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Design As If People Mattered – A Case Study of LED Lighting

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Evaluation Sheet

The work contained in the report entitled DESIGN AS IF PEOPLE MATTERED – A CASE STUDY OF LED LIGHTING has been evaluated on the 25^{th} of July 2009.

Dr. Ashok Rao Guide and Internal Examiner	Dr. K. Raghuveer External Examiner

Comments

Contents

I will give you a talisman. 'Whenever you are in doubt, or when the self becomes too much with you, apply the following test: Recall the face of the poorest and most helpless person whom you have seen and ask yourself if the step you contemplate is going to be of any use to him. Will he be able to gain anything by it? Will it restore him the control over his life and destiny? In other words, will it lead to Swaraj for the hungry and starving millions?' Then you will find your doubts and self melting away.

- M.K. Gandhi

Abstract

The current trend in Corporate India has been toward "Rural Marketing". The premise is that rural India has been a traditionally underserved market and incomes are rising in the hinterland. Therefore, it makes a lot of business sense to market one's products to the rural populace. Even though there has been a lot of lip service towards treating the rural poor as customers and not as consumers, the main focus has been to modify marketing strategies to appeal to the rural populace, rather than on the design of the products themselves. The race for the "Fortune At The Bottom Of The Pyramid" has not really resulted in meaningful and context-appropriate products which can make a difference in the lives of their owners.

This report draws upon existing design principles and tries to integrate it with various pertinent economic and social commentaries particular to India to produce a normative benchmark with which to compare existing product design and marketing efforts. In particular, it evaluates Light Emitting Diode (LED) based lighting - the various technological components, packaging, presentation, social and economic viability and the infrastructure required to make it a true success story in a land where most people do not even have access to regular or reliable source of electricity. Further, this report tries to be a handbook of sorts to enable prospective designers of LED lighting systems to use as a reference while making design choices.

LED lighting looks to make a serious dent in efficiency improvement and aesthetic design of lighting systems. Considering the fact that most commercial electricity is used for lighting, this promises to make energy available for more important uses like rural lighting. It has many advantages and issues, both of which this report looks to address.

By the end of this report, I hope the reader will be convinced that a great product does not just contain good engineering and design, but a particular social, economic and ethical outlook which must try to be in line with the group at which it is targeted. This report does not try to resolve tensions inherent in producer-consumer relations, but tries to enumerate various important requirements which must inform a good design.

Acknowledgements

This study can be considered as a summary of 3 years of design work and interaction with various interesting people who have guided me and shaped the way I look at all things, from a simple LED light to Life, Universe and Everything.

I owe a great deal to my advisor Prof. Ashok Rao who has helped my in every aspect of my journey for the past three years. Not just in academic matters, he has equally been a physical, mental, medical, intellectual, (*)al advisor for as long as I have known him. Thanks for offering me the Red Pill. I am equally indebted to Deepak Malghan and Punit Singh who have been very influential in my intellectual, moral and technical development over the years. I must also thank Mr. Ravi Kumar with whom I have had many illuminating discussions on a variety of topics, from botany to ecology to engineering. Some of the insights in this study are due to these discussions.

I must thank my parents for being as supportive as they have been even though they were not really sure where I was headed. For that matter, neither was I. Their belief and faith in me has pushed me to do something which makes them proud, eventually.

Darshak Vasavada from AllGo Embedded Systems has taught me a great deal about engineering, discipline and sustained commitment to something. If I manage to do anything for a long amount of time, it will be due to him. AllGo has helped me gain other great friends like Abhay, Arun, Srini and Girish and has helped finance my (mis)adventures over the past few years. I am extremely indebted to AllGo and all my friends over there for helping me be something better than what I was before I joined AllGo.

Subba Raju and Dinesh Kumar from the Timbaktu Collective have been always there to help me tune my senses to watch, hear and learn from people whose language and world view I could not understand. They have helped me understand that however different I may be from a child in their Chennakothapalli school, love and curiosity will still enable me to understand him/her.

I owe not little to my classmates in my present course. I have learned much interacting with them and more importantly, they have showed me the many major shortcomings that I still have to overcome to make any real difference in other's lives. At the very least, they have helped me patch up my Kannada to include something other than curse words.

I would not give a fig for the simplicity this side of complexity, but I would give my life for the simplicity on the other side of complexity.

Oliver Wendell Holmes

1

Why *design* lights ?

Before getting to the question of why something as simple as a light needs to go through a design process, it is instructive to understand the present situation with regards to product design for rural areas.

1.1 The Status Quo

The Management Guru, C. K. Prahalad, in his now legendary book "Fortune At The Bottom Of The Pyramid"[CKP], considers various case studies to show how corporations can earn a profit while serving rural customers. Online, one can find innumerable links for a Google Search for "Rural Marketing". For example, LG claims that the fastest growing market for its TVs has been the Indian hinterland[LG]. Coca Cola's *Thanda matlab Coca Cola* campaign was target to appeal to the rural consumer. Coca Cola found that people preferred traditional drinks like *lassi*, and therefore launched an aggressive pricing and marketing strategy to get the rural consumer to switch to its products.

The major issue with case studies mentioned in [CKP], be it the ITC *e-choupal* or the Hindustan Lever Shakti marketing initiative or the above mentioned LG and Coca Cola campaigns are that they are mainly marketing campaigns to make products that the company already produces appealing to the rural consumer. The modifications made to the product are merely cosmetic like repackaging in sachets to make them affordable.

1.1.1 Then Why Are They Successful ?

Even though the number of products specifically designed for the rural customer are extremely limited, the sale of urban-centric products in a new package seems to be working very well. Why is this so ?

To understand this, one must learn to distinguish between *felt* and *perceived* needs of a customer[Reddy]. To the marketer, there will probably be no difference between the two. For a designer, however, there is an ocean of difference between the two concepts.

To make this distinction, we borrow the notion of 'Humans as *explanatory creatures*'[Nor]. Humans make up mental models of cause and effect, of relationships between objects to understand our experiences, predict outcomes of certain actions and to handle unexpected occurrences. These models are based on whatever information we have at hand, regardless of whether it is real, imperfect or even imaginary(false).

A successful marketing strategy aims to fill in this gap of knowledge in the consumer to the advantage of the company being advertised. Given common human needs of comfort, prestige and abridgement of manual labour, advertisements claim to fulfill these needs using certain products. Thus, the consumer creates a mental model, a causal relationship between a want and a means to fulfill it. Therefore, when a woman asks for a "gas stove", what she actually is asking for is a cleaner and safer way to cook. When a teenager asks for a Coke, what he is asking for is a status symbol. Since their knowledge of options to satisfy *felt* needs (cleaner cooking , status symbol) is limited, what a market survey brings out is normally *perceived* needs (LPG stove, Coke).

Therefore, a misconceived notion of being able to fulfill the needs of the rural populace without giving due regard to whether it is a felt or perceived need can make campaigns seem successful, even noble at times.

1.2 Elements of Design

It is common experience that we sometimes have to struggle to use simple, everyday things. Be it a telephone, a swivel door, or a word processor, things that should be easy to use are sometimes not. Though we end up blaming our own technical ineptness for such experiences, the more probable reason is that the device has been poorly designed. In the present context of design for rural usage, the gulf between the cultures and world views of designer and eventual user may be extremely wide.

This makes the imperative toward better design even more important. The large number of poorly designed products being pushed into the rural market make the rural customer extremely hesistant to spend money to buy new devices. These devices are neither well-tested nor sensitive to typical use cases, which cause them to fail or malfunction.

Nowhere has design failure been as prominent as in the design of lighting systems. The effort towards rural electrification starts with installation of lighting systems, and there have been problems galore — poor reliability and robustness, high maintenance, poor knowledge of use-cases — all have contributed toward this end. And from a development perspective, i.e, using lighting systems as a tool for economic and social development, the failure has been even more spectacular. Lighting is a basic need in almost any society. In an economist's parlance, it has an almost inelastic demand. However, the penetration of high quality lighting systems into rural homes is still far from being a reality. This has had many reasons which will be discussed below, not least of which is bad design.

The main elements that one must focus on in any design are[Nor]:

- *Visibility*: The design must incorporate visual cues as to the operation of the device. The way the device operates must be quite clear from the controls on the device. For example, a reading light which hides the switch for visual elegance is a bad design.

- *A Good Conceptual Model*: The position and design of the controls must provide a good conceptual image of how the device works. A button near the window of a car must make it obvious how to lower the window. A slider on a reading light suggests moving the slider controls the brightness of the light, and that is exactly what should happen.

- *Good Mapping*: There must be an obvious mapping between a control and a function performed by the device. A control which controls more than one function should be avoided. Ideally, there must be one control per function. A switch near a car stereo must turn the music on, not switch on the wipers. The state the device is in must be obvious to the user, either by visual or auditory cues.

- *Feedback*: There must be continuous feedback to the user as to the result of her actions. Lights, LCD Screens are among the favorites to perform this task.

All the elements listed above focus on the user of the device. However, one can also factor in other requirements like:

- *Simplicity of manufacture*: The device must be capable of being assembled or manufactured without the requirement of expensive equipment, or assumptions like supply of high quality and reliable electricity.
- *Life-cycle design*: The design must take into consideration who is manufacturing it, who maintains it, availability of spare parts and methods of disposal.
- *Locally available material*: The design must be flexible enough to use locally available material — Bamboo, sheet metal, cheaply available parts like general purpose PCBs, among other things. The number of components that must come from a distant location must be minimized.
- *Status symbols*: The device must be aesthetically pleasing, which sets it apart from similar products.

The use of such highly restrictive requirements must be justified, and the arguments for the same will be presented in the following chapters.

1.2.1 An Example

A very popular LED light that has had excellent success over the past few years has been from Thrive[Thr] in Andhra Pradesh. We have taken their latest offering, the 'Accendo' as an example to check how it measures against the parameters we have set as a benchmark for ourselves.

- The front panel of the light contains nothing but the LEDs. The button for operation is at the side, curtailing visibility.
- The same button is used for both switching on the light as well as dimming the light. This operation is not immediately obvious when one looks at the light.
- Notice the placement of the handle. If a person were to carry this lamp and walk around, there is no comfortable carrying posture — one has to twist his arm to hold it properly. Even then, it does not easily lend itself to focusing applications, which are where such a light would be of great help.
- There is a bottom sliding piece which holds the battery in place. This is invisible to the user unless pointed out, and accidental removal while carrying will destroy the entire system, since the battery is connected to the lighting circuitry via wires which will get pulled down along with the falling battery.

Figure 1.1: The Accendo LED light from Thrive

- There does not seem to be any simple way of knowing whether the battery is completely charged or not.
- The driving circuitry consists of a microcontroller with proprietary code: nothing can be changed even if one wishes to. The PCB is manufactured using surface mount technology, repair is practically impossible and out of reach for all but highly skilled professionals.
- The casing is injection molded, and any breakage will have to be replaced. Impossible to change locally.

Therefore, even though this product will probably become as popular as any other from the Thrive stable, one can see that it does not match up very well to the benchmark that we have tried to formulate for a good design. The apparently trivial question of should one think of spending time to design simple things like lights leads us to interesting insights.

All religions, arts and sciences are branches of the same tree. All these aspirations are directed toward ennobling man's life, lifting it from the sphere of mere physical existence and leading the individual towards freedom.

Albert Einstein

2 Development as Freedom

A more holistic manner of looking at social and economic development is as a process which increases the substantive freedoms and capabilities of a person[Sen]. Thus, markets are an attractive means for development since it increases a person's freedoms to take part in economic transactions. In the same vein, high quality lighting is a useful means for development since it increases the choices a person has as to the time she can work and study. Similarly, easy access to potable water increases the amount of free time(especially for women) to spend in more productive activities.

Similar views were echoed by M. K. Gandhi and J. C. Kumarappa almost a century before [Sen]. They correctly understood the relationship between man, machine and culture — machines can be used as a means for cultural and political domination — and therefore tried to find means to design tools (machines) which empower a person rather than disenfranchise him. This was the driving force behind *Khadi*, and organisations like the All India Village Industries Association (AIVIA). This apparently quixotic and anachronistic viewpoint grew from an intimate knowledge of the socio-economic situation in rural India.

2.1 The Rural Context

Taking cues from the viewpoints put forth above, it is instructive to understand the features of Rural India before one tries to justify the ways and means by which true development — that which increases the freedoms of the people — can take place. The following sections do not claim to be complete or representative, but touch on those aspects which are most relevant to the task at hand, i.e, designing objects as if its users really mattered.

2.1.1 Social Context

- One of the most important changes that one has seen in recent times is the possibility for social mobility. One of the greatest driving factors for this change has been education and an increasing importance of monetary factors in determining social status, as opposed to land holdings, ancestry or caste. The trend toward urbanization has only added to this change.
- The emergence of women as earning members of the family has to some extent resulted in the increase of their status within the family and society as a whole. It is a well known fact that money in the hands of women results in better nutritional and educational opportunities for children[Sen], and such beneficial effects are becoming apparent.
- Increased penetration of transport and communication technologies are helping the rural populace to take better decisions with regards to education, agricultural inputs and markets for end products. This has also increased their willingness to try out new products and technologies which they perceive to be advantageous at home or the workplace.

2.1.2 Economic Context

- There has been a growing migration from agriculture and allied activities to professional and semi-professional industrial trades, practiced in urban areas. However, the amount of 'unskilled' labour force remains too large for the organised sector to absorb[Bhagwati]. This has resulted in a huge percentage of unemployed in the rural areas, partly due to land holding patterns in India which has traditionally been a few owning most of the land and insufficient local demand for traditional products which pale in comparison with their Chinese competitors both in looks and price. These are normally termed 'unskilled' labor since their skill sets are not valued in the urban-industrial context. These skills are generally lost within a generation of migration to urban areas.
- Agriculture in India is still a "Gamble of the Monsoons", and decline in allied income generating activities has resulted in an increasing number of suicides,

increasing rural debt, and distress migration to the urban areas[Sainath]. Programs like the NREGS are helping to a very large extent, but India's increasing fiscal deficit casts a shadow as to how far these can be sustained[Bhagwati].

- The rural customer is interested to buy new products, but is unwilling to pay a large sum upfront[Heierli]. Microfinancing and payment in installments are among the main instruments used to overcome this hesitation. In other words, if it is possible to buy half of anything for half the cost, that will be the preferred option.
- Most skill development programs for rural youth are designed to be used in large scale industries or require large capital if one wants use them to start a business. This discourages entrepreneurial activity and encourages migration to cities.

2.2 Development Imperatives

From the previous section, we can see that there have been certain changes in the rural scenario which can be advantageously used to promote development, and certain changes which need critical attention:

1. Education is slowly becoming a universal reality.
2. Migration from villages has led to a drop in skill levels, demand, and innovation.
3. Women are key to any development initiative — skills that are easily learned by women are to be encouraged.
4. Rural areas demand devices that enhance convenience and comfort, similar to urban areas. But due to lack of alternatives, products designed with the urban customer in mind find their way into the hinterland as well.
5. Alternative income generating activities to supplement agricultural income are a priority.
6. As demand from the peri-urban areas increases, it becomes a pressing need to develop solutions which are ecologically sensitive and energy efficient. Even a small percentage increase in demand results in a large absolute increase, with serious ecological consequences.

7. It must be possible for a rural entrepreneur to source most of his raw material within close range from his place of stay. Otherwise, the resulting transportation and allied costs increases the material and financial demand of the enterprise. Also, relying on local materials provides an incentive to conserve the local environment and native skills.

8. Dissemination of modern technologies and processes in an on-demand basis must be made possible so that these enterprises remain competitive.

2.3 How (In)feasible is it ?

An honest answer will be 'We do not know'. Since the stated objective was to develop a normative benchmark, the question of feasibility is left to particular examples and initiatives. But given the extant situation in rural areas and current trend which systemically encourages migration to urban areas, it may well be impossible to adhere to some or most of these principles. But still, this section of the report serves a useful purpose: to provide NGOs and other organisations with a yardstick with which to measure the initiatives and a rough initial sketch over which to build new ones.

Form follows function - that has been misunderstood. Form and function should be one, joined in a spiritual union.

Frank Lloyd Wright

3 Design and Process Imperatives

Now, we are well placed to combine the elements of design and the development imperatives peculiar to the Indian context to synthesise a set of design and process imperatives for any product that one wishes to introduce into the rural market. Throughout, we will provide examples from to support our reasoning.

3.1 Economies Of Scale

As noted before, one of the major factors due to which rural enterprises are not competitive is the economy of scale. This simply means that mass manufacture makes it easy to reduce the price of a single unit being produced. This is the driving principle behind the present trend toward ever larger retail showroom chains, and among the reasons why China is so dominant in the manufacturing sector. This decrease in cost comes from both cheaper material due to large scale manufacture and process improvements (the learning curve) which occur as an enterprise produces a large number of the same product.

One way for small scale enterprises to gain advantage of economies of scale is to include components in their design which are already mass manufactured, or which easily lend themselves to mass manufacture. A good example of such an innovation is the *Pump As Turbine* technology, which uses mass produced pumps to drive down costs of micro-hydro installations[Deep]. Similarly, in LED lighting, the largest contributor to cost is the LED itself, which can contribute as much as 20-30% to the Bill of Materials (BoM). Using a design which increases the scale at which the LEDs are used decreases the cost nonlinearly.

3.2 Flexible and Modular Design

If there is more than one way to perform a certain function, then knowledge of all the methods must be with the entrepreneur. Then, she can make a decision as to the technology to be used based on market feedback. To complement such flexibility, the design must consist of various self-contained modules which can be freely interconnected with other modules to perform the given function. For example, one gets LEDs of all shapes and sizes and costs. If it is possible to isolate the LED module from the driving module (which also comes in various flavours), then a large variety of options can be made available to the user and producer, depending on his willingness to pay and initial capital available.

3.3 Open and Simple Design

The design must be freely available for anyone to copy and modify. This fosters competition and innovation, and acts as an informal resource for learning. Similarly, the tools required to make the design must be freely available so that access is not a problem.

The design must be simple in the sense that all components used must be easily available in the open market. The number of exotic components must be reduced. The functions performed by such components must be evaluated and discarded unless it is critical. But given the explosion in information, communication and transport infrastructure nowadays, there are very few components which qualify as exotic!

3.4 Life cycle design

All parts of the life cycle of the product, from sourcing of components, manufacture and assembly, sale, repair and maintenance to disposal must be kept in mind while choosing technologies and materials. A couple of questions can be kept in mind during design:

- Is is easy and cheap to manufacture ?

- What assumptions does it make ? (reliable power, access to water, access to spare parts, careful handling, etc.,)
- How light is it on the environment in terms of energy and resource usage ?
- Can some of its components be harvested and reused prior to disposal ?
- Does it carry any gender related bias ?
- Can 'half' or 'by two' of the design be manufactured ?
- Cost and ease of repair, maintenance.

3.5 Process Imperatives and Supply Chain Management

A *process* can be defined as a set of functions that have to be performed in a certain order in order to accomplish a given task. The advantage of a process driven enterprise as opposed to a function driven enterprise are well known[SCM]. Manfacture of products has a typical process behind it, some that we consider critical are presented here.

The product design, manufacture and marketing processes can be considered as a group of companies or individuals supplying goods and services to one another. Any product has a large number of such inputs, and the management of such a 'supply chain' is critical both for economic efficiency and customer satisfaction. A detailed study of this is beyond the scope of this report, and one can refer to [SCM] for details.

3.5.1 Training and Financing

Providing the requisite skills such as soldering, PCB making, component selection, repair, maintenance to would-be entrepreneurs is one of the most important part of the whole process. Without such an infrastructure, it is impossible to maintain a high level of quality in the product nor is it possible to build customer confidence. Also, such skills help enhance the income generation capabilities of the person and increase her choice of gainful activities. Some products may not be as easy to use and may require the user to be trained as to its usage. Such a situation was encountered during the deployment of smokeless *ASTRA* stoves which was ultimately a success.

Financing plays an important role in helping those who cannot afford to pay for the product upfront to be able to purchase objects which have a demonstrably significant impact on their quality of life. Access to credit is also an essential requirement for the success of any enterprise, small or large[Heierli].

3.5.2 Scale of deployment

The social scale at which the product is expected to be used — individual, family, community — is crucial in determining how to go about planning the manufacture, marketing and pricing of the product. Large scale deployments enjoy the advantage of economies of scale but are far more problematic in terms of gaining social acceptance and inevitably involve local politics. Individual level products involve more difficult logistical issues of financing, marketing and maintenance. For example, community-level biogas plants have been far more successful given the large initial cost of the projects but normally require a successful social strategy and development of civic sense among the people.

3.5.3 Local supply chain

As mentioned before, one of the ways to achieve economies of scale is to manufacture those components which cost the most in a large scale or look for alternatives which are already being mass manufactured. However, to ensure that reliable transportation is not a critical part of the process, looking for local materials to include in the design is useful. Bamboo, local metal/wood artisan work help in this workaround. This also has a side-effect of stimulating the local economy without the Government's Planning Commission having too much to do with it.

3.5.4 Feedback

Developing a product is a task that is never quite finished. The success or failure of a process depends ultimately on how feasible it is for the entrepreneur and how satisfied a customer is with the entire setup, from marketing to maintenance. Therefore, one of the main features to build into the process is a means to provide feedback to the designer, the manufacturer, the marketer, and anyone else whose plays a role in reaching a product to the ultimate customer. This can take many forms, from suggestion boxes to surveys.

The drive toward complex technical achievement offers a clue to why the U.S. is good at space gadgetry and bad at slum problems.

John Kenneth Galbraith

4 LED Lighting – The Technical Choices

This chapter goes into LED lighting in detail, enumerating the various functional components that go into an average lighting system and the various technological choices that are available to fulfill each of these functions. It looks at various aspects:

1. Cost
2. Efficiency
3. Availability
4. Environmental Load
5. Ease of Manufacturing
6. Ease of customization

The various trade-offs are made explicit so as to enable a designer to make informed choices as to the technology that is most suitable for her application.

4.1 The Skeleton Of A Lighting System

The most basic features of any LED lighting system are as follows:

- The light source (Light Emitting Diodes)

- The optics
- The circuitry driving the light source
- The energy source
- The housing for the system
- The printed circuit boards (PCB) for both the LEDs and the driving circuitry
- Thermal Management

4.2 The Light Source

LEDs nowadays come, quite literally, in all shapes, sizes and colors. The array of choices one has even for a single application is mind boggling and frankly, quite initimidating. There are a few colors in which LEDs commonly come - Blue, Green, Red, Amber and White. Most of the research nowadays seems to be directed towards White LEDs, which promise to revolutionize the lighting industry within a decade. One can roughly classify LEDs into three categories:

- Low Power LEDs which consume around 0.1 Watt or roughly 30-50 milli Amperes(mA). These are quite efficient and can mainly be used in applications which require little light at relatively small distances like night lights or reading lamps.
- Mid Power LEDs which are in the 0.5 Watt (150 mA) range. These can be used for all kinds of applications except those which are really low power.
- High Power LEDs which are in the 1-3 Watt range (350 mA to 1 A). These are mainly used for general illumination and street lighting. This is where all the R&D interest seems to lie.

The amount of light available per LED obviously increases with increasing power. A more pertinent issue is that design complexity, especially with respect to thermal management increases with increasing power. Efficiency also drops due to high heat production. Since economies of scale have not yet been achieved in the high power range, cost per watt at the customer end is also quite high. However, due to their high directionality, the available light where the LED is focused is much higher compared to Compact Flourescent Lamps (CFLs) or incandescent bulbs of equivalent wattage.

The main players in this market are Philips Lumileds[LumiLeds], Avago Technologies [Avago], Nichia Corporation[Nichia], Seoul Semiconductor[Seoul] and Cree [Cree]. Due to continuous research and development, it is difficult to point out one company which provides the best performance or lowest cost. There are also many taiwanese and chinese players like Edison[Edison] and Kingbright[KingB], who are key to making LEDs competitive by driving prices down.

Therefore, in terms of technical competitiveness, LEDs are bettered only by Sodium Vapor lamps, and are already ahead of Flourescent lamps. Economic competitiveness can only come with time and competition, and that will happen only sometime in the next decade.

4.3 The Optics

This is one of the more neglected part of any system design. This is quite unfortunate since this is also one of the most crucial parts of the design. It is very easy to find a well designed lighting system — just look at the optical design.

There is really no substitute to well designed optics. The savings in cost and power which a good lens can provide can overwhelm most fancy electrical workarounds. Depending on the application, one uses a concentrator or a diffuser. Depending on the typical use cases, the focal length, angle through which light is dispersed, color can change. One can also consider using reflectors and the LED facing away from the place to be illuminated to cut down the glare, since LED light is too intense to be looked at with the naked eye. Also, there are guidelines as to the amount of illuminance (lux)[LuxDef] required for typical activities[LuxRef]. Given a cost or energy budget and trying to achieve the desired lux levels can be made easier if optics are given more attention.

4.4 The Driving Circuitry

Driving LEDs reliably can be tricky, since they are best driven by constant current sources. Since the power dissipated in any circuit element is directly proportional to the squared of the current passing through it ($P = I^2R$), fixing the current is useful. Also, in LEDs the current drawn from the current source at a given voltage increases with increasing temperature. This makes it very probable that an LED driven by a

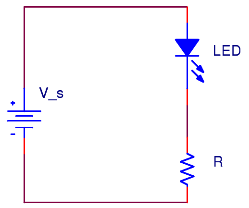

Figure 4.1: Resistor based source

voltage source will burn out. There are atleast three methods of producing a constant current from a constant voltage source like a battery:

1. Resistor-in-series method
2. Linear voltage regulator (LM 317) based source
3. Switching regulator based source

4.4.1 Resistor Method

This is the simplest method available to obtain a constant current. Since the voltage across an LED is approximately constant (say, V_d), a resistor is placed in series with the LED to generate a constant current given by

$$I = \frac{V_s - V_d}{R} \tag{4.1}$$

Where I is the desired current, V_s is the driving voltage and R is the resistance value to be connected in series. This design suffers from the following problems:

- The resistance normally increases with increasing temperature. Therefore, the current is not necessarily constant. The tolerance of the resistor plays an important role here.
- As the driving voltage increases, the power dissipated in the resistor increases.
- There is no negative feedback mechanism — Any increase in current will not be countered by a reduction in driving voltage.

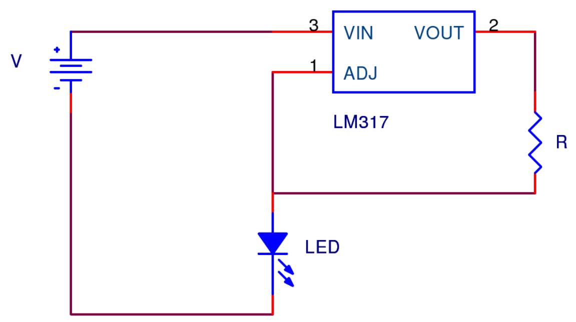

Figure 4.2: LM317 based source

Due to such considerations, this method is useful only for low current (< 100 mA) circuits, with the driving voltage almost equal to the voltage across the LEDs being driven.

4.4.2 LM 317 based source

This is another common method which makes innovative use of a LM 317 adjustable voltage regulator. The feedback resistor in the circuit R fixes the output current according to the equation

$$I \approx \frac{1.25}{R} \tag{4.2}$$

The regulator tries to maintain the voltage between the output and adjust terminals at 1.25 Volts, regardless of variations in input or temperature. Therefore, there is a negative feedback mechanism which maintains the current constant. The LM 317 is rated to provide 1.5 Amperes of current at a voltage range of 1.2 V to 37 V[LM317]. This can therefore be used to drive high power lighting systems as well. However, some things must be kept in mind:

- The LM 317 acts as a variable resistor — It varies its own resistance to maintain the output voltage constant. Therefore, the greater the voltage difference

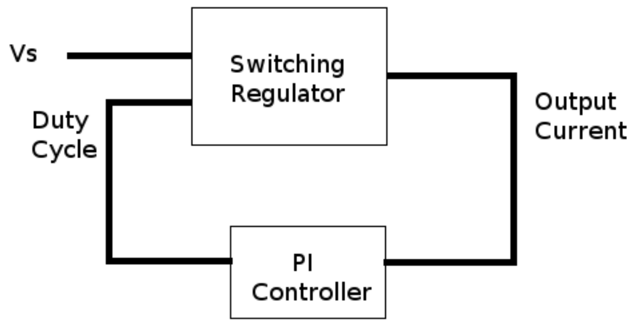

Figure 4.3: Switching Regulator based source

between V_d and V_s, the greater the power loss on the LM 317. Maintaining this difference low is necessary for efficient operation.

- Driving LEDs in parallel can be tricky, since there is no explicit mechanism to maintain the current constant over multiple LED strings.
- There is a minimum drop over the LM 317 which depends on the current delivered and the temperature, and will typically be around 1.5–2 volts. This is called the dropout voltage of the regulator. The difference $V_s - V_d$ must be greater than this value.

4.4.3 Switching Regulator Based Source

The most efficient, and most complicated method to get a constant current source is using switching regulators. The theory and practice of switching regulators cannot be discussed here, but [TexasInst] and [Micro] are good starting points to understand how to build constant current sources using these circuits.

The output voltage is normally fixed by design, and one requires a slightly different approach to get a fixed output current regardless of voltage. The output current is sampled using a low value resistor and this is used to vary the duty cycle of the regulator. The maximum output current of the regulator is also fixed by design, and this can be used to drive an LED string, as long as the combined V_d is lesser than the fixed output voltage.

4.5 Energy Source

The standard energy source for low power (< 20 Watt) lighting systems (which is our focus here) is a rechargeable battery. Though there are many varieties of batteries, the most popular and cheap is the lead acid variety. The main issue with batteries is that they have to be charged. There are many ways to do this, most popular being charging at a central station and distributing the lights at night for a small fee. The techniques to charge are using grid electricity when it is available or solar power. A neglected method is using thermocouples[Peltier], which seems perfectly suited to the rural scenario where availablity of heat (for cooking, bathing) is abundant as opposed to electricity. Pico hydro and gas turbines are also promising technologies but seem more appropriate for large scale use. Another important but neglected source of energy is draught animal (oxen, buffaloes) or human energy which can be converted to electricity. There is a huge gap between the potential of these non-conventional sources of energy and the research that is needed to make them a practical and usable reality.

4.6 System Housing

System housing provides the largest opportunity to use local materials and thus stimulate employment and preserve traditional skills in the rural areas. There are a minimal number of requirements for an LED system housing, like being water resistant and possessing mechanical strength, since the system is not delicate like other lighting systems. This gives the designer great latitude as to the materials and techniques that she can use to develop an attractive and robust housing.

Clay, bamboo, wood, metal, plastics, glass — the choice is seemingly endless. Every man-made object makes a statement about the designer's culture, worldview and ethos and this opportunity must be made utmost use of, as long as the basic usability criteria outlined before are paid due respect.

4.7 Printed Circuit Boards and Thermal Management

The whole electronic system is housed on the PCB, and the type of technology used varies as the sophistication of the system changes. For low power systems, through-hole PCB are sufficient and are also the cheapest alternative. Most high power LEDs are designed to be surface mounted, and therefore, Surface Mount Technology (SMT) PCBs are used. Both technologies are mature and easily available even to the hobbyist. Through hole PCBs tend to use larger components and results in bigger form factor of the system. SMT boards can easily cut the form factor of an equivalent circuit by half. The cost of the board is directly proportional to the area, but other considerations like ease of handling and mechanical strength should be taken into consideration while designing the PCB.

4.7.1 Thermal Management

Thermal management of LED systems is critical in the mid and high power range. Most LEDs are rated to work upto 120°C, but the cooler the working temperature of the LED, the longer the lifetime of the LED and lesser the possibility of the solder joints failing.

There are two approaches to managing heat on the LED — Metal Core PCB (MCPCB) and Thermal Via based heat management.

MCPCB

Metal Core PCB technology is essentially designing a circuit on top of a piece of metal, normally aluminium. This is a very expensive technology, since it is not very widespread. Normally, one buys LEDs which are already mounted on a MCPCB and use it in their design. However, this puts limitations on the designer, since certain parts of the system are out of his control. However, for prototyping, premounted MCPCBs are the best option.

Thermal Vias

LEDs which are entering the market now are making it possible to mount power LEDs on standard PCBs. Thermal management using thermal vias and by adding copper areas onto the board are well known to power system designers. Recent research by Philips[Philips] has showed that it is possible to get a thermal resistance using standard PCB technology which is as good or better than that achieved using MCPCBs. This is more suitable for mass production but involves a quite involved design process which includes thermal simulation the careful placement of vias around the LED which carry the heat away from it. Also, the copper area required for optimal heat management needs to be calculated.

This type of design is therefore non-trivial and should only be attempted if pre-mounted LEDs are unavailable for prototyping or the design aims to go into production.

They say that time changes things, but you actually have to change them yourself.

Andy Warhol

5 Conclusions

Change is inevitable; given that different people often have conflicting needs, change in any direction always makes a certain set of people feel shortchanged and proponents of a certain change cannot really know the full effects of their actions. This obvious fact must not discourage us from atleast *trying* to understand the ramifications of our actions. All endeavours of mankind, from the sciences to art to religion provide us with clues as to how all of us are interlinked. Therefore, the onus is on us to learn from everyone — only then can we be truly citizens of the world.

The scientific method has proven to be an excellent tool to reductively understand things and gain unprecendented knowledge about the world we live in. But the burden of behaving responsibly and with compassion and understanding towards other living beings ultimately lies within each one of us. Science can only provide us with facts; learning the Truth is synonymous with living the Truth. One hopes this report acts as a resource of facts, all collected while looking at the same problem from a variety of viewpoints — engineering, developmental studies, psychology, economics — which have helped the author develop a new respect as to how many things we have to take for granted if we are to function effectively in our day to day lives.

Again, learning the facts is welcome, but even more welcome is taking action knowing what we know. The missing 'something' that facts cannot encompass comes to us only when we create, interact, reflect and recreate. Working with lighting systems has lead the author to meet many people, understand their viewpoints, needs, desires and hopes and has lead to a learning which transcends the facts that this report carries. It has been said that *"Education is reflection in the process of relating"*. In this context, working on this project has been a truly educational experience.

It is also hoped that this report contributes constructively not only to the LED lighting and development communities but also highlights the importance of knowing more than one subject well, however unrelated they may seem at first glance. The various foci that this project has should give an idea of how difficult it is to get things right in any endeavour, and the importance of making explicit what are normally intuitive decisions. Due to the large scope that this study had, many topics may have been treated lightly (like switching regulators) and many others completely ignored (like community building, product initiation and marketing). Therefore, this report acts more as a pointer to important directions in this area rather than a one-stop shop for everything.

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