Sustainability and New Opportunities in Electronic Engineering Research

[#]David V. Thiel [1]

[1] Centre for Wireless Monitoring and Applications, Griffith University
N44 Nathan, Qld 4111 Australia, d.thiel@griffith.edu.au

1. Introduction

The main focus of engineering and engineers around the world is to improve the human condition. The same is true in engineering research. While scientists may undertake research in the pursuit of knowledge and understanding, engineers have an obligation to undertake research that might yield positive outcomes for humanity – for example, in areas such as communications, transportation, medicine, sensing and control, security and of course, entertainment. Despite the economic downturn, the market for consumer electronics has not diminished significantly. Next generation mobile telephones, high-definition digital television, digital radio and the latest computer systems result in the rapid turnover of devices and significant volumes of electronic waste (e-waste). While research engineers have a major role to play in the development of these new products which offer improved functionality and longer battery life, it is important to consider new innovations, preferably in the light of recycling ("cradle to cradle") or alternatively in the safe disposal of such devices at their end of life ("cradle to grave"). These concepts require the developers of new technology to consider the energy requirements of manufacture, the energy requirements during use, and the energy requirements in recycling, reuse and disposal [1]. This is commonly known as Design for the Environment (DfE) [1].

A number of countries have introduced legislation which addresses these issues. For example in the European Union, the Waste from Electrical and Electronic Equipment (WEEE) directive requires manufacturers to recycle up to 80% of the contents of the products sold [2]. The Reduction of Hazardous Substances (RoHS) directive [3] prohibits the use of toxic materials such as lead, and carcinogenic flame retardants (PCBs) in electronic circuits. In addition the Basel Convention [4] prohibits the exportation of toxic waste to other countries. This means that the e-waste must be dealt with locally. One unintended consequence of this convention is that the efficient disposal of e-waste in one country is not available to other countries [4].

The energy requirements for manufacturing and recycling/disposal are important, as industries attempt to significantly reduce their carbon emissions [1]. Other resource requirements for manufacture and recycling/disposal include the availability of the raw materials (either from mining operations or recycling operations) and energy requirements for extraction, refining and the disposal of waste streams associated with the manufacture and preparation of these raw materials. All of these issues impact on the energy requirements of electronic circuit and system production. For this reason, researchers seeking to improve the quality of the human condition worldwide must not ignore these additional manufacturing requirements. This paper explores these factors and their incorporation into a total cost function which might be used in circuit and system optimisation.

2. Optimisation Techniques

Mathematical optimisation techniques are commonly used to improve circuit and system design. For example, when designing antennas, the goal might be to maximize the antenna gain G_a and efficiency η and minimize the return loss S_{11} from the RF source. The technique requires a forward modelling program which can take a physical layout and convert it to these electromagnetic parameters. The parameters of interest are combined to form a single number - the cost function *C*. For example, a simple weighted cost function is:

$$C = w_1 G_a + w_2 \eta + w_3 S_{11} \quad (1)$$

The object is to minimize *C* which implies that the weighting factors w_1 and w_2 must be negative and w_3 must be positive for the best antenna performance.

On this basis, the quality of the design is assessed and can be compared with other designs. In a guided optimization routine, the physical layout is modified strategically, and the new design is subjected to the same assessment using the cost function. A generic optimization scheme is outlined in figure 1. The program is terminated when there is no significant improvement in design as defined by the smallest possible value of *C*.

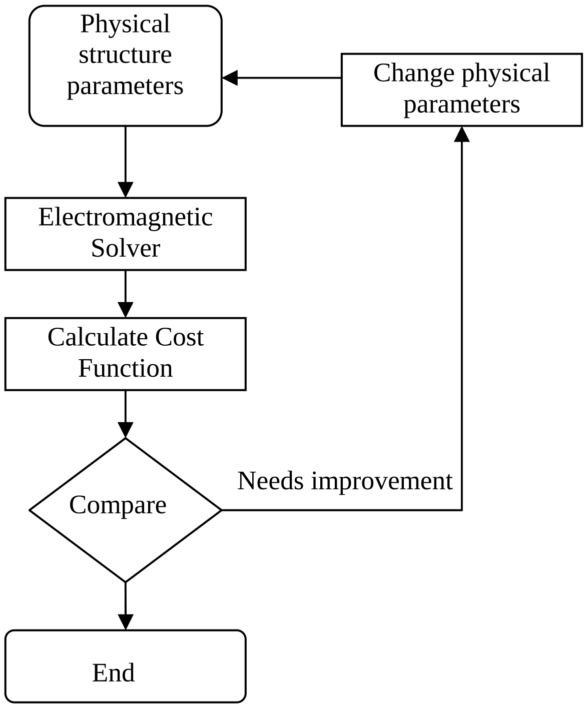

Figure 1: The major steps in an antenna optimisation routine.

Various optimisation algorithms use different techniques to modify the physical layout of the design. For example, some common optimisation routines are [5], [6]:

- The Genetic Algorithm
- The Monte Carlo Method
- Simulated Annealing
- The Simplex Method
- The Method of Steepest Descent (the Gradient Method)
- The Ant Colony Algorithm

3. Sustainability Cost Functions

A simple method of reducing the cost (both monetary and environmental) is to reduce the volume of the conductor. Galehdar and Thiel applied this technique to meander line antennas for application in radio frequency identification (RFID) systems [7]. Wider tracks were used at high current parts of the antenna and narrow tracks at low current areas. They showed that the volume of conductor required can be reduced by 50% with very little loss in antenna efficiency.

In addressing the issues of sustainability outlined in Section 1, the environmental impact of the technology used to fabricate the antenna can be included in the cost function. In particular, the conducting and dielectric materials might be selected by factoring in material properties, the energy requirements for fabrication and recycling/disposal and their toxicity in disposal [8]. For example, it may be preferable from an environmental point of view to choose a conductive material with a lower conductivity, requires less energy to acquire and process, and still allows the antenna to function effectively.

This consideration leads directly to a discussion of different conductive materials, their method of processing (including forming the antenna shape) and their conductivity. There is now a strong move away from etched copper circuit boards towards conductors that can be screen printed or ink-jet printed onto plastic or paper substrates. A major difficulty with these printed materials is that their conduction is relatively low unless a thermal or chemical annealing processing step is used to improve conduction between the discrete more-conductive colloidal particles.

Additional attributes of these alternative conducting materials are listed in Table 1. This list of attributes can be added to the cost function in an optimisation routine to ensure DfE.

Table 1: Important attributes of alternative conductors

Attributes	Properties
Effectiveness	Conductivity Oxidation/Corrosion Mechanical properties Patterning techniques Connections (solder/glue) Adhesion to substrate Thermal conductivity
Availability	Earth abundance Refining costs Recycling costs
Toxicity	Solubility Carcinogenicity
Energy Costs	Extraction Mining/recycling Beneficiation/purification End-of-life recycling

4. Conducting Materials

RFID antenna technology requires a very low cost process (less than $0.20USD per unit). Commonly these antennas are fabricated on thin flexible plastic sheeting using silver, carbon or aluminium. More commonly ink jet printing has been suggested for both carbon and silver. These technologies present a much lower cost alternative in terms of energy costs and the volume of conductive material required. However, the conductivity of carbon and silver deposited as a thin film from a colloidal solution is much lower than solid metal sheeting. This problem of reduced conductivity can be solved through over-printing to increase the thickness, using wider conductive tracks, and using a curing process (heat, chemical, UV annealing of the material after deposition). Silver, aluminium and carbon on plastic sheeting are much lower pollutants compared to copper and lead used on traditional printed circuit boards. Table 2 gives a brief summary of some commercially available inks together with the quoted DC resistivity. The resistivity may be significantly different at UHF.

Table2: Commercially available conductive inks for screen printing

Manufacturer	Conductive material	Code Number	Resistivity (μΩcm)
Paralec	Silver	Parmod VLT	9
Dow Corning	Silver	Thermoset #1	31
DuPont	Silver	5028	17-8 – 30.5
Acheson	Silver	Electrodag PF-046	25
Creative Materials	Silver	110-03	50
Creative Materials	Carbon	121-35	50,000
Creative Materials	Carbon/Silver	121-30	400

There has been recent research into the use of carbon nanotubes as potential conductors in printed electronics. This work has indicated that this material requires significant post-processing to achieve conductivity values as high as silver and carbon. In addition the bending, strain and temperature all affect the conductivity significantly. There have also been suggestions of detrimental health effects from this material.

5. Construction Methods

In RFID, un-encapsulated silicon dies are glued to the antennas using conductive epoxy. For more complex electronic circuits, the integration of electronic devices and circuit elements into plastic with the antenna was investigated [8]. The technology employed bare die and standard (i.e. encapsulated) components. This allowed the design and construction of circuits using existing PCB software with the currently available range of components, but with the additional possibility of using printed components such as resistors, capacitors, display technologies, batteries and transistors. With this technology, a rigid plastic circuit board containing components with screen printed tracks was fabricated using a hot embossing process. The electronic systems (including the antenna) formed in this way, was sealed from the environment to prevent environmental degradation from oxidation, dust and corrosion. The sealing step removed the need for an additional enclosure.

The RF characteristics of printed antennas on very thin, flexible substrates introduced an additional problem for antenna designers. That is, the antenna is likely to be bent during normal operations. Bending an antenna can shift the resonant frequency both up and down [9]. In addition, when the antenna is attached to an object, the dielectric and conductive properties of the object can change the efficiency and centre frequency of the antenna. For this reason, three dimensional meander line antennas was investigated to reduce this effect [10].

6. Conclusions

There are new important research and development problems for electrical engineers to address. These problems have arisen from the need to design for the environment (DfE). Global warming, green-house gas reduction targets and new legislation relating to recycling, toxic waste and lower cost production techniques need urgent attention, but the electronic devices must still function efficiently.

Acknowledgments

The author wishes to acknowledge the assistance of all members of the Centre for Wireless Monitoring for their enthusiastic support and interest in this work. Interactions with Peter Healy, Sunil Heart and Cheryl Desha from Griffith University were very informative and greatly appreciated.

References

[1] P. Stasinopoulos, M. H. Smith, K. C. Hargroves, C. Desha, *Whole system design: An integrated approach to sustainable engineering*, Earthscan, London, UK, 2009.

[2] A. Gottberg, J. Morris, S. Pollard, C. Mark-Herbert and M. Cook, "Producer responsibility, waste minimisation and the WEEE directive: Case studies in eco-design from the European lighting sector," *Science and the Total Environment*, vol. 359, (1-3), pp 38-56, April 2006.

[3] M. Goosey, "End-of-life electronics legislation – an industry perspective," *Circuit World*, vol. 30 (2), pp. 41-45, 2004.

[4] J. Kruger, "What's to become of trade in hazardous wastes? The Basel Convention one decade later," *Environment*, Vol. 41, no. 9, pp. 11-21. Nov 1999.

[5] D.V. Thiel, S. Smith, *Switched parasitic antennas for cellular communications*, Artech House, Boston, USA, 2001.

[6] A. Galehdar, D.V. Thiel, A. Lewis, M. Randall, "Multi-objective optimization for small meander wire dipole antennas in a fixed area using ant colony system", *Int. J. RF and Microwave CAE*, (in press), 2009.

[7] A. Galehdar, D.V. Thiel, "Tapered meander line antenna for maximum efficiency and minimal environmental impact," *IEEE Antennas and Wireless Propagation Letts*., vol 8 pp. 244-247, 2009.

[8] D.V. Thiel, "Sustainable electronics: wireless systems with minimal environmental impact," *Proc. ISAPE*, Kunming, China, pp 1298-1301, Nov. 2008.

[9] A. Galehdar, D.V. Thiel, "Flexible lightweight antenna at 2.4 GHz for athlete clothing," *IEEE APS Symposium*, Honolulu, USA, pp. 4160-4163, June 2007.

[10] A. Galehdar, D.V. Thiel, S.G. O'Keefe, "Design methods for 3D RFID antennas located on a conducting ground plane," *IEEE Trans. Antennas and Prop.* vol 57 (2), pp. 339-346, 2009.