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"MAN'S ORBIT ABOUT THE ELECTRON"

By

SALAWU, R. I.

UNIVERSITY OF LAGOS PRESS - 1998
INAGURAL LECTURE SERIES

"MAN'S ORBIT ABOUT THE ELECTRON"

An Inaugural Lecture delivered at the University of Lagos on Wednesday, 11th February, 1998.

by

SALAWU, R. I.
F.A. Eng., F.N.S.E., FSESN

ISBN-978-017-064-2

University of Lagos Press, 1998.

First Published 1998

By

University of Lagos Press, Unilag, P.O. Box 132,
University of Lagos, Lagos, Nigeria.

ISBN 978 - 017 - 064 - 2

Printed by University of Lagos Press

MAN'S ORBIT AROUND THE ELECTRON

PROLOGUE

Mr. Vice-chancellor Sir, we shall in the next 3600 seconds focus our microscope on man and how he has evolved from his primitive beginnings to what he is today. His ascent has been made possible mostly through the use of the tools he initially acquired and later developed to explore his environment.

His exploration of nature led him to the discovery of the atom and with it the electron and a few other particles and a host of sub particles. The electron he was to find out plays a major role as to the physical and chemical properties and characteristics associated with a substance and its behaviour under prescribed environment. The primary role of the electron is the manifestation of electricity. This property has been exploited over the last 50 years to create new materials that have made the information age a saga of wonders!

In the course of this lecture we shall trace the story of the semi-conductor and how it has influenced our work in the areas of filters, energy conversion and generation. The enthusiasm generated in the laboratory has sustained us in the classroom and propelled us out into the professional field. Our experience in these two allied areas of engineering education and professional practice will also be reviewed.

Finally, these forages are integrated into a recipe for national development and actualisation in engineering and technology.

1. INTRODUCTION.

1.1 Man's Evolution

Over the last two million years, man evolved from the little dark creature with the stone in his hand, Australopithecus, in central Africa, to what he is today; but out of this period it was his transition within the last twenty thousand years that made him the creature that you and I aspire to be: artist and scientist, engineer; analyst of history and planner of the future; reader of exploits and an eager explorer of human emotions; immensely richer in experience and arrogantly bolder in imagination than any of our ancestors.

Van Loon, in his book "The Story of Mankind' remarks that a hairy creature with a low brow and sunken eyes, a heavy jaw and a strong tiger-like teeth would hardly look attractive in a gathering of modern scientists, but would nonetheless command their respect and admiration as the father of technology; for it was he who used the stone to crack a nut and a stick to pry the boulders. He was the inventor of the hammer and the lever, our first tools, and thereby did more than any human being to give man his enormous advantage over the other creatures with whom he shares this planet.

Since then man has not looked back. He has continued to improve on the tools with which he has continuously improved his lot.

In this journey, the largest single step taken in the ascent of man is the change from nomadic life to village agriculture; and the most powerful inventions in all agriculture is the plough. The plough is a wedge that divides the soil; but it is also a lever which

lifts the soil and it is among the first applications of the principles of the lever. The step beyond simple agriculture was the domestication of draught animals. The lever initiated the principle of systematically integrating the scientific law in the design of artifacts for man's use in his daily pursuits. That tradition was to give birth to the field of engineering a few thousand years down the line.

2. ENGINEERING

In relatively recent times "Engineering" has been defined by Robert E. Doherty as the art based primarily upon training in mathematics and the physical sciences, of utilizing economically, the forces of nature for the benefit of man. However this has not always been the case but rather metamorphised over time.

To be sure, Engineering has been practised, though rudimentary, since prehistoric times. Evidence of this are the remains of early works in Mesopotamia, the pyramids and other monumental buildings in Egypt etc. The development showed skill of very high order of execution. The romans constructed roads, and highways such as the famous appian ways, aqueducts, tunnels, municipal buildings etc. These constructions showed very high standard of development. Though the works that survived give evidence of the high state of development at their time, lack of rational methods of design and absence of iron and steel as basic construction materials seriously limited their structures in comparison with those of today.

In the middle ages, engineering construction virtually ceased except for the construction of Gothic Cathedrals in Western

Europe and England. These structures though built with empirical methods, involved many difficult problems of design and construction and are to a great extent monuments to their constructors. The Renaissance on the other hand signalled the revival of construction of public works, roads, canals, bridges harbour works and quays. These were done under the forerunners of the profession such as James Brindley (1716 - 1772), John Smeaton (1724 - 1792) and James Telford (1757 - 1834), the first president of the British Institution of Civil Engineers.

2.1 Divisions In Engineering.

In the early days, there was only military engineering. John Smeaton was the first person to use the term civil engineering to differentiate the civilian engineer from the military engineer. Thus there became two disciplines of engineering - military and civil which included mining engineering. But gradually over time and as the steam engine replaced muscular power as the chief means of production, mechanical engineering emerged. Mechanical engineering was later split into Mechanical and Electrical which was itself later broken into heavy current and light current Electrical Engineering. As illustrated in Figure 1, light current is electronics which can be regarded as the workhorse of the various offshoots.

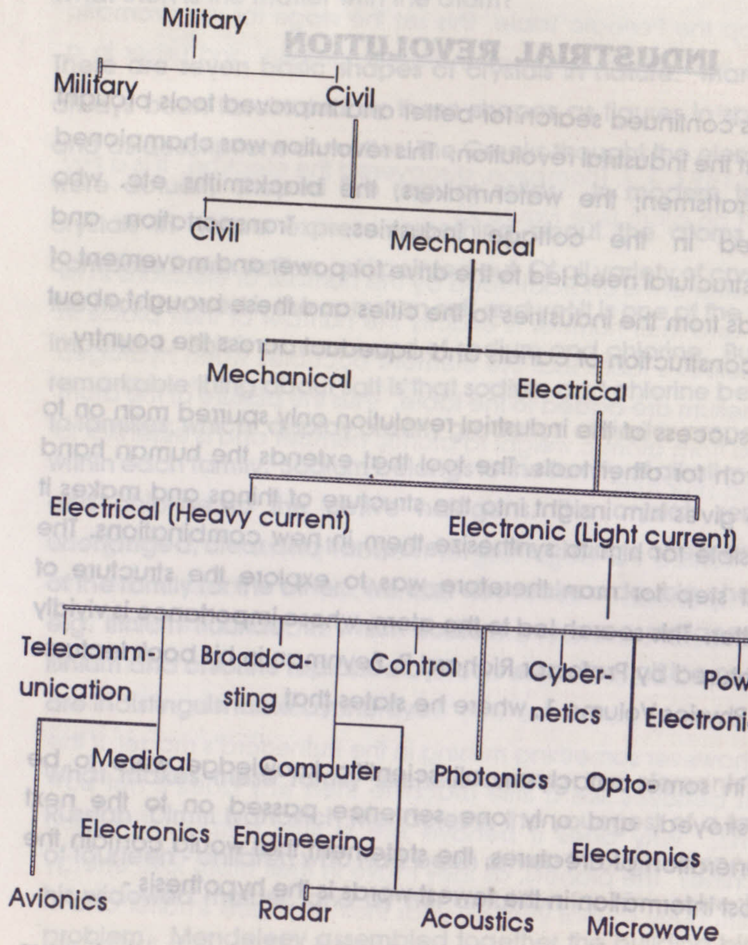

Figure 1. Evolution of Electrical/Electronic Engineering

3 INDUSTRIAL REVOLUTION

Man's continued search for better and improved tools brought about the industrial revolution. This revolution was championed by craftsmen; the watchmakers, the blacksmiths etc. who worked in the cottage industries. Transportation and infrastructural need led to the drive for power and movement of goods from the industries to the cities and these brought about the construction of canals and aqueduct across the country.

The success of the industrial revolution only spurred man on to search for other tools. The tool that extends the human hand also gives him insight into the structure of things and makes it possible for him to synthesize them in new combinations. The next step for man therefore was to explore the structure of matter. This search led to the atom, whose importance is vividly captured by Professor Richard P. Feynman in his book lectures on Physics Volume 1, where he states that

"If in some cataclysm, all scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, the statement that would contain the most information in the fewest words is the hypothesis -

"that all things are made of atoms - little particles that move around in perpetual motion attracting each other when they are a little distance apart, but repelling each other upon being squeezed into one another" ".

4 THE ATOM

What then is the matter with the atom?

What then is the matter with the atom?

There are seven basic shapes of crystals in nature. Man has always been fascinated by these shapes as figures in space, and as descriptions of matter. The Greeks thought the elements were actually shaped like regular solids. In modern terms, crystals in nature express something about the atoms that compose them. As Bronoski pointed out Of all variety of crystals, the most modest is the common salt and yet it is one of the most important. Salt is a compound of sodium and chlorine. But the remarkable thing about salt is that sodium and chlorine belong to families, which display orderly gradation of similar properties within each family. Sodium belongs to the family of alkali metals and chlorine to the active halogens. The crystals remain unchanged; clear and transparent, as we change one member of the family for the other. We can also make a double change e.g. lithium fluoride; in which sodium has been replaced by lithium and chlorine replaced by fluorine and yet all the crystals are indistinguishable by the eye.

What makes these family likeness among the elements? A Russian, Dimtri Ivanovich Mendeleev, the youngest of a family of fourteen - children who had been driven through science by his widowed mother, and by her ambition for him, solved the problem. Mendeleev assembled together the building blocks of what was to be later known as the Periodic Table.

As early as 1805, Dalton had proposed that each element has a characteristic atomic weight. By writing the elements out on cards and shuffling them Mendeleev found evidence for a mathematical key among the elements, by assigning numbers to them and unravelling the underlying patterns he was able to

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Thus in 1897, J. J. Thompson, discovered the electron. It is a tiny part of an atom.(see Figure 2)

Each element is characterised by the number of electrons in its atom and their number is exactly the number of their place in Mendeleev's table that the element occupies when hydrogen and helium are added to the table. Thus the picture of the atom shifted from atomic weight to atomic number and is essential to atomic structure.

That marked the beginning of modern physics and the great age opened!. In 1911, Rutherford, a Professor at the Manchester University, proposed that the bulk of the atom is in a heavy nucleus or core at the centre and the electrons circle it on orbiting paths, the way the planets circle the sun. There was however something missing in the Rutherford's model. If the atom behaves like a little machine then why does it not slow down?. Why does it behave like a little perpetual motion machine? The planets, as they move in their orbits lose energy continuously so that year by year their orbit gets smaller and in time they will fall into the sun. But that is not so with the atom. It took Niels Bohr in 1913, to use the work which Max Planck had published in 1900 in Germany together with Rutherford's model, to propose the modern structure of the atom.

4.1 Neils Bohr's idea on the mechanics of the electron

The inside of the atom is invisible, but there is a window in it - the spectrum of the atom. Each element has its own spectrum, which is not continuous like that which Newton got from white light, but has a number of bright lines which characterise that element. For example hydrogen has three rather vivid lines in its visible spectrum:- a red line, a blue-green line, and a blue line. Bohr explained them each as a release of energy when the single electron in the hydrogen atom jumps from one of the outer orbits to one of the inner orbits. In 1924, Erwin Schrodinger used wave mechanics to set up the basic wave equations; Later Heisenberg (1926) Pauline (1927) and Dirac (1926) perfected this quantum mechanical tool for describing phenomena in atoms, molecules and solids.

Quantum mechanics can be used to explain practically all observations satisfactorily. This has made it possible not only to determine the structure of the atom, but also to determine the distinguishing characteristics of the atom of the various elements, and thereby construct the periodic table of elements. It has also been used to explain the cluster of atoms that form a solid and particularly, the electronic structure that governs all the observable physical properties of the solid. *The most important point to be made here is that all physical and chemical properties of materials depend on the behaviour of electrons.* Thus electrons are in addition to being responsible for such properties as the colour, electrical and magnetic behaviour of materials, and, by being involved in the interatomic/intermolecular bonding, also responsible for both thermal and mechanical properties as well. For example all materials that are good conductors of electricity are also good conductors of heat.

4.2 The Electron

The electron exists naturally in bound states. They are contained in "atomic shells" or enclosed in "energy walls" in solids as an electron gas. When in bound states they possess only potential energy but when in free state they also have kinetic energy with which they have been freed, in addition to energy gained as a result of the acceleration process. The electron is regarded as a fundamental particle and bears the smallest known unit of electric charge: 1.69×10^{-19} coulomb. For this purpose a coulomb is defined as the amount of charge transferred by a current of 1 Ampere flowing through a point in one second. That is, one Ampere represents 6×10^{18} electrons passing a given point every second. The transfer of charge involves energy and the fundamental measure of the energy is obtained from the potential energy converted to kinetic energy, through whatever medium that is used to effect the transfer. Thus when an electron has fallen through a potential difference of one volt, it has gained a kinetic energy of one 'electron-volt'. Thus 6×10^{18} electron-volts represent movement of one Ampere through one volt which gives one watt-sec; that is one joule of energy.

Since the electron is a fundamental (that is indivisible) particle, its charge and mass are fundamental physical constants. The rest mass is always constant but changes with velocity of the electron in accordance with Einstein's laws of relativity

$$E_o = m_o c^2$$

Where c is the velocity of light

However under ordinary circumstances in electronics, electrons never get to speeds that significantly change their masses.

In whatever position an electron is, whether in the electron gas or in the shell of an atom, it always spins on its internal axis, thus making it a small magnet that possesses a magnetic moment. The spin is directional, that is, it could be either positively or negatively oriented with respect to a particular sense. This has effect on the total rearrangement of the electrons when agglomerated in a solid.

4.2.1 The Electron and Electrical Engineering Materials

As stated earlier, the electron determines the various properties of materials. In this section we shall discuss its effect on the properties of electrical engineering materials. (Figure 3 shows : The Energy bands and their occupation in different materials.)

4.2.2 Electrical Conductivity

In a metallic conductor, the top occupied band (conduction band) is partially filled as shown in Fig. 3(a). Electrons can increase their energy continuously even at low temperatures and this results in very high conductivity. Another possible conduction mechanism where the two band gaps overlap to some extent, results in somewhat different conduction properties. Band overlap occurs in divalent metals, transition metals and semi-metals?.

In an insulating material, such as diamond or silicon dioxide, the band gap is several times wider, and even near melting temperatures, the thermal energy is not sufficient to transfer an appreciable number of electrons to the conduction band. Its resistivity is therefore extremely high. The energy bands in an insulator are shown in Fig.3(b).

An intrinsic semiconductor crystal i.e. a crystal containing no impurities has the very special property that the upper occupied band, called the valence band, is completely full. Above this band is a relatively narrow (about 1eV) forbidden energy band called the band gap, and above this is another allowed but normally empty band called the conduction band. This band picture is shown in Fig 3(c). The band-gap width is normally denoted by E_g. Applying an electric field to such a material, when it is held at low temperature, does not result in any current, since the field must accelerate the electrons that is, increase their kinetic energy, which means that they have to transfer to slightly higher, empty energy levels. There are no such levels available. E_g is much too wide a gap for an electron to jump across by virtue of field acceleration. Therefore NO CURRENT FLOWS. If the temperature is raised, a few of the valence electrons (electrons populating the valence band) will gain sufficient thermal energy to overcome E_g and appear in the conduction band. The electron in the conduction band and the hole left in the valence band can also now be accelerated and so carry current. The conductivity, however, is small, and hence the name 'SEMICONDUCTOR'. (may also be called SEMINSULATOR).

5. ELECTRONICS

The invention of the vacuum tube by Lee De Forest in 1907 gave a big boost to electronics. The triode amplifier and stable oscillators of reasonably high power could now be designed .

The work of Marconi and others earlier, had shown that low frequencies were better suited for long range radio communications. The technology of low frequencies was easier and well within the scope of the triode-electron-tube technology.

The vacuum tube therefore became the work horse of electronics until in 1948 and 1949 when Shockley, Bardeen and Brattan discovered the transistor. This discovery made possible by studies on the semiconductor has brought about dramatic changes in the way we live.

The life of the modern man is so dependent on electronics that it is difficult to imagine a world without it. Today, we are almost suffocated by manifestations of electronics: antennas are in the field of view everywhere, television aerials perched on virtually every building, microwave relay stations on hill tops, radar scanners on ships etc. Electronics provide major means of entertainment; radio, television broadcasting, audio systems, the telephone, the computer, camera, sound and motion pictures etc. Without electronics, modern air transportation will be impossible and sea travels will become hazardous. Industrial activities have all been taken over by electronics; perhaps a good testimony to this is the merging of the institution of production engineers with the Institution of Electrical Engineers in Britain and elsewhere. In fact the influence of the electron is so pervasive that today it has both a hand and a leg in every human activity.

5.1 Metal Oxide Semiconductor (MOS) technology

MOS technology presently dominate the Very Large Scale Integration (VLSI) and will continue to do so in the near future.

For that reason we shall briefly discuss it. It is the technology used for the devices which shall be discussed presently.

The integrated circuit processing is based on photolithography. The starting material is a highly polished silicon wafer of 75-100mm in diameter. The wafer is oxidised in a furnace through which pure oxygen is passed at about 1000°C for about one hour. The process grows a layer of silicon oxide of about 0.1- 1 μm thick on the wafer. On top of the oxide is then applied a layer of a photo sensitive polymer called resist. The resist is then exposed to ultra-violet (UV) light through a photographic plate, containing the pattern that is desired. The exposed parts dissolve (for 'negative' resist). Through the holes in the resist we can then etch holes in the oxide layer, thus forming a 'mask' in the silicon oxide. Finally the wafer is processed, for example doped as in Fig. 4 during which operation, the oxide mask directs the process to certain areas only. The geometry of the process can be very well controlled. (In the surface directions the geometry is controlled by the lithography with the accuracy of a light wavelength (about 1 μm) and in the depth direction, the geometry is controlled by the physiochemical processes, for example by atom diffusion rate.

Table 1. Circuit Densities on Chips

Device Scale	Abbreviation	Number of Circuits Per Chip	Smallest Feature Size (Micrometers)	When Developed
Small Scale Integration	SSI	1 - 100	10	1960's
Medium-Scale Integration	MSI	100 - 1000	5	1970's
Large-Scale Integration	LSI	1000 - 10,000	3 - 1	1980's
Very Large Scale Integration	VLSI	>10,000	1<	1980's
Ultra Large Scale Integration	ULSI	10^{12}	0.1-0.001	2000
Molecular Integration	-	?	0.001<	2010

5.2 MINIATURIZATION of Electronic Devices

How far can circuit integration go? A rough estimate can be obtained by dividing the largest practical chip size by the smallest practical transistor size. The limit on a transistor is a physical one. The transistor consists of three adjacent regions on the chip; the source, the gate and the drain. The three regions are given the desired electrical properties by doping them with impurities.

Based on the number of impurity atoms required, there is a theoretical limit to how small a transistor can be; no less than approximately 400 lattice constants on a side. The lattice constant measures the size of a unit cell in a crystal. In practice the space occupied by a transistor on a chip must be about three times that long. The lattice constant for Silicon is 5.4×10^{-8} centimetre, and so the smallest practical transistor would be $1200 \times 5.4 \times 10^{-8}$ or roughly 10^{-4} centimetre or $100\mu m$ on a side. Such a transistor would take an area of 10^{-8} square centimetre on the surface of a chip. Presently chips of diametres ranging from 75 to 100mm are available. And for a 100mm chip, if only 10% of the area is used for devices and the rest of the surface area used for interconnections, then we are talking of a density of about 1 billion transistors. (This is shown in Table 1 and Figure 5)

5.3 Current Considerations- How light is light current? [Is the term a misnomer?]

Another problem that can develop when a large number of circuit elements are packed on a single chip is electromigration the unwanted movement of material through interconnection lines i.e. the "wires" that join the elements to one another. Although, the amount of current that flows through an integrated circuit is small compared with the amount that flows through a household appliance, the current density per unit cross-sectional area is very much higher; in some cases the current density increases by the square of the factor of miniaturisation.

Table 2. Comparison of Current Densities

Item	Integrated Circuit	Household Connection
Current (A)	10^{-2}	1
Cross-section area of interconnection of (Cm^2)	10^{-8}	10^{-4}
Current Density Amp/cm^2	10^6	10^4

For example a typical integrated circuit electronic line having a cross-sectional area of 10^{-8} square centimetre might carry a current of about 10 milliamperes(one hundredth of an ampere). This gives a current density of a million Ampere per Square centimetre. A wire going from an electrical outlet to a household appliance, in contrast, might have a cross-sectional area of 10^{-4} square centimetre and carry a current of one ampere: a current density of just 10,000 ampere per square centimetre. Thus the current density on a chip is 100 times higher. Electromigration in such cases can result in catastrophic failure of the metal line. To prevent such failure, metal lines are now made of alloys of copper-and aluminium.

Thus the current density on a chip is of the order of 100 times larger than that of the household current, hence the term light current for today's electronics may be a MISNOMER.

6. PHOTONIC MATERIALS and PHOTONICS.

In 1960, an operating laser was practically demonstrated. This suggested to many people that light might replace electrical signal as the common carrier for information in the near future. The coherent monochromatic light emitted by the laser eliminated a major obstacle to light-wave communication.

The enormous information capacity of a coherent source of light made it possible for the first time to give serious thought to the need of a new technology, analogous to electronics, for the generation, transmission, reception and procession of signals made up of photons instead of electrons. The technology is now called PHOTONICS. Glass is the most familiar photonic material. A photonic transmission system, in addition to guiding a light signal over long distances, must also convert electrical signals into light at the transmitting end and change the light back into electrical signals at the receiving end. For these functions entirely new semiconductor alloys, whose properties are quite different from those of silicon have been developed. These alloys are called III-V semiconductors after the columns of the periodic table to which their elemental components belong (GaAs). They are made into a wide variety of solid-state lasers and light-emitting diodes that generate a light signal, electro-optical repeaters that amplify the signal as it travels along the optical fiber and detectors that convert into an electronic pulse. The evolution of photonic technology has thus led to an intricately symbiotic relation between photonics and electronics: information transmitted purely by photons is generated, processed and stored by devices in which both photons and electrons play essential roles.

Purely photonic devices that might be capable of assuming electronic functions other than information transmission has not yet proved to be economically viable. This does not necessarily mean that emphasis on communications has limited the general development of photonic materials. Their development, perfection, complexity and the elegant new methods that were employed to fabricate them represent fundamental advances in material science that can readily be extended to other applications.

In the laboratory a non-linear optical response has been exploited to create a photonic analogue of a transistor, a purely photonic device that amplifies an incoming signal. By suitably arranging the light incident on a non-linear material, it is possible to build logic gates which optically model the properties of the logical connectives AND, OR and NOT. Photonic transistors and logic gates would be the basic components of a super computer based entirely on photonic technology, which some people believe will one day replace the electronic machine.

6.1 Information

For communication purposes, compound semiconductor (III - V compounds) and ultra pure glass are to photonics what iron and copper were to electrical transmission systems of a century ago. (see Figure 6 where Glass replaces Copper as an interconnector)

The bulk of the materials and that of the costs in a modern information or communication system today are accounted for by the simple task of moving electrons and photons from one point to the other. In other words the expense lies not in the components of the system but in the interconnections among them. This is true at every stage from the individual silicon chip to the transcontinental telephone network.

Table 3 : Cost of Integrated Circuit Connections

Connection	Location	Cost Dollar (U.S)	Naira
Among Circuit elements	On chip	10×10^{-6}	8×10^{-4}
Metal leads (from chip to external wiring)	Chip carrier (plastic or ceramic)	0.01 (1 cent)	0.8 (80 kobo)
Inter connection between Chip carries through copper wiring patterns	Printed wiring bound	0.1 (10 cents)	8 (800 kobo)
Inter connection between pack (al)	Back plane	1	80
Connection between frames (optical fibres)	Coast to coast or transcontinental	millions of dollar	billions of naira

Since all elements are fabricated together, the cost of each element is negligibly small! less than a cent. (80 kobo)

It is therefore appropriate to make a simple analysis of the cost of a typical system in terms of the cost per interconnection at each scale. The cost of the chip or the network divided by the number of interconnections it provides. As expected, the longer

the interconnection is, the more the material needed to make it and the higher the costs.

The aluminum conductors that link circuit elements on a silicon chip are usually only a few micrometers long. They may be deposited by the millions in a single exposure through a photomask that defines the metallisation (wiring) patterns. Despite the fact that the wiring may be very complex, each interconnection costs only about 10 millionth of a dollar (over 8 hundredth of a kobo). On the other hand, connecting the chip to external wiring is significantly more expensive. The chip is first mounted on a plastic or ceramic carrier that measures a couple of centimeters across and is fitted with a dozen or more metal leads (Figure). The cost per lead of the cheapest plastic chip carrier is about 1 cent, (about 80 kobo) or a 1000 times the cost per interconnection on a chip.

Chip carriers are mounted on a printed wiring board, either directly, or by first affixing them to a ceramic device called a hybrid integrated circuit. The cost of a printed wiring board depends on how many layers of wiring it incorporates. In complex systems, a wiring board usually consists of about eight sheets of epoxy-coated fibre-glass, each with a copper wiring pattern etched on to it. The sheets are bonded together and connected electrically by copper-plated holes (Figure) in the epoxy. Such a multi layer board may provide a large number of interconnecting-paths but is also physically large, and so it requires a lot of materials. Furthermore it is hard to assemble and to test; from chip carriers to printed wiring board, the cost per interconnection rises by another factor of 10, to about 10 cents (8 naira). A wiring board that has been filled with chip carriers (as well as with discrete circuit elements such as resistors and capacitors) is called a circuit pack. A personal computer may contain the equivalent of a single circuit pack, but a more complex system may contain a number of interconnected circuit packs. The interconnections are often printed on a large multi layer wiring board called a back plane, and the circuit packs are mounted upright in a metal frame and linked to the back plane either electrically or optically. The cost per interconnection at the frame level is about (=N= 80.00).

Connections between frames are increasingly being made with optical fibres. This is particularly true when the frames are miles apart in different machines. The cost of such interconnections is very high and it rises with distance. The cost of interconnections across the Atlantic for example, using fibre link runs to millions of dollars and trillion times the cost of an interconnection on a chip.

Because costs of interconnections is such a large part of the total cost of a system, hardware designers face two great pressures. The first pressure is to push the complexity of silicon chips to its ultimate limit - the point is not to maximise the number of circuit elements as such, instead it is to put as many interconnections as possible on the chip, where they cost least. The second pressure is to push lasers and fibreguides to their ultimate capacity, thus cutting the cost of interconnections that cannot be miniaturised.

7. CONTRIBUTIONS

Mr. Vice-chancellor Sir, in the Electrical Engineering Department of this University, we have over the years made some modest contributions and these will be discussed. Our contributions as

discussed earlier are in areas of materials, Energy and Engineering Education and Training.

The first area to be discussed is in the area of SIGNAL CONDITIONING otherwise known as filters.

7.1 Filters

In general, an electronic signal could occupy wide band of frequencies, extending from direct current zero frequency to infinity as shown in Fig. 7. But usually only a band of frequencies may be of interest. It is therefore necessary to provide a means of selecting the part of the spectrum that is needed. This is achieved by filtering. Depending on which part of the spectrum is required you may have Low pass, High pass, bandstop or bandpass filters by removing the unwanted points as shown.

Traditionally, these were achieved by means of lump passive elements - resistors, capacitors and inductors. Unfortunately at the advent of integrated circuits, it became difficult to realise inductors and more expensive to realise resistors and capacitors as they occupy large areas. Besides, inductors become heavy at low frequencies. Hence the need to find alternative means of realising these circuits.

In our work we have used MOS technology to realise distributed RC networks that are used in various form of filtering. In some cases these have been used together with active elements - Active RC filters, to improve the performance of RC filters whose responses are not as sharp as those of LC networks as shown in Figure 7

7.2 Materials - MOS technology

7.2 Materials - MOS technology

Studies were carried out on the Metal Oxide Semiconductor Technology to design, fabricate and analyse distributed (RC) networks to be used for frequency selection in integrated circuits.

As a result of these studies, along with S. M. Bozic and C. A. Miller, the following contributions were made and published in the journal "*Microelectronics and Reliability*" (UK)

i(a)Lumped Approximation to distributed RC Notch networks for linear Integrated Circuits. (1972).

In this contribution a lumped approximation for the analysis of notch networks was examined. Generalized expressions were derived for the open circuit voltage transfer function valid for n-lumped sections. This resulted in rational polynomial functions instead of the transcendental functions of the exact analysis. The rational polynomial is easier to handle for analytical purposes. The results were applied for cases of n from two to seven sections and results obtained were compared with those of exact analysis. The approximation is applied to various forms of Tapering that can be applied to the device eg. URC, ERC, LRC etc.

i(b)"Integrated MOS Distributed RC Networks for Frequency Selective Networks" (1972).

In this contribution a technique of fabricating distributed RC networks for producing frequency selective circuits in integrated circuit form was proposed. An MOS-capacitor with compatible nichrome thin-film resistor was used. The available range of R_oC_o product of about 1.5×10^6 to 3×10^3 psecs. were shown to allow for notch filters or phase-shift oscillators with centre frequency ranging from about 11KHZ to 0.6GHZ. Responses were given for some devices which were made and the results show that attenuations of over 60dB are attainable at the notch frequencies (see Figure 8)

i(c)Effect of Substrate Resistance on MOS Distributed RC Notch Network (1975).

In this contribution results of further work on MOS distributed structure were reported. The theory was extended by taking into consideration the effect of the substrate resistance and this has been shown to give good agreement with measured results.

i(d)Effect of Pad Capacitance on the Notch Frequency of MOS-RC Notch Network.

ii(a)A Note on the distributed lumped active-all pass Network Configuration (1973)

This contribution examined a distributed lumped active all-pass network proposed by Huelsman and Raghunath using 3 - section lumped RC approximation for the distributed RC structure. A straight forward analysis, in terms of rational polynomials was obtained which gives comparable results to the exact method of the authors referred to above.

ii(b) An Active Distributed RC Bandpass Filter.(see Figure 9)

(a) **Active RC Realization of RL Impedancies (1977 with Ifesie)** *published in IEEE Proceedings USA*

In this contribution an active RC circuit was used to realize an RL Impedance. It realizes both linear and nonlinear RL impedances.

iii(a) **Realization of all-Pass Transfer Function using a second Generation Conveyor;** *(Proceedings of IEEE.)*

7.3 Energy

i(a) **An Electronic Sun Finder and Solar Tracking System (1986) (with Odu[illegible]mi) in** ***Solar and Wind Technology UK.***

The paper discusses an electronic sun finder and solar tracking system. The system consists of two photodiodes separated by an opaque body in an enclosed rectangular structure. Two pairs of solar cells are mounted in quadrature, externally, on opposite sides of the structure. The cells connected to a differential amplifier whose output is used to drive a d.c. motor through a relay. The solar cells activate the relay whenever light of unequal intensity falls on them, and the output of the differential amplifier then drives the motor to align it with the sun. The system was tested and operated satisfactorily. It showed a little time lag between the movement of the sun and the movement of the system. (see Figure 10)

i(b) **Solar Chimney - A cheap Source of Energy for Developing Countries.(see Figure 11)**

7.4 Education and Training

7.4 Education and Training

On Education of course as you know we have been involved with the education and training of a generation of engineers. Mr. Vice-Chancellor sir, nothing has ever given me more joy (apart from my family) than seeing these young men and women at entry grow in the knowledge of electronics and by their final year able to come up with ideas and designs which with the availability of the proper materials at the relatively affordable prices, would compare favourably with their counterparts anywhere in the world. And we say this with all sense of responsibility, having had the opportunity of teaching and examining in several Universities outside this country, on the continent and in Korea and Canada.

As you may be aware, Engineering like law, medicine, accountancy etc. is a profession that cannot be completely mastered in the classroom, it has to be accompanied by exposure to practice. This acceptance has led to the inclusion of a period of attachment in industry in this country. This was championed by our Faculty and was eventually copied by others. The modification increased the period of study to 5 years with a cumulative stay in industry of twelve calendar months during the period of the undergraduate studies.

In addition to this, the newly graduated engineer is expected to serve a period of tutelage for 2 years to satisfy the requirement of COREN for registration. Surely for this to be useful, there must be meaningful engineering activity within the economy. Unfortunately our current situation in the country, whereby engineering practitioners go for long periods without commission, and when they do get commission are not paid as and when due, has tended to negate some of the objectives of the scheme. The reality of our times is that these practitioners due to lack of commission, are not able to absorb these students in their practices. The recent abrogation of the indegenisation decree is bound to make the situation worse as the multinational companies are no longer compelled to accept these young men and women.

7.5 Engineering Institutions

COREN was established by Decree 55 of 1970 and amended by Decree 27 of 1992. In the early years, regulations and bye laws were formulated by the Council. The earlier decree recognised engineers only and did not cater for other members of the engineering family. This omission was to destabilise the profession and set off a fued that raged for over two decades within the rank and file of the engineering family. Normalcy was to return only after the amendment that changed the name COREN to 'Council for the Regulation of Engineering in Nigeria' thus empowering Council to cater for the regulation and control of the engineering profession in its entirety.

7.6 Engineering Assembly

One of the first activities of the new Council after the promulgation of the amendment was to call an engineering assembly which brought all the members of the engineering family together to discuss matters affecting the profession. The focus of the first assembly was on the importance of registration. At the assembly lead papers were presented by invited

professionals from each cadre of the family. At the end of the proceedings there was some sense of belonging and unanimity of purpose among the various cadres.

However, Council did not stop at this, it encouraged the formation of cadre associations within the umbrella of the profession. I had the priviledge of serving in Council at this critical period and wish at this point to gratefully acknowledge the generosity of the University of Lagos for allowing me time off to serve as Registrar of COREN from 1991 to 1997

7.7 Formation of Associations

As regards such above-mentioned associations, the engineering technologists, technicians and craftsmen were each brought together to form associations through which they were to be represented in Council. As stipulated by the Decree, members of each cadre were registered in the appropriate category. The outcome of this move was to fight for the recognition of various cadres by employers and accord them their proper designation and remuneration. To a large extent this helped in removing the acrimony among the members of the family.

7.8 Finances

Another achievement recorded during my tenure as Registrar was the turning around of the fortunes of the Council. Hither to the Council was generating less than 2 million naira yearly. By the time we left, the expected revenue was in the neighbourhood of twenty-five million per annum; In addition greater awareness was created among members of the family and they were coming out in large numbers to register.

Next was the registration of engineering consultants. This was aimed at guaranteeing safety of life and property, by ensuring that only firms headed by properly qualified professionals were registered and entitled to be patronised by members of the public.

7.9 Supervised Industrial Training Scheme (SITSIE)

Sometime in 1992 the Supervised Industrial Training Scheme in Engineering (SITSIE) was introduced for the training of newly graduated members of the family (This started with engineers and engineering technologists). The result was initially encouraging and it is delightful to note that the Federal Government has now agreed to place SITSIE on the rolling plan to be fully funded. This will go some way to ensure that all engineering graduates get the required practical exposure in their first two years after graduation.

7.10 Inspectorate Unit

Another scheme that we introduced was the inspectorate scheme (now tagged Engineering Regulations Monitoring Scheme). The objective of this scheme is to ensure that members of the family are properly designated and remunerated by their employers and that non qualified persons are not placed in engineering cadres.

7.11 Registration

Apart from the registration of individuals in his cadre, within the profession, a modest level of mobility is guaranteed within the cadres by allowing cross over courses either in the University or

at the Colleges of Technology. The mature candidate route otherwise known as the 'grandfather' route enables experienced technologists of ages above 40 years and over 15 years post qualification to be examined and registered as engineers if they pass the appropriate examination.

7.12 Engineering That Need Not Be Physics Based:- Software and Systems Engineering

About half a century ago, it was believed that the role of engineering was to exploit the discoveries of physics. Whatever truth that was embodied in that statement may not be exactly so today.

Since the introduction of the first microprocessor, intel 4004, by Intel in 1971, the electronic engineer, the physicist and the computer scientists have been moved closer together. Microprocessor has introduced several flexibilities into the design of electronic units and systems. This has ultimately led to the growth of software engineering and the result is that we now have hardware and software engineers in the industry. The software engineer may be regarded as an engineer in the full sense. He has the same attitude to his work as his hardware colleague and accepts the same responsibilities. He plays similar roles in the development of products and his effort determines the success or failure of his product. The software engineer may not have studied electrical engineering at the University; in fact he may have only studied computer science, engineering physics or mathematics etc. But the peculiar brand of logical thinking which this training develops, fits him for certain kinds of hardware design; For example he need not have more than rough knowledge of what the packages contain, provided that he understands the logical principles on which the circuits are constructed and the hazards that are to be avoided. The physics comes sealed inside the packages and all the designer needs to do is to study their specifications, and use them.

However, advances in Systems Engineering need not come as a result of physical discoveries as do major advances in hardware, but rather as a consequence of far reaching and unifying insights being obtained. Such insights can be as important in every way as physical discoveries.

At another level is the assembling of processors, disc files, printers and so on, to form, together with the appropriate software, a computer system. These are all different problems in systems engineering. In this regard Mr. Vice-chancellor, I'll like to congratulate you on the proposal to introduce system engineering as a discipline within the faculty of Engineering of this University. As you are aware both COREN and NSE have commended the University on this initiative. It is a novelty which is likely to be followed by other faculties of Engineering and Technology in the country.

7.13 The Software Engineer and The Engineering Profession

The position of the system engineer with a software background and the software engineer has been the subject of discussion within the professional engineering bodies for sometime. The position of the Institution of Electrical Engineers (London) is that subject to their meeting suitable educational requirements they may be welcome to the Institution. It should however be noted that not every practitioner in software is a software engineer. COREN and NSE are invited to note this. This also brings to mind

the relationship between such registration bodies as COREN, COPREC and Council for Regulation of Earth Science Professionals and Mining Engineers. Whilst talking of the newly emerging branches in the engineering tree as a result of the explosion in information technology and communications, it is relevant to stress that the apex professional accreditation body in engineering in Nigeria is COREN as it has been confirmed at a meeting held sometime ago at the Presidency that once an engineer is registered by COREN, he does not need to register with any other registration body to practise his profession, be it COPREC, etc.

8.0 WHAT FUTURE?

To move beyond the limits of silicon, attention has been directed to other chip materials and chip design. An example of such a material is the III - V compounds like Gallium arsenide. Innovations in design now include the three-dimensional chip design, in which circuit components, are arranged in stacked layers instead of on the chip surface.

8.1 Photonics

As stated earlier, photonics is replacing electronics in communications systems. In order to get to a purely photonic system there is the need to concentrate research and development efforts in some of the underlisted areas viz:

(i)use of optical guides that are non lossy so that there will be no need for conversion to electron/electronic amplification enroute.

(ii)development of high power phototransmitters - lasers with enough power to carry the signal across the entire transmission medium without repeaters.

(iii)development of photonic repeaters, and other active elements such as switches and gates.

Such targeted research are beginning to yield results. For example

(a)By depositing impurities in the glass the refractive-index profile has been modified so that the rays can travel longer distances in it without attenuation

(b)A new technique of growing gallium arsenide GaAs on silicon, which combines the photonic utility of GaAs (III - V) with the well known advantage of silicon electronics has been developed.

This results in a super lattice with a different lattice constant. Within the new lattice structure (i.e. super-lattice) we now have very thin cascade of layers especially where the difference between any two lattice constants is minimal. Within such an environment the mutual strain between the atoms in the adjacent layers give rise to a new perfect crystal with properties unlike those of either of its constituents.

(c)Investigations have also shown that certain III-V semiconductor superlattices along with other materials exhibit a non-linear response to optical signal. - A small increase of the incident light intensity on the material causes a sudden large increase in the intensity of the output. (see Fig. 12)

Electrooptical switches have also been developed. (see Fig. 13)

8.2. The 'Organic Photoconductor' - the Biochip

In 1962 the organic photoconductor' was patented by H. O. Sus and N. Neugebauer. It is made of carbazole - the donor molecule and trinitroflurenone - (TNF) - the acceptor molecule. When organic molecules are exposed to light, they effect a photo-induced charge transfer in which one electron moves from the donor molecule (- carbazole) to the acceptor molecule (TNF). Thus the effect of the light is to produce an electron-hole pair (as in semiconductors) that can be separated and moved in an electric field. In other words, light can change an organic polymer film from a non-conductive state, with no free charge carriers, to the conductive state. (see Fig 14)

The results achieved in this area to date show that the level of carrier mobility, which determine how fast charge carriers can move in a given electric field, is still very moderate in organic materials. Results obtained for polymers are in the range (10^{-3} - 10^{-5} cm^2/vs) and cannot compare with a rate of 10^4 cm^2/vs characteristic of semiconductor crystals. Because of their low mobility, these organic semiconductors are not yet capable of performing high speed switching functions, which are typically of the order of milliseconds. On the other hand, organic materials possess some other outstanding advantages viz:

-they are non-toxic and are recyclable

-they can be made into almost perfect large-area films which, as a result can be used for parallel data processing. Typical of this technique is electrophotography (or xerography) in which the desired data rate of 100 G byte can be achieved. Thus by designing a machine appropriately while using the relatively slow material, it is possible to produce very fast machines for optical data transfer.

Molecules of the size of carbazole and TNF are currently being used to make thin easily characterizable, usually polymer films that permit highly complex physical applications. Some of such applications are in the areas of photo conduction, holographic imaging (photorefractive effect), organic field-effect transistors, frequency doubling and light switching, piezoelectric polymers (microphones and speakers) and conductive polymers (batteries, screening).

In the near future, further and more sensational results are expected in this field; such confidence and optimism emanates partly from the realisation that light-induced charge transfer is the first stage of photosynthesis. Compared with the technical use of molecules, however, Nature uses an apparatus that is 1000 times larger.

If the drive for efficiency must be everlasting, then the fact that the distant future will be organic is both apparent and inevitable. An indisputable pointer in this direction is the human brain where 10^{15} bits are stored in approximately one liter of space while using less than 50W of power. The equivalent system measured in number and cost of silicon chips would translate to billions of dollars. Herein lies some of the argument and wisdom for the development of human capital!. Perhaps this is the point to pause and make a few recommendations as to how this nation can be part of the future we have been talking about.

Such recommendations must take cognition of where we are in the scheme of things and the seeming unbridgeable gap between us and where we want to go. As a teacher, I belong to the group that believes that all dreams of development are possible provided that they are hinged on education, discipline and sound organisation.

Recommendations

Mr. Vice-chancellor Sir,

This brings up the issue of access to education.

1.We understand that admission into Federal Universities have been ordered to be reduced by sixty per cent. We do not know what informed the decision but, based on our earlier submission in the course of this lecture and learning from what is going on in other parts of the world, this decision appears to be ill-advised. Government also needs to be advised to differentiate between sharing the cost of education and trying to control access to education which appears to be a fundamental right guaranteed in our constitution. It may be useful to recall that even the colonial administration provided opportunity for University education and also made available opportunities through correspondence studies.

If government wishes to reduce in take into its funded Universities, it may do so; but must also provide alternatives.

Private Universities and Polytechnic should be allowed, but the requirements for establishing them should be relaxed. Government should provide guidelines and monitor and ensure that these guidelines are strictly adhered to.

2.Just as in information technology, expertise have been developed in hardware electronics in the country. These can be improved upon only if there are opportunities for practice. There is now a large market for finished electronics products in the country and the subregion. To encourage development of

this sector, duties on electronic components must be removed, and importation of simple electronics that can be designed and built or copied in the country dropped.

This will assist the development of a local electronics Industry.

3.At the level of the University of Lagos I recall that my colleague Prof. S. A. Adekola in his inaugural lecture made a request for renaming of our department to Department of Electrical, Electronics and Computer Engineering. I lend my voice to that. Both his lecture and mine have demonstrated that we teach not only Electrical, but Electronics, Computer engineering and much more!.

4.In the past, students in the departments of Physics and Computer Science used to take some courses such as Fundamentals of Electrical Engineering, and some electronics courses in our department. They no longer do. I am not aware that the course content of what they now take is sufficiently different from what the engineering students are taught, to justify what might border on duplication. We believe that having these courses taught in individual departments sometimes negate the advantages of the Unit Course System. Mr. Vice-chancellor Sir, the University should please have a second look at this.

EPILOGUE

Mr. Vice-chancellor Sir, in the period of this discourse during which not less than 22,000 trillion electrons must have passed through *a one Joule cable*, we have discribed how man has managed to use his intellect to understand and overcome the forces that surround him. In doing so, he has studied the creatures that share the earth with him and the materials that abound therein. We have also learnt that his knowledge of matter has led him to discover the electron and its potentials. By his understanding of the capabilities of the electron, he has managed to establish his dominion over the world and is anticipating the future with a sense of confidence and optimism.

Within the family of man only those that are able to free themselves of the fetters of ignorance and poverty can dream of such a future. We in Nigeria are currently locked in a grim battle with our culture of self emolution and condemnation of the efficacy of our organs and institutions. Whilst we acknowledge the importance of education, we are not so sure we need so much education; whilst we clamour for industrialisation and modernisation we do not plan for it to be internally led or sustained. Ours is a nation that has built castles in the air since that is where they should be; luckily our structural engineers tell us that all need not be lost as we can still put foundations under them. In this task our lecture reveals that the electron has a major role to play, be it in our survival as a nation or in our self actualisation as worthy and productive members of the family of mankind.

In pursuing this goal we will need the focused attention of all the men of vision in our society. They are the members of a different clan that are part but must stand apart from society. We here tonight pay tribute to some members of this clan; to the Nigerian Engineer, the Scientist, alas the academia for:

"They are the Willing

led by the Unknowing

Prepared to do the Impossible

For the Ungrateful

They have done so much

For so long

With so little

And are now qualified and

Prepared to do anything

With almost nothing"

Yes; with the electron!

Mr. Vice-chancellor Sir, Ladies and Gentlemen, I thank you for your patience and attention.

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Acknowledgment

Mr. Vice-chancellor Sir, I'll like to pause here to acknowledge those who have affected my life and have made this day possible.

-First, I'll like to thank the Almighty God for sparing my life till today. In 1957, I was nearly electrocuted but for the fact that I fell on the cable of the electric iron that I was using, which snapped the cable from the ceiling rose to which it was connected. In fact that is the reason why I decided to study Electrical Engineering.

-Next I wish to acknowledge the influence of my Physics and Mathematics teachers at both Accra Academy and Prampeh College (Messrs. Adwedaa, Okine and Dadson).

-At the University my interest in electronics was created by both Mr. Brian Holdsworth and John McCormnack both of them introduced the transistor to me, apart from being my lecturer, Mr. Holdsworth was my tutor/adviser throughout my stay at Kumasi and Zaria. We used to spend some evenings with his family, and that drew some of us closer to him. I use to be in contact with him until recently.

-I also like to acknowledge my supervisors Dr. S. M. Bozic, and Dr. C. A. Miller, for their assistance and Professors Wright and Shearman head of microelectronics group and head of Electronics section at the University of Birmingham respectively.

-On leaving school I had my baptism in Engineering practice at the WNTV-WNBS under two distinguished engineers, Engrs. Teju Oyeleye and V. I. Maduka both of them are here tonight and I

must also mention Mrs. Joana Maduka with whom I started there. I have been close to all of them since.

-When I left school all I wanted was to be a damn good engineer, because that was what our lecturers used to say. But ·Dr. Akinleye brought me to the Department of Electrical Engineering of this University after I returned from Zaria during the civil war. In the department , I met Prof. O. A. Seriki, both of them have always taken me like their kid brother. They have assisted in my career in this University. When I was in UK, Dr. Akinleye always made sure he visited me in Birmingham or he invited me to Notingham anytime he was visiting. Prof. Seriki arranged several of my visits to and training at Siemens headquàrters at Hoffmann Streissor in Munich I say thank you to both of them. To my colleagues in the Department and Faculty and my students both old and current, I say thank you. Also professionally two other people have affected me, one is Engr. Bodede who refused to employ me at NET because my grammar was too much but I later got to learn a lot from him when he headed the first accreditation team on which I ever served and during my subsequent interaction with him. The other is Engineer A. O. Faluyi who was my president at both NSE and COREN. He drafted me to COREN I have since got close to them. And to all Nigerian engineers for the opportunities and support they have given me to serve, I say a big thanks to you all.

Particularly, I'll like to thank Chief 'Layi Balogun and my brother and friend Prof. 'Segun Olunloyo. We have spent several evenings together arguing on the various issues, and in some cases agreed to disagree on some. Prof. Olunloyo has been quite helpful in the final stages of the preparation of this lecture.

To my parents, I say thank you for all you have done for me, my dad died in 1974 just as I was arriving from U.K, but not long enough for me to meet him. Although he never went to school, he nonetheless appreciated the power of education. My mum, I am grateful to God she is alive to witness the result of the education they both struggled to give me. I thank them all for all they have done for me.

Now, to my children Omowunmi, Ayo, Damilola and Omolade, I thank you for sharing me with other people' children. I particularly thank you for your forbearance when we have to mount students projects in the living room to test whenever they bring them home, and we have to scatter your systems.

Finally to my wife Adetola Morenike, a loving wife and a good mother you have been and continue to be a great and strong woman; a great support. I'll like to publicly acknowledge today the sacrifice you made when you had to give up your career when a house girl locked-up our second child in 1981 and ran away. You bought this gown in which I am adorned today when I refused to buy one. This is of course one of many such gowns my refusal has milked out of you over the last 20 years but I dare say this is the one I most enjoy modeling for you and having you pay for. I thank you for your encouragement, your constant support and your patience.

May God continue to shower His blessings on all of you.

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UNIVERSITY OF LAGOS PRESS - 1998
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