to obtain nano-porous titanium nitride (TiN) stimulation electrodes on the implant. This enables enhancement of electrode surface area by a factor of up to 100 which is a critical prerequisite.
for efficient charge transfer from chip to tissue. SEM micrograph of thin film electrode: nanoporous surface texture provides for excellent charge transfer from chip to tissue.

Fig 3.2.8: The electric performance of the interface between chip and tissue is critical for the proper function of the implant. From the point of view of an electrical engineer, this interface acts like a capacitor. For this reason, no DC currents may be used in electrostimulation but only current transients may be applied. Micro-graph of cross-section through retinal tissue on micro-photodiode obtained by transmission electron microscopy. The electrical properties of the interface may be described by an equivalent circuit. Only transient current pulses may be used to stimulate tissue.

**ASR IMPLANT PROCEDURE**

The microsurgical procedure consists of a standard vitrectomy plus an additional step. The surgeon starts by making three tiny incisions in the white part of the subject’s eye, each incision no larger than the diameter of a needle. Through these incisions, the surgeon removes the gel in the middle of the eye and replaces it with saline. The surgeon then make an opening in the retina through which fluid is injected: the fluid lifts up a portion of the retina from the back of the eye and creates a small pocket in the “subretinal space” just wide enough to accommodate the ASR microchip.

The surgeon then slides the implant into the subretinal space, much as one might slip a tiny coin into a pocket. Finally, the surgeon introduces air into the middle of the eye to gently push the retina back down over the implant. Over a period of one or two days, the air bubble is reabsorbed and replaced by fluids created within the eye. The procedure takes about 2 hours and is done on a hospital outpatient basis.
Scientists have created a device that allows them to communicate directly with large numbers of individual nerve cells in the visual part of the brain. The device is a silicon electrode array may provide a means through which a limited but useful visual sense may be restored to profoundly blind individuals.

This shows the development of the first visual prosthesis providing useful "artificial vision" to a blind volunteer by connecting a digital video camera, computer, and associated electronics to the visual cortex of his brain. This device has been the objective of a development effort begun by our group in 1968 and represents realization of the prediction of an artificial vision system made by Benjamin Franklin in his report on the "kite and key" experiment.

This new visual prosthesis produces black and white display of visual cortex "phosphenes" analogous to the images projected on the light bulb arrays of some sports stadium scoreboards. The system was primarily designed to promote independent mobility, not reading. It has a battery powered, electronic interface that is RF isolated from line currents for safety. This interface can replace the camera, permitting the volunteer to directly watch television and use a computer, including access to the Internet. Because of their potential importance for education, and to help integrate blind people into the workforce, such television, computer, and Internet capabilities may prove even more valuable in the future than independent mobility.

First of all passing an electric current through a single electrode into the visual cortex causes a blind subject to see a point of light called a phosphene. The visual scene before the subject will be encoded by miniature video camera attached to a pair of eye glasses. The resulting video signals will be processed by custom circuitry. The processed signals pass across the skull to an array of electrodes implanted in the primary visual cortex.
Relaying the electric signals to the cortical implant could be accomplished by two methods—conductive and inductive. In the former connectors are attached to the cranium and provide access to the external circuitry with the later a transformer is formed with one coil under the skin and the other one on the outside.

Fig 4.1 Cortical Implant

A platinum foil ground plant is perforated with a hexagonal array of 5 mm diameter holes on 3 mm centers, and the flat platinum electrodes centered in each hole are 1 mm in diameter. This ground plane keeps all current beneath the dura. This eliminates discomfort due to dural excitation when stimulating some single electrodes (such as number 19) and when other arrays of electrodes are stimulated simultaneously. The ground plane also eliminates most phosphene interactions when multiple electrodes are stimulated simultaneously, and provides an additional measure of electrical safety that is not possible when stimulating between cortical electrodes and a ground plane outside the skull. Each
electrode is connected by a separate teflon insulated wire to a connector contained in a carbon percutaneous pedestal.

When stimulated, each electrode produces 1-4 closely spaced phosphenes. Each phosphene in a cluster ranges up to the diameter of a pencil at arms length. Neighboring phosphenes in each cluster are generally too close to the adjacent phosphenes for another phosphene to be located between them. Indicate the primary visual cortex (area 17) would permit placement of 256 surface electrodes on 3 mm centers on each lobe in most humans (512 electrodes total.

**Figure 4.2.** Blind volunteer with sub-miniature TV camera mounted on the right lens of his sunglasses, and the laser-pointer (position monitor) on the left temple piece

### 4.1 THE ELECTRONICS PACKAGE

The 292 X 512 pixel CCD black and white television camera is powered by a 9 V battery, and connects via a battery powered NTSC link to a sub-notebook computer in a belt pack. This f 14.5 camera, with a 69° field of view, uses a pinhole aperture, instead of a lens, to minimize size and weight. It also incorporates an electronic "iris" for automatic exposure control.
The sub-notebook computer incorporates a 120 MHz microprocessor with 32 MB of RAM and a 1.5 GB hard drive. It also has an LCD screen and keyboard. It was selected because of its very small size and light weight. The belt pack also contains a second microcontroller, and associated electronics to stimulate the brain. This stimulus generator is connected through a percutaneous pedestal to the electrodes implanted on the visual cortex. The computer and electronics package together are about the size of a dictionary and weigh approximately 10 pounds, including camera, cables, and rechargeable batteries. The battery pack for the computer will operate for approximately 3 hours and the battery pack for the other electronics will operate for approximately 6 hours.

This general architecture, in which one computer interfaces with the camera and a second computer controls the stimulating electronics, has been used by us in this, and four other substantially equivalent systems, since 1969. (9) The software involves approximately 25,000 lines of code in addition to the sub-notebooks' operating system. Most of the code is written in C++, while some is written in C. The second microcontroller is programmed in assembly language.

4.2 STIMULATION PARAMETERS

Stimulation delivered to each electrode typically consists of a train of six pulses delivered at 30 Hz to produce each frame of the image. Frames have been produced with 1-50 pulses, and frame rates have been varied from 1 to 20 frames per second. As expected, (4) frame rates of 4 per second currently seem best, even with trains containing only a single pulse. Each pulse is symmetric, biphasic (-/+ with a pulse width of 500 µsec per phase (1,000 µsec total). Threshold amplitudes of 10-20 volts (zero-peak) may vary +/-20% from day to day; they are higher than the thresholds of similar electrodes without the ground plane, presumably because current shunts across the surface of the pia-archnoid and encapsulating membrane.
The system is calibrated each morning by recomputing the thresholds for each electrode, a simple procedure that takes the volunteer approximately 15 minutes with a numeric keypad.

Although stimulation of visual cortex in sighted patients (2) frequently produces colored phosphenes, the phosphenes reported by this volunteer (and all previous blind volunteers to the best of our knowledge) are colorless. We speculate that this is the result of post-deprivation deterioration of the cells and/or senaphtic connections required for color vision. Consequently, color vision may never be possible in this volunteer or in future patients. However, optical filters could help differentiate colors, and it is also conceivable that chromatic sensations could be produced if future patients are implanted shortly after being blinded, before atrophy of the neural network responsible for color vision.

The problem kindling of neural tissues or the triggering of seizures in those tissues by periodic electrical stimulation has to be solved. Biocompatibility is another issue of concern. This particular vexing problem has yet to be solved. A power supply to the system has to be efficiently designed. The position of the implant within the skull has to be decided upon. Lastly the implant should function flawlessly for years.
The application of the research work done is directed towards the people who are visually impaired. People suffering from low vision to, people who are completely blind will benefit from this project. The findings regarding biocompatibility of implant materials will aid in other similar attempts for in human machine interface. Congenital defects in the body, which cannot be fully corrected through surgery, can then be corrected.

There has been marked increase in research and clinical work aimed at understanding low vision. Future work has to be focused on the optimization and further miniaturization of the implant modules. Commercially available systems have started emerging that integrates video technology, image processing and low vision research.

Implementation of an Artificial Eye has advantages. An electronic eye is more precise and enduring than a biological eye and we cannot altogether say that this would be used only to benefit the human race. In short successful implementation of a bioelectronic eye would solve many of the visual anomalies suffered by human’s to date.

To be honest, the final visual outcome of a patient can not be predicted. However, before implantation several tests have to be performed with which the potential postoperative function can be estimated. With this recognition of large objects and the restoration of the day-night cycle are the primary goals of the prototype implant.