The University of Zambia

School of Engineering

Department of Electrical and Electronic Engineering

The Telemetry network design and the implementation
(Case study ZESCO network)

Mulenga Bwalya Geoffrey

December 2003

Dedication

This work is dedicated to wife Lombe and children Chanda, Bwalya, Kalaba and Lombe for the inspiration and motivation during this period

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"Report submitted in partial fulfillment of the Requirements for the award of degree of Bachelor of Engineering, University of Zambia."

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Mulenga Bwalya Geoffrey

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List of Abbreviations

ADC	Analog to Digital Converter.
ASCII	American Standard Code for Information Interchange
CPU	Central Processing Unit, the main processing chip of a computer.

CRC Cyclic Redundancy Check; a self-test for error detection and correction

DAS	Data Acquisition System
DMA	Direct Memory Access
DCE	Data Communications Equipment e.g. your modem
DTE	Data Terminating Equipment e.g. Your PC
EPROM	Erasable Programmable Read Only Memory:
HF	High frequency (Radio frequency spectrum between 3 and 30 Mega Hertz.)
ISA	Industry Standard Architecture
ROM	Read Only memory, which can be erased using ultra-violet light
PCI	Peripheral Component Interconnect
TMS-1000	Tidal Monitoring system. This brand name of data acquisition
VSWR	Voltage Standing Wave Ratio.
WDB	Water depth bubbler,

Summary

Telemetry is the capability of transmitting or retrieving data over long distance communication links, such as satellite, radio or telephone. The telemetry in this project was designed to use radio communication. The monitoring system comprises the following major components, data acquisition systems, antennas, transceivers, modems, and transducers.

Chapter three deals with data acquisition systems that provide control of sensors, data storage and telemetry programming. Modems, the devices that enable a computer to transmit data over analogue channels and vice verse. Transducers that transforms physical quantity being measured into an electrical signal.

Chapter four discusses the antenna as vital part of the communication system for efficient transfer of RF energy between the transmitter and receiver. Transceiver as radio communication system that has a dual function of a transmitter and receiver.

The electromagnetic waves are used to propagate radio signals in the ionosphere. The ionospheric conditions play a major role in propagation and frequency selection. These are dealt with in chapter five, while chapter six deals with the software programs that are used to run and manage the information exchange between remote stations and master station.

The discussion in chapter seven is concerned with recommendation and benefits e.g. need to maintain certain equipment like rain gauges, water bubblers, antenna structures and TMS-1000.The features included were temperature, relative humidity and wind speed sensors. The social consideration to enhance communication and the main benefits included reduction in time and error judgment for data collection due to scheduled and upon request collection. Low operational cost attributed to automation and enhanced scheduling of power production and public safety by providing data for forecasting and managing floods have been alluded to in this chapter.

Chapter 1

1.0 INTRODUCTION

The introduction gives the general background of the project, giving the technology concepts of telemetry and the general function view of the system. Then outlining the aim and objectives of the project which necessitated the study of such a project in which not only it is the gaining of the knowledge, but the appreciation and utilization of the gained knowledge which is the essence of human education and development.

1.1 Project background

ZESCO limited operates a hydrometric telemetry network whose main use is hydrological data collection. Since Hydro Power generation depends on water availability there is need for prudent water management. Steps taken to achieve this include

- Monitoring of water levels and flows in the Kafue and Zambezi river basins.
- Maintaining acceptable levels of water in reservoirs (Kariba and Itezi-tezi) for power production.
- Measurement of rainfall, evaporation and humidity
- Regulating the inflows in the flats to ensure that environmental ecology is preserved.

To monitor the amount of water, water level measurements should be obtained in real time. Forecasting of flows for future use of water resources are made from the same readings using different computer models. To get the readings in real time a Hydrometric telemetry system with the following subsystems was designed:

- HF Radio subsystem This includes the radio, RF controllers and antennas
- Data acquisition subsystem-data acquisition equipment, water gauges and rain gauges
- Power supply subsystem comprising photovoltaic modules, lightening protection units, requlators and battery.
- Master and sub master subsystem, mainly this is the data processing equipment

As can be seen above, the readings are made at a remote station and the values of water level, rainfall etc are sent to a central master station in Lusaka via HF radio.

1.2 Rationale

The project was initiated to carry out a study on the design, implementation and performance of the Telemetry network run by ZESCO Ltd.

In this project the literature review was carried out on the technology behind composition the network. This involved studying the general and specific operations of the data acquisition systems, various transducers, modems, HF transceivers and HF antennas. In addition to the above, hardware, the interfacing of the modems to radio and telephones and the antennas operations and propagation characteristics has been discussed.

The role of the ionosphere characteristics on HF frequency propagation and selection the selection of optimum frequency was also looked at. The software review was mostly concerned, with its use in the interface and operations of the radios, modems and the data acquisition equipment. The report also looks on the relationship between the theoretical knowledge and the practical aspects on site.

The discussion deals with the issues, pertaining to the performance of the current system and the challenges being faced. The proposals or recommendation that must be carried out to enhance the system i.e. additional monitoring features and services to be provided. It as also deals with the sustainability, costs and the key or main benefits to be or being derived.

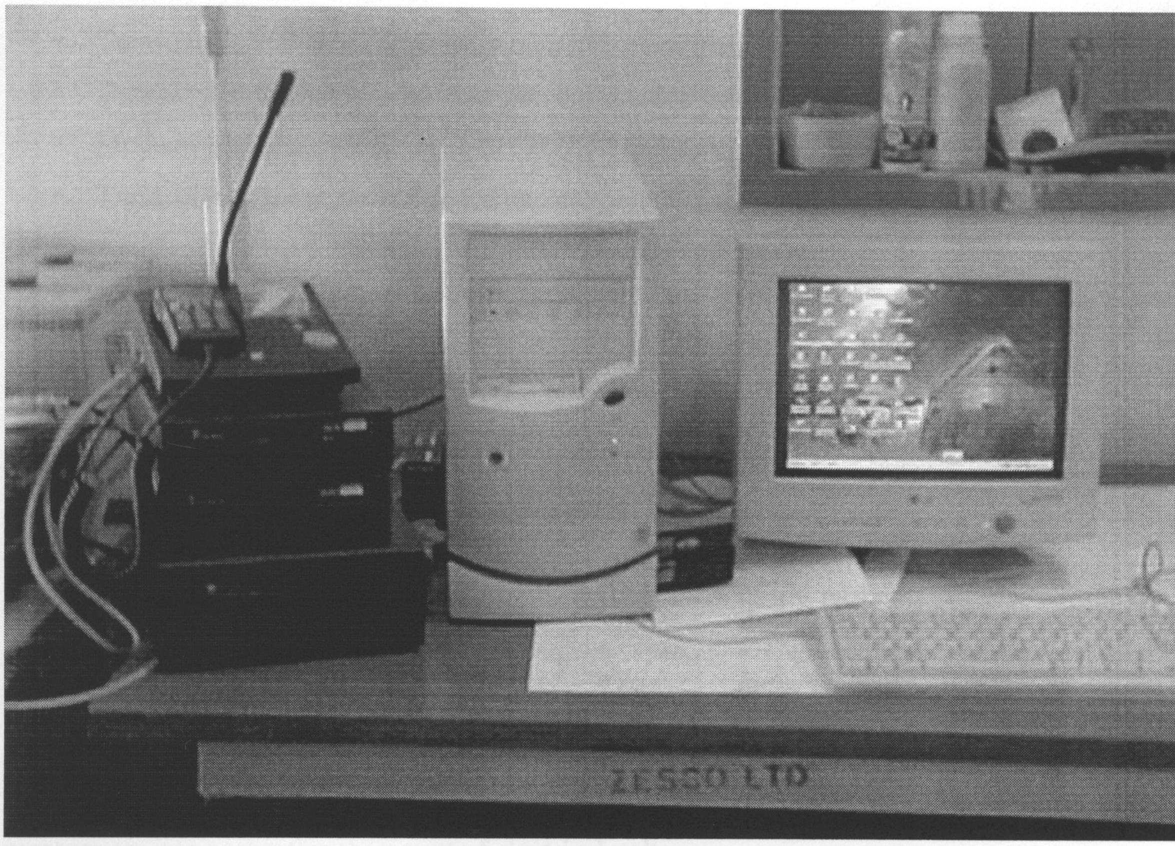

Figure1.1 Showing communication radio/modem interface to PC at Master station (ZESCO ltd)

1.3 Telemetry – The technology Concept

Telemetry is defined as measurement at a distance. It takes many and various forms. The principles of radio, electricity, optics or hydraulics may be used to convey measurements made at one point to indicators, actuators, recorders or computers at another point.

The most popular telemetry systems are electrical and use radio to convey information. To measure at a distance or remote point, there is need for transducer and communication link or channel.

- Transducer is required to convert a physical quantity being measured into an electrical signal for easy transmission
- Communication channel- is the transmission line or medium from the point where the measurement is being made, to the point where the signal is recorded or required.

Radio telemetry systems comprises

- Transducers that convert measurement into electrical signals.
- Data acquisition subsystems that are connected to transducers.
- Modems -as controllers.
- Transceivers, these are radios for transmission and receiving.
- Antennas – provides transfer of radio frequency energy.

The point where information is needed, there can be recorders, or computers to process data and store the information.

1.3.1Functional Overview of a Telemetry System

Telemetry systems are configured differently to meet each user's particular needs, but they all have certain common elements such as transducers or sensors, multiplexers etc.
Any form of measured physical data is converted by transducers or sensors into electrical quantities. Electrical data starts at sensors. Some sensors measure electrical quantities such as gain, voltage, and current, while others convert physical conditions like temperature, pressure etc into proportional amount of electrical voltage.

A multiplexer combines these electrical voltages and timing data into a single data stream. The transmitting device (radio transmitter, coaxial cable, telephone line, tape recorder, etc.,) then passes the data stream to a distant receiver. A bit synchroniser followed by a demodulator accepts the data stream from the receiver and separates it into its original measurements. The original measurements are then selected, processed, and displayed according to specific design.

The Telemetry system for ZESCO Ltd is as follows; each remote station is programmed to power up the controller at a unique time. To save on power consumption the remote station radio and controller are kept off except for two windows when it is about to transmit or when it is listening for a call from the master's. A call is made to the Master station on the first channel. If there is no response or if the quality of the signal is poor, the second channel is then tried, and if not the third one. If all the channels are poor, a link is established using the better of the channels. If no response from the Master on all the channels, the auxiliary sub-master is then interrogated using the latter protocol. Data is then sent using the error-free mode of the controller.

After all the remote stations have sent (or attempted to send) data, there is a period of time during which, all remotes are turned on and start scanning for the incoming calls from the masters. This is to allow manual interrogation of the remotes by the master station's operator for retrieving additional data, changing parameters, etc. The operator should know the time frame to make it simple for him to know when to call a particular remote.

There would be another period in the day reserved for the master and sub-master to communicate to exchange raw data. As for the stations having their own AC power supplies, power consumption (or on-air time) is not an issue. The following are the calculations on the power requirements for (using solar batteries) the radio controller portion based on two channels:

Total TX time =4 minutes (based on 2400 bps @ 2 minutes with 1/8 the data)
Total link set up time = 15 seconds per channel
X 2 attempts
X 2 channels
X 2 stations (master and Sub-master if fail)
Total Tx on time = 4 + 2 = 6 minutes @ 300W
= 30 Wh
= 2.5 Ah @ 12V
Total Rx on time = 60 minutes @ 20W
= 20 Wh
= 1.7 Ah @ 12V
Total Power = 2.5 Ah + 1.7 Ah
= 4.2 Ah @ 12V

Battery Specifications:

14 day life at 5% reserve = 4.2 X 14 X 1.05 = 52 Ah

The Battery must at least be 60 Amp- Hour.

Solar Panel Specifications:

5 Hours per day, so minimum current is = (4.2 Ah/5h) X 2 (factor to recharge battery – 14 day) = 1.68 A @ 12V
= 20

1.4.0 Aim and Objectives

The aim and objectives are what the project's concern are and outlines the goals which are to be attained at the end of the study, hence there are stated clearly and simply as below.

1.4.1 Aim

To study the design and the implementation of the **ZESCO** telemetry network.

1.4.2 Objectives

- Evaluate the performance in line with the original objectives of the telemetry project. That is to improve availability, quality and accessibility and utilization of hydrological data.
- Develop innovations and improvements
- Learn its possible uses in information communication technology related application i.e. telephone/fax and e-mail/internet.

Chapter 2

2.0 Methodology

This chapter looks on the procedure for the data collection and technical analysis, evaluation of the telemetry system performance and the actual basic configuration of the network in relationship to the information gathered.

2.1 Data collection from.

The data in this report has been mainly collected from the ZESCO hydrology and telemetry departments, this has involved the physical seeing or checking of the equipment and literature collection. The data collection has also been done through visiting certain places like Itezi-tezi where I was able to see the operations on the automated systems in comparison to the manual systems. Then there has been valuable information collected through the interaction with various persons dealing in data measurements (especially data readers).

The other sources of information has been textbooks on the technical issues, the manuals have played a major role in understanding the concepts and the original objectives of the Telemetry project. The newest research tool the Internet has also contributed valuable information.

2.2 Evaluation of Telemetry system at ZESCO:

The evaluation of the Telemetry network has been in view of the following, original specification, original and new international standards in auto-link establishment procedures and modems, sustainability of the project in terms of operation and maintenance. The major cost benefits of having an automated telemetry network and need to include enhancing the system.

2.3 Practical design aspects of Telemetry

In this aspect the emphasis to look on what is involved through literature reviews on a design of basic telemetry using HF radios as communication channel. Looking at the interface and operations or roles of various telemetry equipment i.e. HF radios, computer, modems, antennas, data acquisition systems and transducers.

2.4 **Project focus**

The project focus has been to study the design and the implementation of the **ZESCO** telemetry network. The goals of the project includes, evaluating the performance in line with the original objectives of the telemetry project. That is to improve availability, quality, accessibility and utilization of hydrological data. Develop innovations and improvements, including the proposal on the implementation the possible uses in information communication technology.

The attainment of the focus has been through collection of data and literature on telemetry operation and hydrological data. Looking at the process of data, collection, how it is been used and challenges being faced. Coming up with technical analysis report on telemetry current state and recommendation. Proposals for a network that will meet the current needs and address hurdles encountered. Then economical analysis of the system i.e. economical and social benefits and comparison of automated telemetry and manual radio systems

Chapter 3

3.0 Literature review.

- Data acquisition subsystems.
- Transducers.
- Modems.
- HF transceivers.
- Antennas.
- Frequency propagation and selection.

3.1.0 Data Acquisition Systems (DAS)

These provide a level of flexibility for the control of sensors, data storage and telemetry with easy programming. Certain models of DAS can be used in varied applications i.e. meteorology, hydrology, forestry, seismology, air and water quality management and other areas where reliable monitoring of environment is essential.Depending on the data acquisition systems model and manufactures certain hardware features include

- Analog input that can be configured for various modes of voltage and current measurement. Then sensitivity ranges are selected by software, and inputs can be paired to provide differential inputs.
- Analogy to digital conversion to a given precision with compensation for temperature effects.
- Frequency input intend for wind speed sensors.
- Digital input to detect up or down changes of state of external switches or voltages.
- Rainfall measurements switching inputs for tipping buckets.
- Serial Digital interface-12 input, which allows the connection of a cable to support smart sensors that generate data according industry standard for management smart sensors.
- Data storage memory –usually standard data storage memory in RAM for 128K bytes of binary.

The ZESCO ltd s main principal element in the remote data acquisition is the Tide Monitory System (TMS-1000). This is an electronic data acquisition unit designed to measure environmental and meteorological parameters .The TMS-1000 can be used to collects data from various hydrological or meteorological sensors, and log the data into memories, transforming the raw data into engineering units and transfer this information to the HF equipment for transmission to the master or sub-master station. The data that could be stored include water levels atmospheric pressure, salinities, water columns and water temperature

The sensors that are connected at the moment are the water depth (WDB-300) bubbler unit, the rain gauge bucket, intrusion alarm, fire alarm and gate opening position. The intrusion and fire alarms are normally closed contact devices.

The TMS-1000 `s software is used to retrieve and process data and to automatically activate the HF radio call to transfer data or alarms to the master or sub-master station. Data and programs are stored in battery-supported non-volatile CMOS static memory (RAM) to provide maximum versatility with low power drain. An RS 232 communication interface is provided for direct on–site communication with personal computer. The TMS-1000 database can be interrogated from the master/sub master station to retrieve data and or change parameters.

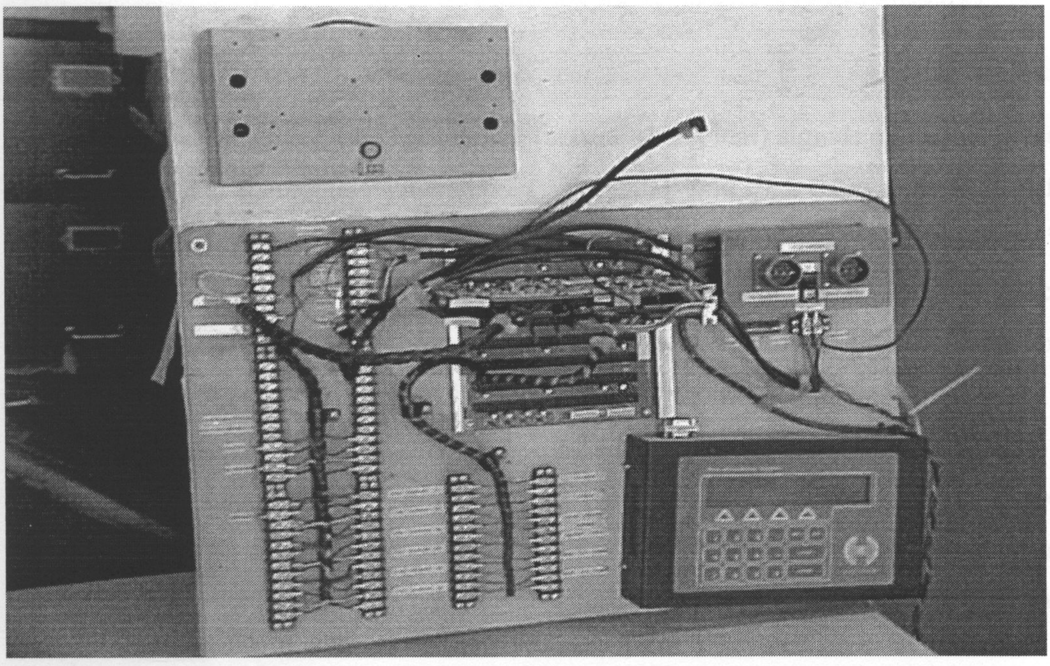

Figure 3.1 TMS-1000 (operational) mounted on the board for testing purposes

The principal hardware and software functions of the TMS-1000 as implemented in the ZESCO telemetry project include the following:

- Data acquisition, here the internal application software conducts the sampling of transducer inputs at predetermined levels selected by the user.
- Data transducer and processing of the raw data input from the water level requires the application of algorithms to convert its values to water height to its values.
- Data base i.e. software management functions include the storage of transducers sample values in a database for under dynamic allocation and control of requests for storage and retrieval.
- RS-232 serial communication has the software that handles the RS-232 serial communications both in direct connection to a locally connected personal computer and to the Skyline controller data port.
- HF subsystem power control, it controls the preset start time of data transmission by activating the skyline controller and radio transceiver through the power relay.
- Low power mode, when it is not performing the active data sampling, storage or transmission, it reverts to a quiescent state to reduce its power drain on battery.

3.2.1 Data acquisition concepts

3.2.1.1 Analogue Data

Data acquisition systems capture Analogue (natural sinusoidal) signals and convert them into a digital form that a computer understands. To understand this, there is need to define the principles of digital measurement technique. An analogy is defined as 'continuous' signal represented by the continuous changing physical quantity while digital is defined as a 'discrete' in time signal represented by separate individual units. Units are represented by 'bits' (binary digits), the bits can be represented by one of the possible states: on/off, true/false or 1/0. The word digital is used in a wider context for designating the way of expressing phenomena such as quantities and states in digits. Others such as temperature, velocity, and fluid quantity vary in nature, almost entirely without steps, i.e. an infinitely variable. Consequently, the most natural and exact way of expressing such phenomena is the analogue method.

Even if digital apparatus can receive and send signals that express well any number we like, the individual components operate with only two numbers. These are represented by two voltage levels or states, which are designated by 0 and 1. In a system that is realised with relays, 0 can be used to designate the release relay and 1 to represent the operate relay. In a system that is realised with electronic digital circuits (usually called logic circuits) we can let 1 be represented by a positive voltage, for example +5V, while 0 is represented by 0V. When 0 and 1 are used as designations for states we usually call them logic zero (0) and logic one (1) respectively. In a system where only two levels occur it is convenient to use the binary numeration system, this only contains the digits 0 and 1. Physical units such as logic circuits, relays, lamps switches etc., which work with only, two states or positions can be designated as binary elements. In data technology, the designation "word" is used, which is usually given by W and which constitutes a number of consecutive bits, the number of bits being defined for each system. The "word length" gives the number of bits per word and can vary for different systems and parts of systems. The choice of word length is entirely dependent on the design of the system, and is usually the number of bits that can be transferred or processed together. In order for a computer to be able to handle and process parts of a word, the word is structured in parts.

3.2.1.2 Digital Data

To make measurements with a personal computer you need a data acquisition interface; the heart of a system for data acquisition is an analogy to digital (A/D) converter. This comprises an interface between the systems` analogy and digital sections and is the most decisive component in determining the basic performance of the system in terms of resolution and sampling speed. The interface cards are fundamental in use for the computer-controlled card system for measurement and control. The performance of the measurement system is determined by the accuracy and conversion speed of the AD converters, it is essential to determine the requirements to be placed on the system before choosing the ADC cards. Most cards have a muiltiplexer to permit the use of sixteen single ended or eight differential inputs. The ADC cards usually lack built-in intelligence, and a setting command is generally required whenever a card is instructed to make measurement. Hence it helpful that a card has its own RAM-memory to store measured data for the computer to read all measurement sequence at a time.

3.2.1.3 Data Logger

You connect your signals to the interface hardware and it converts them to a form that a computer can understand. The DATA LOGGER has a central processing unit (CPU) board, which is its heart. An INTEL 80C188EB microprocessor controls all the main functions and orders all mathematical calculations. The CPU board was designed to support various new additional cards such as digital control lines, analogue and digital input and output cards, and memory printed circuit boards (PCBs) with capabilities up to 16 Mbytes.

The CPU board has 512 Kbytes of standard live memory, which can be extended on board up to 3 Mbytes. However, it is possible to extend the memory up to 768 Kbytes with the same 128 Kbytes memories for memory sockets supporting up to 128 or 256 Kbytes of EPROM present.

A lithium battery with a two-year autonomy provides supply voltage to live memory when the system is being transported, stored or normal supply voltage is cut off for different reasons.

An oscillator ensures clock stability in real time superior to four seconds per month over the extended temperature range of –40 to +85°C. One of the software's features is to stop the supply voltage to various components between each sequence of acquisition, thereby improving the system's autonomy. The CPU features a direct memory access (DMA) controller, memory and input/output wait state generator, programmable interrupt controller, 8 parallel printer input/output lines, 2 82C50A type serial input/output ports with an RS-232, watchdog timer, an SDI port, communication master slave and precision power-fail detect and reset circuit.

The system may connect to any computer through a communication link using an RS-232 with standard communication protocol, i.e. 9600 baud's, eight data bits, one stop bit, no parity The interface hardware comes in many different physical formats, a common one being the plug-in cards. This fits into a free expansion slot in your PC. The card generally connects to the main (or a subsidiary) data and control bus of the computer. There are a number of PC bus structures for which cards are available: ISA, PCI and PC (MCIA). The main advantages of a plug-in card are its low cost, its high speed and ease with which it is installed. The main drawbacks are the limited potential for system expansion and the fact that the computer has to be located close to the signal source. The many different methods of connecting data acquisition devices to the computer are summarised below. These exchange messages between the PC and the data acquisition and control system.

3.2.2 RS232 Serial Link

The Electronic Industries Association gave birth to the RS-232 standard in 1962. RS stands for recommended standard, but may now be replaced by EIA (EIA232). It has/is been used extensively for communication between computers and terminals, at standard data rates ranging from 110 to 38,400 bits per second. You may only connect one device to an RS232 lead, but multi-port serial cards are available for PCs, which let you connect several devices at once. Many instruments have RS232 ports, such as balances, data loggers, chromatographs, oscilloscopes and spectrometers.

The RS–232 standard specifies the properties of both drivers and receivers: the driver must generate voltage levels of +5 to +15 volts (logic LOW input), and –5 to –15 volts (logic HIGH input), into a load of 3k to 7k, with a slew rate of less than 30V/us and the ability to withstand a short circuit to any output; a receiver must present a 3k to 7k load resistance, converting an input of +3 to +25 volts to logic LOW, and an input of -3 to –25 volts to logic HIGH. Note that logic 1 is inverted by the RS-232 driver to a negative level, called 'mark'; logic 0 is a positive level 'space'.

RS-232 specifies the connector type and the pin assignments. However the are two (2) basic problems to be appreciated. (1) There are two types of device definition, with input pins of one type corresponding to output pins of another that is connecting two similar devices. The other is the complementary device. (2) The are five handshaking signals; some devices send them and expect to receive them back, while others ignore their inputs.

The RS- 232 was designed and developed for connecting data terminal equipment (DTEs) to data communication equipment (DCEs). A terminal always looks like a DTE, and a modem always looks like a DCE, while certain devices can be either. Therefore when you connect a DTE to a DCE, you just connect corresponding pins of their DB-25 connecters, which could either be male or female. Its operation will still depend on which handshaking lines each device expects from the other, and bothers to drive itself and hence the need to agree on baud rate, parity, and a few other software parameters even the cable is right.

When two similar devices are connected, corresponding pins are not connected i.e. A DTE transmits on pin 2 and receives on pin 3, while the DCE does the reverse. Hence a criss- cross cable is used

Table 3.1 RS-234 Signal

Name	25-pin	9-pin	Direction (DTE↔DCE)	Functions (as seen by DTE)
TD	2	3	→	Transmit data
RD	3	2	←	Receive data
RTS	4	7	→	Request to send (=DTE ready)
CTS	5	8	←	Clear to send (= DCE ready)
DTR	20	4	→	Data terminal ready
DSR	6	6	←	Data set ready
DCD	8	1	←	Data carrier detect
RI	22	9	←	Ring indicator
FG	1	-		Frame ground (=chassis)
SG	7	5		Signal ground

The table shows all the important lines .TD and RD are the data transmit and receive lines, RTS and CTS are the ready to send and clear to send lines; DTR, DSR, and DCD are data terminal ready, data set ready and data carrier detect. There are two grounds, the frame and signal grounds and five handshaking –type control signals. Some devices use the RTS/CTS hardware handshakes to start and stop transmission while slower devices (e.g. printers) catches up. Others transmit a ' software handshake': CTRL-S (to stop) and control CTRL-Q (to resume). The software approach method means you can use simpler cable.

Other serial standards include RS-422, RS-423 and RS-485.The RS-422 is a unipolarity differential protocol good to 10Mbaud with. RS-423 is an improved bipolarity single ended protocol good to 100baud.The RS-485 is similar to the RS-422, but with additional specifications so that many drivers and receivers can share a single .The table below summaries the characteristics of the four (4) standards.

Table 3.2 Serial data standards

	RS-232C/D	RS-423A	RS-422A	RS-485
MODE	Single-ended	Single-ended	Differential	Differential
Max. No. drivers	1	1	1	32
Max. No. receivers	1	10	10	32
Max. cable length	15m	1200m	1200m	1200m
Max. data rate (bits/s)	20k	100k	10 M	10M
Transmit levels	±5v min ±15v max	±3.6v min ±6.0v max	±2v min (differential)	±1.5min
Receive sensitivity	±3v	±0.2v	±0.2v	±0.2v
Load impedance	3k to 7k	450Ωmin	100Ωmin	60Ωmin
Output current limit	500mA to Vcc or ground	150mA to ground	150mA to ground	150mA to ground 250mA to -8 or +12v
Driver Zout min (min power off)	300Ω	60k	60k	120k

3.2.3 GPIB (General Purpose Interface Bus)

Many signals such as temperature, pressure, strain, flow and speed will originally be analogue. These need converting to a digital signal before being transferred to the computer. This is done by an analogue-to-digital (A-D) converter. This project explains the meaning of some of the A-D specification terms that hardware manufacturers use, namely range, resolution, sample and hold acquisition time, throughput, integration time, linearity, offset errors and re-calibration.

3.2.4.0 Specification of A/D Converters

The input (or gain) range refers to the maximum and minimum voltage that will be digitised by the A-D converter. An input may be bipolar, covering a range of –10 mV to +10 mV for example or unipolar, perhaps covering a range of 0 volts to 10 volts. Many systems offer a choice of ranges, and you can select the most appropriate using software. It's best to choose the smallest range that encompasses your signal, as this optimises the resolution.

3.2.4.1 Resolution

The resolution of the A-D converter is the number of steps into which the input range is divided. The resolution is usually expressed as bits (n) and the number of steps is 2 to the power n. A converter with 12-bit resolution, for instance, divides the range into 2 to the power 12, or 4096,steps. In this case, a 0-10 V range will be resolved to 0.25 mV, and a 0-100 mV range will be resolved to 0.0025 mV.

Mathematically this can be expressed as

$$\text{For n bits resolution} = 2^n, \text{ for 12-bits resolution} = 2^{12} = 4096 \quad (3\text{-}2\text{-}1)$$

For an A-D or D-A converters with a resolution of *n* bits, the quantisation interval is given as

$$U_{step} = U_R / 2^n \quad (3\text{-}2\text{-}2)$$

Where U_R corresponds to the measuring range in this case 0-10V

U_{step} represents the quantisation interval

Hence $$U_{step} = 10V / 4096 = 0.25mV \quad (3\text{-}2\text{-}3)$$

Although the resolution increases when you narrow the range, there is no point in trying to resolve signals below the noise level of the system: all you will get is unstable readings. Some A-D converters have a choice of resolutions (offering 12-, 13-, 14-, 15- and 16-bit for example). You choose the most suitable for your application, balancing speed and accuracy .In the final analysis factors that limit the characteristics of a digital system for measurement and control are the capacity of the measurement computer and perhaps more important, the analogy input and outputs. Then the accuracy of the system can never be better than what the weakest link in the measurement chain is capable of.

3.2.4.2 Sample and Hold Acquisition Time

A sample and hold circuit freezes an otherwise varying analogue voltage now that the sample is required. This voltage is held constant whilst the A-D converter digitises it. The acquisition time is the time between releasing the Hold State and the sample circuit settling to the new input voltage. Sample and hold circuits are not used with integrating converters.

3.2.4.3 Throughput

Throughput is the maximum rate at which the A-D converter can acquire and transfer data values. Roughly speaking, it will be the inverse of the (conversion time + the acquisition time) A-D converter. Thus, a converter that takes 10 microseconds to acquire and convert will be able to generate about 100,000 samples per second. Throughput may be slowed down, however, by other factors that prevent data transfer at the full rate. For example, signals that are switched (multiplexed) into the converter may need time to settle - especially highly amplified signals or signals from high impedance sources. Some A-D converters measure the signal over a period. To reduce noises perform integration. Note that the throughput of an integrating converter isn't the inverse of the integration time.

3.2.4.4 Integration Time

Integration A-D converter averages the input signal over an integration time. In countries with a 50 Hz mains supply, a 20-millisecond integration time will average over a complete mains cycle. Helping to reduce the frequency interference.

3.2.4.5 Offset Errors

Offset is getting a reading other than zero for a zero condition: every reading will be inaccurate by this amount.

3.3.0 Transducers

Transducers are needed to convert physical quantity being measured into an electrical signal for transmission. An example of a transducer is a submersible pressure sensor, which is used to measure water depth in the rivers and lakes. It generates a current of 4 to 20mA in proportional to the pressure over the particular sensors sensitivity range. A load resistor converts the current to voltage range of 0.4 to 2.0V.

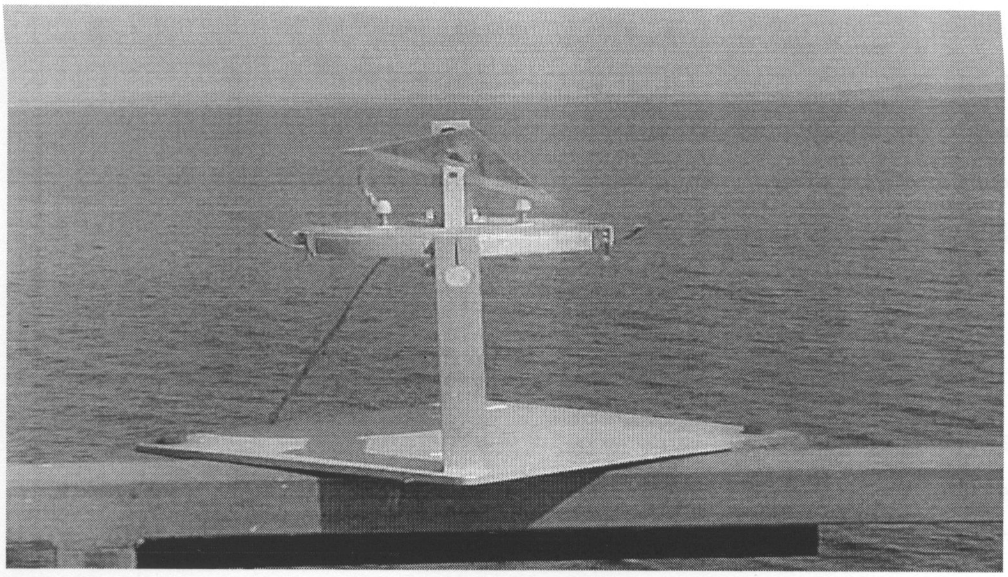

Figure 3.2Rain gauge transducer at Itezi–tezi (ZESCO LTD)

3.4.0 Modems

The word modem comes from the combination of two words modulation and demodulation.

- Modulation involves two waveforms: a modulating signal that represents the message and, a carrier wave that suits a particular application. A modulator alters the carrier wave in corresponding with the variation of the modulating signal. The resulted carrier wave " carries" the message information.
- Demodulation; modulation is a reversible process and the extraction of the message from the information bearing waveform produced by the modulator is accomplished by the demodulator.

The benefits of modulation are efficient transmission, overcoming hardware limitation, reduction in noise and interference, frequency assignment and multiplexing. The Modems are used to convert bit serial digital quantities to analogy signals that can be sent over telephone transmission channels or other paths.

An internal modem is plugged into a computer slot or it may be a built in, while an external modem is a stand alone box, powered from the ac power line, with RS-232 connection to the computer serial port .The sending of data on a single telephone channel in both directions simultaneously is referred to as full duplex.

There are three full –duplex formats in common use namely, 300 baud rate frequency shift keying (FSK), 1200 baud rate phase-shift keying (PSK) and the 2400 baud rate phase –shift keying. A modem designed for say 1200-baud rate will generally support 300baud rate. A standard 300baud rate Bell (103) modem has a designated pair of audio tones representing mark and space: 1270Hz(mark) and 1070(space) in one direction and 2225Hz and 2025Hz in the other direction.

The 1200baudrate standard (Bell 212A) operates differently. The digital stream is grouped into bit pairs (dibits), each of the possible dibits as transmitted as designated phase shift of a fixed: frequency carrier (00: +90°, 01:0°, 10:180°, and 11: -90°), with smooth transitions of the transmitted dibit to the next. The dibits are transmitted at 600Hz rate .The carrier frequency is 1200Hz in one direction and 2400Hz in the other. The receiving modem decodes by looking at the difference in phase adjacent dibits.

The 2400baud rate full duplex modems also use phase-encoded dibits, though with different set of phases. These modems tend to use real–time adaptive equalizers to correct the frequency and time in delays errors of telephone line, and highly optimized filters for both transmitted and received signals. Here the error rate is not significantly degraded as compared with 300-baud modem.

3.4.1 Flow (handshaking) Control

The next step in setting up a modem is to place the proper parameters in the communications program. Each communications program is different in its detailed setup. Nearly all communications programs however do, require knowledge of the modem brand name, or at least, whether or not it is "Hayes compatible"; the modem speed, the computer serial/com port, and IRQ. In addition, high-speed modems must set the "flow controls".

Flow control or “handshaking” establishes who talks, when. Like ham radio operators who say “over” when each is through speaking to signal to the other that he is finished, flow control in modems does the same thing. This prevents the modems from both transmitting at once. The RS-232 standard supports two forms of flow control in PC serial ports. These are “software handshaking and hardware handshaking”. Software handshaking, as the name implies, involves sending a signal within the data stream to indicate when the transmission is complete, to say “over”, and hardware handshaking involves sending signals via a separate channel to indicate “over”.

Additionally, there are two areas of Local flow control specifies how handshaking is accomplished between the serial/com port and the modem. End-to-end flow control dictates the type of handshaking between the two modems. Further, end-to-end flow control is determined automatically by the error-control standards in the modem or by the file-control protocol used by the communication program being used. The communications program setup provides a choice between hardware or software handshaking. The setting should always be on hardware handshaking at higher speeds, 9600bps or higher.

3.4.2 Modulation Standards

There are many standards for modulation: The bell 103 and 21A are old standards. Bell 103 transmits at 300 bps at 1 bit per baud. Bell 212A is the next step up, capable of two bits per baud. It was capable of 1200bps at 600 baud. Each used a different type of modulation.

The V.21 Used mainly outside the U.S., it is a sort of international standard. It is not compatible with Bell protocols, and is only capable of 300 bps.

The V.22 Shares the features of V.21 but is capable of 1200 bps. V.22bis protocol came next. It is used both in the U.S. and outside, and runs at 4 bits per baud for a total of 2400 bps.

The V.23 Used mainly in Europe, this allows the modem to send and receive data at the same time, although it can only sent data at 75bps. This standard was developed to lower the cost of modems.

The V.29 This is a half-duplex standard, meaning one-way. It works at 9600 bps. The standard is not laid out well for modems; therefore, it isn't much used. The protocol is most often used for fax machines.

The V.32 This standard got users into the ballpark we are all in now. It is a full-duplex standard and operates at 9600 bps, with a 2400-baud rate. It incorporates error correcting and negotiation. The error correcting allows V.32 to work well over phone line noise.

The V.32bis is one step up from V.32. It transmits 6 bits per baud, allowing throughputs of 14,400 bps. It also allows fallback onto regular V.32 if the phone line was impaired. Many still use this modem standard primarily.

The V32 fast is better known as the 28,800 bps modem.

TheV.34 is the latest real modem standard. It provides a reliable 28,800 bps connection. With upgrades to the ROM BIOS on the modem, the standard is often used for 33,600 bps transmissions.

3.4.3 HF Communication radio modems

Have to comply with the United States Federal Standards FED – STD –1045 for automatic link establishment (ALE) radio (and its military counterpart MIL-STD-188-141A). MIL-188-141A Standard, also known as Automatic Link Establishment (ALE), specified by the US Department of Defense, is a procedure whereby radio stations are able to automatically set up their link thus eliminating

- The need for skilled operators - in fact the growing lack of trained and experienced staff was a driving force behind the idea of ALE.

A station will transmit a link quality burst, which may or may not contain the address of another station on a series of pre assigned frequencies. The listening station(s) will continuously scan through these frequencies. While scanning the receiving station will perform a link quality analysis and measure signal to noise ratio and bit error ratio. These measurements are used to set up a table in memory of link quality assessments for each station and frequency.

Based on the values of the table, the best frequency available is selected when the station wishes to transmit. When the ALE controller of a receiving station hears its own address (or the address of the group to which it belongs) it will stop the scanning and respond to the call. The stations will then either switch to a low speed data exchange mode or to a high-speed data (FSK or PSK) modem or to voice mode.

The MIL-188-141A signal is an 8-tone MFSK signal in the range 750 - 2500 Hz spaced 250 Hz apart. Each tone (symbol) is 8 ms long corresponding to 125 Baud and represents three bits giving a bit rate of 375 bps.

The MIL-188-141A bit-stream is structured in 24-bit frame, which includes three bits preamble for the frame type and three 7-bit ASCII characters or just 21 bits unformatted binary data.

To increase robustness the 24-bit frame is Golay encoded (24, 12), then interleaved giving a total frame length of 48 bits + 1 stuff bit. Each 49-bit code word is transmitted three times one after another to combat burst interference.

The MIL-188-141A mode decoder processes the signal automatically after the center frequency is set. It synchronizes the signal in both USB and LSB polarities, display readable message in ASCII, HEX or both ASCII and HEX formats.

- The Standards ensures that radio controller from different manufactures will communicate with each other.
- Telemetry modems allows data retrieval from data acquisition systems.

Chapter 4

4.0 HF Transceivers

A transceiver is a radio communication system having a dual function of a transmitter and receiver in one. As transmitter it is required to transfer information from location to another and as a receiver to receive the information.

In the telemetry radio system, the transmission system converts the message provided by the data acquisition subsystem through the Skyline modem 1045 into a modulated electromagnetic signal that is transmitted .The receiver will then convert or demodulate the signal at the far end into the original form.

4.1.0 Antennas

The antenna is an extremely vital part of the communication system. The time spent in the selection, proper installation and tuning will be well re-paid in superior communication. The function of the antenna is to provide an efficient transfer of RF energy between the totally contained and guided environment of a coaxial cable and the uncontained unguided environment of free space. The signal and noise levels, received over a given HF link are depended considerable upon antenna characteristics.

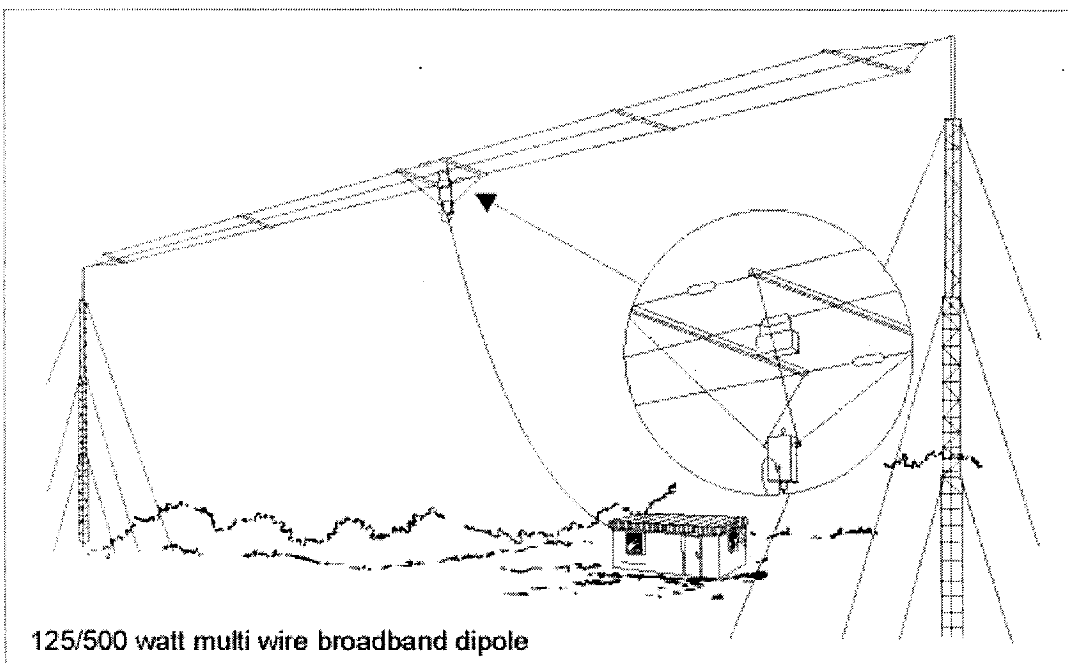

Figure 4.1 broadband antennas

4.1.1 Antenna Considerations

4.1.1.1 Matching

Propagation effects and levels of ambient noise play a crucial role in HF communications link performance. The antenna characteristic play a major role on the signal and noise levels received .The review of the role of the antenna and its impact upon link performance is necessary before the system performance is undertaken.

The high frequencies pose serious challenges to communication systems. The usefulness of the system performance estimates depends on realistic power gain and radiation patterns estimates of the antennas on the operational circuit. It is vital to pinpoint sources of antenna degradation.

The physical size of HF antenna systems is usually much smaller than their wavelength. The tend to have a low radiation resistance R, and high reactance X.The antenna tuning unit is required to tune out reactive term and to present suitable resistance to the transceiver. The antenna and the tuning units exhibit loss resistance r. The antenna losses are due to ground resistance, corona effects, imperfect dielectrics near the antenna, energy loss due to eddy currents induced into nearby metallic objects and I^2R losses in the antenna itself. This is expressed as follows:

$$p_{in} = p_d + p_r \qquad (4\text{-}1\text{-}1)$$

Where p_{in} is the power delivered to feed point.

p_d is the power lost.

p_r is the power actually radiated?

The radiation efficiency n is defined as the ratio of power radiated by the antenna to the power supplied by the transmitter. Mathematically this is expressed as

$$n = \frac{r}{(r + r_1)} \qquad (4\text{-}1\text{-}2)$$

Where, n is the radiation efficiency

r is the low radiation resistance

r_1 is an equivalent series loss resistance.

4.1.1.2 Gain and directivity

Antenna gain is the measure of how well its concentrates its radiated power in a given direction. It is the ratio of the radiated power in a given direction to the power radiated in the same direction by a standard antenna, keeping the input power constant. The power gain does not involve impedance or polarization mismatch losses. The radiation patterns are such that power flux is maximized in certain preferred directions. The power gain G is defined as follows.

$$G = \text{max power intensity} / \text{average power intensity} \qquad (4\text{-}1\text{-}3)$$

In decibels the gain of an antenna is expressed as follows:

$$A(db) = 10\log_{10}(p_1/p_0) \qquad (4\text{-}1\text{-}4)$$

Where $A(db)$ is the antenna voice in decibels.

p_0 is the power of the unidirectional antenna

p_1 is the power of reference antenna.

The effective area A_r is the ratio of power available at the antenna terminals to the power per unit area of the appropriately polarized incident wave. In a loseless effective area determines the useful power delivered to the load, hence indicates efficiency. Effective area is defined by

$$A_r = \frac{Gh^2}{4(pi)} \qquad (4\text{-}1\text{-}5)$$

Where G is the antenna gain and h is the wavelength

In HF communication it's the directivity of the antenna rather than its absolute gain that is valuable on receive. Directivity is the property that enables antenna to discriminate in favour of the signals coming from a particular direction. The directivity D and the gain G are directly related in terms of antenna efficiency n as follow

$$G = nD \qquad (4\text{-}1\text{-}6)$$

Directional antennas have a number of advantages including an improvement of signal -to – noise ratio, an increase in traffic handling capacity and a reduction of the susceptibility of the receiver to interference. Usually it is a practice to have the same antenna for both transmission and reception in a communication link.

4.1.1.3 Polarization

The maximum power transfer between two antennas occurs, when the antenna and the characteristic wave polarization matches. In the process of HF propagation the polarization keeps on varying. In sky wave propagation the plane of the polarization of the received signal is time dependent.

A horizontal polarized signal undergoes a phase reversal on reflection and requires a high antenna for efficient low angle radiation. A vertically polarized signal undergoes a phase reversal at the angle of incidence.

4.1.1.4 Transmitting Antennas

To radiate maximum power, the impedance of the transmitting antenna to the driving source must be within certain limits over the frequency range it is designed to operate. There is a normally specified nominal impedance and maximum permissible voltage standing wave ratio (VSWR). The impedance values are typically 50ohm, 75ohm, 300ohm and 600ohm, while the maximum VSWR are 1.2:1,1.5:1,2:1,2.5:and 3:1.

Figure 4.2 broadband antenna at Itezi-tezi (ZESCO Ltd)

The HF propagation is broadly classified in three classes.

1. Self-resonant antennas-this is the half-wave dipole, the total length which is nominally ½ wavelength at the carrier frequency. These operate at a specified frequency.
2. Resonated Antennas-these antennas are used over a range of frequencies by employing a matching unit which transforms the widely varying antenna impedance to some specified value. An end –fed whip antenna is a good example.
3. Broadband Antenna-These antennas are designed to present impedance that remains within an acceptable range over a wide band of frequencies. Some types, such as the fan dipole, are basically self-resonant antennas with a very broad bandwidth capability.

The broadband antennas at HF frequencies are large devices, their size being proportional to the longest operating wavelength; size also tends to increase as the required operating bandwidth is increased. Then it is acceptable to connect a broadband antenna directly to a transmitter even if the VSWR of the former remains within the limits acceptable to latter. Tuning is necessary, to reduce harmonic radiation.

4.2.0 Frequency propagation and Selection

Propagation in the HF band is mainly dependent upon the reflection of radio waves from ionized layers in the earth's atmosphere. This is typically true for rangers greater than 50 Km.The are three (3) mode of propagation, namely Sky wave, ground wave and space wave propagation.

The correct choice of frequency is vital to the establishment of successful communication link with a distant station and certain factors to be taken into account include time of day, season of the year, short solar flare activity and the long-term sun sport cycle.

4.2.1 Variations due to the solar cycle

The Sun goes through a periodic rise and fall in activity, which affects HF communications; solar cycles vary in length from 9 to 14 years. At solar minimum, only the lower frequencies of the HF band will be supported by the ionosphere, while at solar maximum the higher frequencies will successfully propagate see, figure 1.4. This is because there is more radiation being emitted from the Sun at solar maximum, producing more electrons in the ionosphere, which allows the use of higher frequencies.

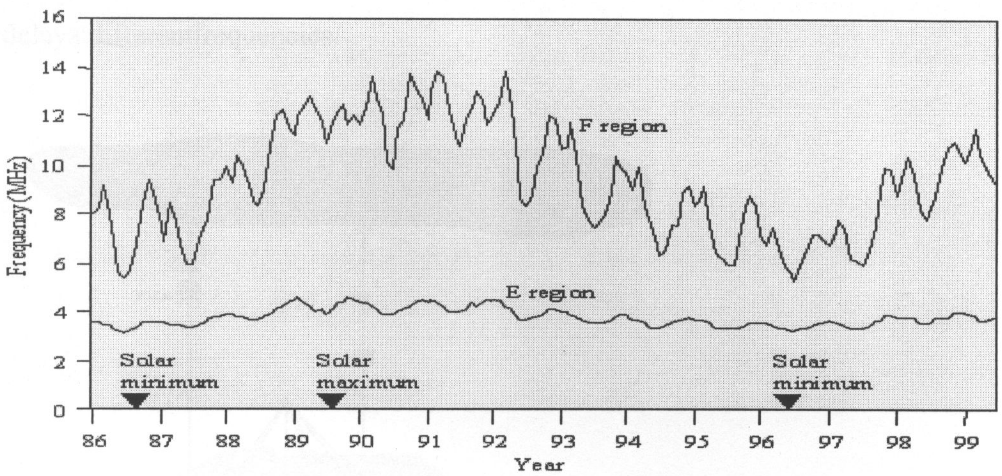

Figure 4.3 Solar cycle and seasonal dependence of E and F region frequencies for a near vertical incidence sky wave (NVIS) circuit in the southern hemisphere. (IPS Radio & Space Services)

There are other consequences of the solar cycle. Around solar maximum there is a greater likelihood of large solar flares occurring. Flares are huge explosions on the Sun, which emit radiation that ionizes the D region causing increased absorption of HF waves. Since the D region is present only during the day, only those communication paths, which pass through daylight, will be affected. The absorption of HF waves traveling via the ionosphere after a flare has occurred is called a short wave fade-out. Fade-outs occur instantaneously and affect lower frequencies the most. Lower frequencies are also the last to recover. If it is suspected or confirmed that a fade-out has occurred, it may help to try using a higher frequency. However, if a flare is very large, the whole of the HF spectrum may be rendered unusable. The duration of fade-outs can vary between about 10 minutes to over an hour depending on the intensity and duration of the flare.

4.2.2 Frequency Assignments procedures

Feasibility studies are carried out to determine suitable frequencies for radio stations. Propagation tests at various sites are carried out. An ionosonde, which is high frequency radar, is used. Ionosonde sends very short pulses of radio energy vertically into the ionosphere. If the radio frequency is not too high, the pulses are refracted back towards the ground. The ionosonde records the time delay between transmission and reception of the pulses. By varying the oscillation frequency of the pulses, a record is obtained of the timedelayatdifferentfrequencies.

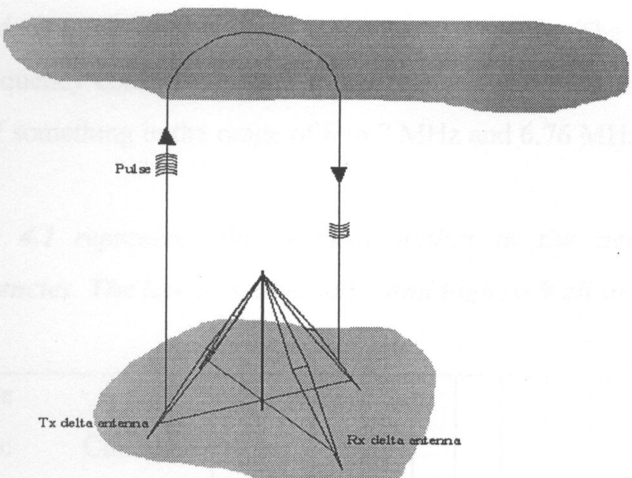

Figure 4.4 Ionosonde operations. (IPS Radio & Space Services)

Amplitude modulated (AM) broadcast stations interfere with frequencies less than about 1.6 MHz As the frequency is increased, echoes appear first from the lower E region and subsequently, with greater time delay, from the F1 and F2 regions. Of course, at night echoes are returned only from the F2 region and possibly sporadic E since the other regions have lost most of their free electron. As for the ZESCO network during the initial project, temporal aerials would be mounted and tests carried at different times of the day. Tests were carried out in the morning about 6.00hrs to about 8.00hrs, in the afternoon about 12.00hrs to 14.00hrs and in the evening from about 17.00hrs to 19.00hrs.

A number of remote sites and all the three master sites were considered critical in terms of HF telemetry data due to their topological and geographical locations. Taken into consideration were the gauging sites already in existence though in some cases were abandoned. A number of considerations were put forward in locating suitable sites such as noise interference, transmission lines and difficult terrain. As an example, three different frequencies were considered. These were 3.2 MHz, 5.1 MHz, and 9.1 MHz. carrying out tests at each site three times. That is in the morning, afternoon and evening and evaluates which one is suitable. Then taking into consideration the various models developed for the ionosphere behaviour, the variables obtained would be put into the equation and then work out the maximum usable frequency at that particular time of the day and of the year as the behaviour also changes with the season. In the implementation stage 9.1 MHz was not picked, as it was only relevant to the furthest station. The other reason was that the regulators of frequency could not permit to operate this particular frequency but instead suggested the use of something in the range of 6 to 7 MHz and 6.76 MHz was settled for.

Table 4.1 represents the furthest station in the network and the figures represent frequencies. The lowest 3, medium 5 and highest 9 all in MHz (ZESCO ltd)

Remote Station:	Chavuma																					
UT (GMT)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	2
Master																						
LUSAKA																						
January 1F	35	3	3	3	3	5				9	9	9	9	9	9	9	5	35	35	35	35	3
January 1E						5	5	5	5	59	59	59	59	59	5	5	35					
July 1F						5	5	9	9	9						5	35	35	35	35	35	3
July 1E						3	5	5	5	5	59	5	5	5	5	5						
KARIBA																						
January 1F	35	3	3	3	3					9	9	9	9	9	9	9	59	35	35	35	35	3
January 1E					3	5	5	59	9	9	9	9	9	9	5	5						
July 1F						5	9	9	9	9	9	9	9	9	9	59	35	35	35	35	35	3
July 1E						3	5	5	59	59	59	59	59	59	5	5						

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Master																						
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January 1F	35	3	3	3	3	5				9	9	9	9	9	9	9	5	35	35	35	35	3
January 1E						5	5	5	5	59	59	59	59	59	5	5	35					
July 1F						5	5	9	9	9						5	35	35	35	35	35	3
July 1E						3	5	5	5	5	59	5	5	5	5	5						
KARIBA																						
January 1F	35	3	3	3	3					9	9	9	9	9	9	9	59	35	35	35	35	3
January 1E					3	5	5	59	9	9	9	9	9	9	5	5						
July 1F						5	9	9	9	9	9	9	9	9	9	59	35	35	35	35	35	3
July 1E						3	5	5	59	59	59	59	59	59	5	5						

CAHORA B																					
January 1F	35	35	3	3	5		9								9	9	9	359	359	359	359
January 1E					5	9	9	9	9	9	9	9	9	9	9	9	5				
July 1F	3				3	9	9	9	9					9	9	9	359	359	35	35	35
July 1E						5	9	9	9	9	9	9	9	9	9	5					
Lusaka Time	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

5.0 Radio Propagation-Introduction to HF Communication systems

5.1 The Electromagnetic Waves

The electromagnetic waves are used to propagate radio signals. The principles of electromagnetic plane waves are based on the relationship between electricity and magnetism. A change in magnetic field induces an electric field and vice versa. The sinusoidal form of the waves causes energy to be interchanged between magnetic and electric fields in the direction of propagation.

The rate at which electromagnetic energy is transmitted through free space, stored in the magnetic and electric fields and is dissipated as heat is answered when we look at the **poynting** theorem .The complex power view, in terms of the complex power field vectors, the time average of any two (2) vectors is equal to the real part of the product of one complex vector multiplied by the complex conjugate of the other vector. The time average of instantaneous poynting vector in steady state is given by

$$\langle P\rangle = \langle E \times H\rangle = \tfrac{1}{2}\mathrm{Re}\left(E \times H^{*}\right) \qquad (5\text{-}1\text{-}1)$$

Stands for average time and factor of ½ appears in the complex power equation, when peak values for the complex quantities E and H.

A poynting vector can be defined as.

$$P = \frac{1}{4}\left(E \times H^{*}\right) \qquad (5\text{-}1\text{-}2)$$

Maxwell's equations in frequency domain for electric and magnetic fields are.

$$\nabla \times E = -jw\mu H \tag{5-1-3}$$

$$\nabla \times H = -jw\varepsilon \mathrm{E} \tag{5-1-4}$$

Dot multiplication of equation 3 by H* and of the conjugate of equation 4 by E yields.

$$(\nabla \times E)H^* = -jw.\mu H.H^* \tag{5-1-5}$$

$$(\nabla \times H^*)E = (J^* - jw\mu E^*)E \tag{5-1-6}$$

Then subtracting equation 5 from equation 6 results in

$$E.(\nabla \times H^*) - H^*.(\nabla \times E) = E.J^* - jw(\varepsilon|E|^2 - \mu|H|^2) \tag{5-1-7}$$

Where E.E* is replaced by $|E|^2$ and H.H* by $|H|^2$

The left hand side of equation 7 is equal to $-\nabla.(E \times H^*)$ by the vector identity. Hence

$$\nabla.(E \times H^*) = -E.J^* + jw(\varepsilon|E|^2 - \mu|H|^2) \tag{5-1-8}$$

Substituting equation 5 and 6 into 8 yields

$$\frac{1}{2}E.J_0^* = \frac{1}{2}\sigma E.E^* + jw\left(\frac{1}{2}\mu H.H^* - \frac{1}{2}\varepsilon E.E^*\right) + \nabla.P \tag{5-1-9}$$

Integration of the equation 9 over a volume and application of Gauss's theorem to the last term on the last term on the right –hand side give

$$\int_v \frac{1}{2}(E.J^*)dv = \int_v \frac{1}{2}\sigma|E|^2 dv + jw\int_v (W_m - W_e)dv + \oint_S P.ds \tag{5-1-10}$$

Where

E = electric field intensity in volts per meter,

H =magnetic field intensity in amperes per meter,

D = electric flux density in coulombs per square meter,

B = magnetic flux density in Weber's per square meter,

J= electric current density in amperes per square meter,

ϵ = dielectric permittivity,

μ = magnetic permeability,

σ = the conductivity of the medium in mhos per meter

$\frac{1}{2}\sigma|E|^2 = \sigma\langle|E|^2\rangle$ Is the time average dissipated power

$\frac{1}{4}\mu H.H^* = \frac{1}{2}\langle |H|^2 \rangle = W_m$ Is the time –average magnetic stored energy

$\frac{1}{4}\varepsilon E.E^* = \frac{1}{2}\varepsilon\langle |E|^2 \rangle = W_e$ Is the time – average electric stored energy

$-\frac{1}{2}E.J_0^* =$ The complex power impressed by the source J into the field.

Equation 10 is known as the poyntig theorem in frequency domain. Simplifying the equation.

$$P_{in} = -\int_v \frac{1}{2}\left(E.J_0^*\right)dv$$

$$\langle P_d \rangle = \int_v \frac{1}{2}\sigma |E|^2 dv$$

$\langle w_m - W_e \rangle = \int_v (W_m - W_e)dv$ The difference between time average magnetic and electric energies stored within the region.

$$P_{tr} = \oint P.ds$$

The simplified equation is as follows

$$P_{in} = \langle P_d \rangle + j2w[\langle W_m - W_e \rangle] + P_{tr} \qquad (11)$$

The theorem is stated as follows, the complex power fed into a volume is equal to the algebraic sum of the active power dissipated as heat, plus the reactive power proportional to the difference between time- average magnetic and electric energies stored in the volume, and plus the complex power transmitted across the surface enclosed by the volume

5.2.0 The ionosphere

5.2.1 The regions of the ionosphere

In a region extending from a height of about 50 km to over 500 km, some of the molecules of the atmosphere are ionised by radiation from the Sun to produce an ionised gas. This region is called the ionosphere, figure 5.1.

Ionisation is the process in which electrons, which are negatively charged, are removed from (or attached to) neutral atoms or molecules to form positively (or negatively) charged ions and free electrons. It is the ions that give their name to the ionosphere, but it is the much lighter and more freely moving electrons that are important in terms of high frequency (HF: 3

to 30 MHz) radio propagation. The greater the number of electrons, the higher the frequencies that can be used.

During the day there may be four regions present called the D, E, F1 and F2 regions. Their approximate height ranges are:

- D region 50 to 90 km;
- E region 90 to 140 km;
- F1 region 140 to 210 km;
- F2 region over 210 km.

During the daytime, sporadic E is sometimes observed in the E region, and at certain times during the solar cycle the F1 region may not be distinct from the F2 region but merge to form an F region. At night the D, E and F1 regions become very much depleted of free electrons, leaving only the F2 region available for communications; however it is not uncommon for sporadic E to occur at night.

Only the E, F1, sporadic E when present, and F2 regions refract HF waves. The D region is important though, because while it does not refract HF radio waves, it does absorb or attenuate them.

The F2 region is the most important region for high frequency radio propagation as:

- It is present 24 hours of the day;
- Its high altitude allows the longest communication paths;
- It usually refracts the highest frequencies in the HF range.

The lifetime of electrons is greatest in the F2 region that is one reason why it is present at night. Typical lifetimes of electrons in the E, F1 and F2 regions are 20 seconds, 1 minute and 20 minutes, respectively.

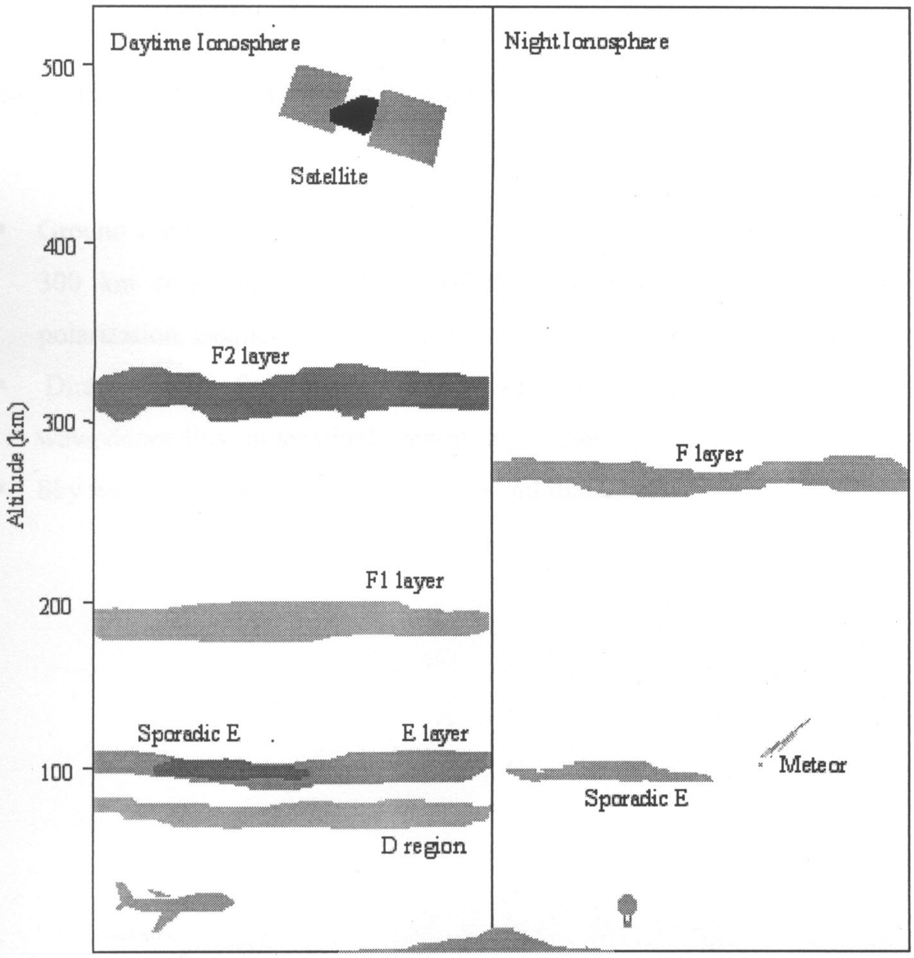

Figure 5.1 Day and night structure of the ionosphere. (IPS Radio & Space Services)

5.2.2 Production and loss of electrons in the ionosphere

Radiation from the Sun causes ionization in the ionosphere. Electrons are produced when this radiation collides with uncharged atoms and molecules. Since this process requires solar radiation, production of electrons only occurs in the daylight hemisphere of the ionosphere.

5.3 High frequency communications

5.3.1 Types of HF propagation

High Frequency (3 to 30 MHz) radio signals can propagate to a distant receiver, figure 2.1, via the:

- Ground wave: near the ground for short distances, about 100 km over land and 300 km over sea. The range of the wave depends on antenna height, polarization, frequency, ground types, vegetation, terrain and/or sea state;
- Direct or line-of-sight wave: this wave may interact with the earth-reflected wave depending on terminal separation, frequency and polarization;
- Sky wave: refracted by the ionosphere, all distances.

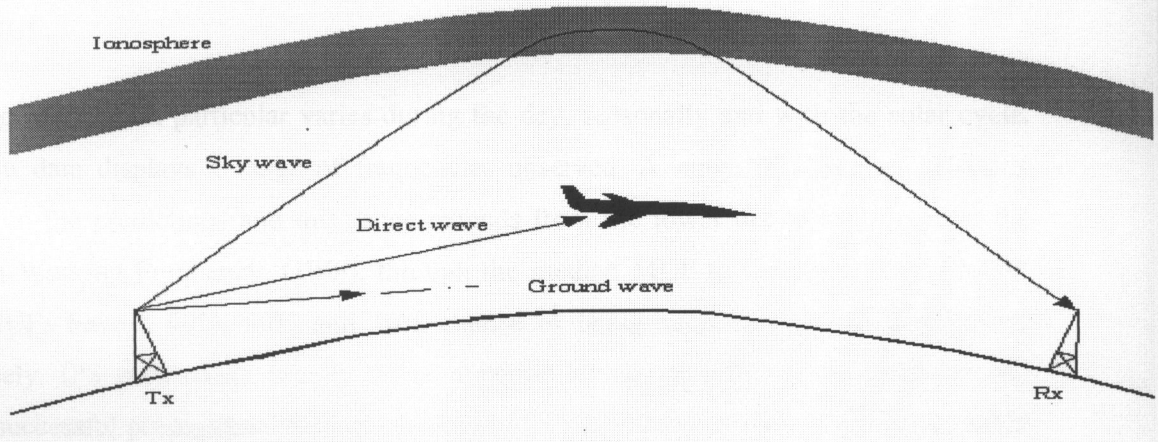

Figure 5.2 Types of HF propagation. (IPS Radio & Space Services)

5.3.2 Frequency limits of sky waves

The ionosphere refracts not all HF waves; there are upper and lower frequency bounds for communications between two terminals. If the frequency is too high, the wave will penetrate the ionosphere, if it is too low, the strength of the signal will be lowered due to absorption in the D region. The range of usable frequencies will vary

- Throughout the day;
- With the seasons;
- With the solar cycle;
- From place to place;
- Depending on the ionospheric region used for communications.

While the upper limit of frequencies varies mostly with these factors, the lower limit is also dependent on receiver site noise, antenna efficiency, transmitter power, E layer screening and absorption by the ionosphere.

5.3.3 The usable frequency range

For any circuit there is a Maximum Usable Frequency (MUF) that is determined by the state of the ionosphere in the vicinity of the refraction area(s) and the length of the circuit. The MUF is refracted from the area of maximum electron density of a region. Therefore, frequencies higher than the MUF for a particular region will penetrate that region. During the day it is possible to communicate via both the E and F layers using different frequencies. The highest frequency supported by the E layer is the EMUF, while that supported by the F layer is the FMUF.

The F region MUF in particular varies during the day, seasonally and with the solar cycle. Long-term data displays a range of frequencies observed. A range of F region MUFs is provided in the predictions and this range extends from the lower decile MUF (called the Optimum Working Frequency, OWF), through the median MUF to the upper decile MUF. These MUFs have a 90%, 50% and 10% chance of being supported by the ionosphere, respectively. IPS predictions usually cover a period of one month, so the OWF should provide successful propagation 90% of the time or 27 days of the month. The median MUF should provide communications 50% or 15 days of the month and the upper decile MUF 10% or 3 days of the month. The upper decile MUF is the highest frequency of the range of MUFs and is most likely to penetrate the ionosphere.

The chances of successful propagation discussed above rely on the monthly prediction of solar activity being correct. Sometimes unforeseen events occur on the Sun resulting in the monthly predictions being inaccurate.

The D region does not allow all frequencies to be used since the lower the frequency the more likely it is to be absorbed. The Absorption Limiting Frequency (ALF) is provided as a guide to the lower limit of the usable frequency band. The ALF is significant only for circuits with refraction points in the sunlit hemisphere. At night, the ALF is zero, allowing frequencies that are not usable during the day to successfully propagate.

5.3.4 Hop length

The hop length is the ground distance covered by a radio signal after it has been refracted once from the ionosphere and returned to Earth. The upper limit of the hop length is set by the height of the ionosphere and the curvature of the Earth. For E and F region heights of 100 km and 300 km, the maximum hop lengths with an elevation angle of 4 degrees, are 1800 km and 3200 km, respectively.

5.3.5 Propagation modes

There are many paths or modes by which a sky wave may travel from a transmitter to a receiver. The mode by a particular layer that requires the least number of hops between the transmitter and receiver is called the first order mode. The mode that requires one extra hop is called the second order mode.

5.4.0 Noise and Interference

5.4.1 Noise

Noise is the limiting factor whether a communication system signal is usable for the transmission. Hence it is vital to have knowledge of ambient noise in order to know the power that is necessary to overcome noise problems.

Electromagnetic radiation from the Solar and cosmic sources limit the information that can be carried in the HF spectrum here on earth. This is further bound by the noise, within the troposphere, the terrestrial environment and, manufacturing made radio frequency noise.

The amplitude of man made noise decreases with increasing frequency and varies considerably depending on location. Noise arises from electric motors, neon signs, power lines and ignition systems and propagation is usually via power lines and by ground waves.

Galactic noise originates outside the earth and its atmosphere. Receive antennas with high angle lobes are more prone to this type of noise.

5.4.2 Interference

Serious communication problems are frequently present as a result of the occupation of the band by multiple users; the problem is acute in the lower band at night when it is severely congested. This problem is caused by the number of transmitters over a wide area and reaches the receiver via sky propagation. The need of the accurate knowledge of how frequency varies with frequency, time, bandwidth, threshold level and geographical area is vital to help in the short –term channel selection process and long–term assignments.

Chapter 6

6.0 Software

6.1 General aspects of software

In data acquisition the other important thing is the software associated with the system and is generally divided into two: the system software and the user interface program.Both must be designed properly in order to achieve the maximum use of the system. The system software is mainly written in assembly language with many lines of code, where as the user interface is built using high level software development tool.

As for system software one part is used for handling the input-output (I/O) operations.
The use of the assembly language results in fast executions of I/O commands. This software has to deal with how the basic input-output programming tasks such as interrupt and DMA handling are done. The other aspect of the system software are to perform the internal control tasks such as the providing trigger pulses for analogy to digital converter (ADC) and sample and hold amplifier (SHA), addressing the input multplexer, the accessing and editing of the channel-gain list, transferring data into the on-board memory and the addition of the clock/calendar information into data. Multitasking software programs are best suited for many data acquisition systems because it may be necessary to read data from the data acquisition module and display and print it at the same time. Menu driven user interfaces are common and a have a variety of functions built into them.

6.1.1 Specific aspects of software in the project

The software used in the project is divided into two basic program types:

- Application software that is specifically developed by the equipment suppliers to communicate with the data acquisition equipment in various modes of operation; and
- Commercially available packages such as ProComm to handle modem file transfer and any spreadsheet analysis software.
- Other application software like LINUX apart from MS WINDOWS

6.2 The RF Server Softwar

The software runs on every master station computer and is responsible of managing the informationexchange between remote stations and master stations. It runs as a daemon on a LINUX system and takes control of a selectable serial device on which a radio modem is hooked. The software acts as an information dispatcher between the master computer and the remote stations. It also configures and controls the radio modem. Any other program may communicate with RFServer using text files. Once a new activity file is made available, the software verifies the content and executes the commands. The available commands and characteristics are:

- Immediate poll – a request is sent to a remote station to read the different *environmental sensors and to transfer the results back to the master. The rain counter,* water level and gate position is then stored into one file called <station>. rt. The 'rt' extension stands for real time. This feature will only be available during open HF windows.

  Data download – this command is used to download saved records from a remote telemetry station to the master stations. Since the telemetry station can store large amounts of acquisitions, it is imperative that the command includes a parameter that specifies a period. For instance, if the last successful data transfer were yesterday, there would be no reason to get information older than yesterday.

- Read configuration – this command invites a selected remote unit to transmit its configuration file. The file includes the operating parameter file, the log activity file and water level sensor files. The result is stored in a file called <station>. cfg. The 'cfg' extension stands for configuration file.
- Upload a new configuration – new operating parameters can be uploaded into any remote station through the radio link. For example, someone, with the proper authorisation, could decide to increase the rhythm of the water level acquisitions. The new configuration file is called new <station>. cfg.
- Clock synchronisation – the software is also responsible for keeping the remote stations' clocks synchronised. It is assumed that every station will be called at least once a day therefore keeping the clocks synchronised on a daily basis. System requirements – 486 and above computer with 8 megabyte of RAM, a 500 megabyte hard drive, a CD-ROM and an Ethernet adapter

- Network definition – the software uses a text file (network. Cfg), containing the address of every remote station, to determine the message envelop for data exchange.
- Data validation – any message transmitted or received is encapsulated into a frame. The frame includes a destination address, a command and a CRC16 for data validation. A failing CRC16 results in the rejection of the message. Data transfer at the radio level is also achieved with a packet scheme protocol guarantying that only validated packets are considered, therefore adding a second level of verification.
- Communication errors – a text file containing communication errors is generated in any occurrence of communication error. Every record includes a timestamp, a station number and the command that was issued. This information is for trouble shooting and issuing maintenance reports.
- User interface – the software has no user interface for the moment. A daemon process is run continuously to supervise data transmission and reception between remote stations and master stations. At the master station, the operator will be able to initiate a call to one or all remotes, to transfer an immediate reading of the sensors and the general system status. If, for some reason, a station does not respond to the call, an error message will be logged into a file to inform the operator.

6.3 The Telemetry Network Manager

- The Telemetry Network Manager (TNM) is an application used primarily to access the data stored in remote Data Logger units. Its simple user interface allows the user to exchange data from the available units through a transmission control protocol/internet protocol (TCP/IP) network connection and a data link. The TNM is very versatile and is capable of:
- Programming remote DATA LOGGER units
- Downloading the available databases
- Uploading sensor files
- Interfacing with the RFServer communication package
- The user interface was designed to prevent the end user from having to deal with complex network and radio communication protocols. Once the acquisition unit is set, basic operations are only a few mouse clicks away.

Chapter 7

7.0 Discussion and Conclusion

7.1 Introduction

The original objectives of the Hydroelectric Hydrological Telemetry project was to improve the availability, quality, accessibility and utilization of the hydro metrological data required for Hydroelectric development and operational purposes within the SADCC region. To achieve this an integrated data communication network specifically for this was designed to provide the acquisition and transmission of rainfall and water levers in designated catchment areas namely the upper and lower Zambezi and Kafue catchments areas. In the discussion we look at the performance of current (existing) system, the proposed innovation and improvements implementation strategy, key projects benefits, sustainability and costs.

7.2 Current (existing) System

7.2.1 Introduction

The telemetry network uses the HF radios to transmit the data from the remote stations to the Master station in Lusaka. The communication components supplied under the project were:

- HF radio (Model SCL 150 made by Spilsbury of Canada),
- HF controller (modem of model Skyline 1045 made by RACAL of Canada)

The radios have been failing at the fast rate and the modems (Skyline 1045 units) have had problems even during the initial implementation stages. The other problem is that the original supplier Spilsbury of radios and modems had financial difficulties and was bought by Racal of Canada, which was later bought by Thales-Racal of UK.Then Thales-Racal, has stopped the manufacture of both radios and modems.

7.2.2 Specifications

The main specification for the radios and modems were as follows

- To operate in the HF frequency range 2 to 30 MHz
- To comply with the United States Federal standard FED-STD-1045 for Automatic link establishment (ALE) radio controllers. See details in literature view on ALE(page 22)

7.2.3 Other Challenges

Taking the example of Chifumpa remote station, the original radios have been replaced by Yaesu FT 80, which was operational as early as this year. The computers supplied under the project could be described modest in terms of the technological trends today. At the time of starting the study, most of the stations were in operation.

As a case study carried on the Kasaka (Kafue) and Nana' farms (Livingstone) remote stations as of February 2002 both were dumping or transmitting the data, but the Nana's farm the data was invalid. The comparison charts for the month were made that is using the equipment and manual readings. For Kasaka the comparison chart did not have any problem as illustrated in the attached graph and table. The observation were that excerpt for some 18.00hrs readings on the following days 6th, 7th, 8th, 11th, 15th, 16th, and 20th.the gate plate readings and the telemetry readings difference was about 2cm(0.02m). The assumption is that the manual reading was taken at the wrong time or not at all.
The other observation has been that with the ageing of the instruments other problems like poor reception of signals creep in.

7.3.0 Proposed System innovation

Looking at the current infrastructure, things like the broadband antennas, the rain gauge, the water bubbler and the TMS 1000 data acquisition equipment must be maintained

The **broadband antenna** will just require the normal planned maintenance and adjustments as and when the reception and transmission become poor. The main advantage is the benefit of 'instant tuning' on the unlimited number of channels, without the complexity of mechanical antenna tuners. The physical antenna structures are still solid and will stand for many more years. The other advantage is the ability to level out the standing wave ratio (SWR) peaks to a usually low value. The disadvantage is that it has higher losses as compared to the full-length resonant dipole antenna.

The **rain gauge** units as seen in figure are still robust mechanical instruments. The need to checking of level fluid balance to ensure the continued smooth operation. The observation has being that once in while due to high temperature the container of the level fluid cracks. The pilot cables from the rain gauge to the data acquisition units will need replacements in certain places if not all due to scotching of the sun that results in pilling of the insulator.

The **water bubbler unit** is an air bubbler generator. The bubbles are forced through small diameter tubing to an orifice located at the riverbed. The static pressure required to force the bubblers through tubing is proportional to the hydrostatic head of water above the orifice. This static pressure is sensed by the pressure transducers in the bubbler unit and converted by the TMS-1000 data acquisition unit. Its accuracy is within 0.1% of the full-scale output.

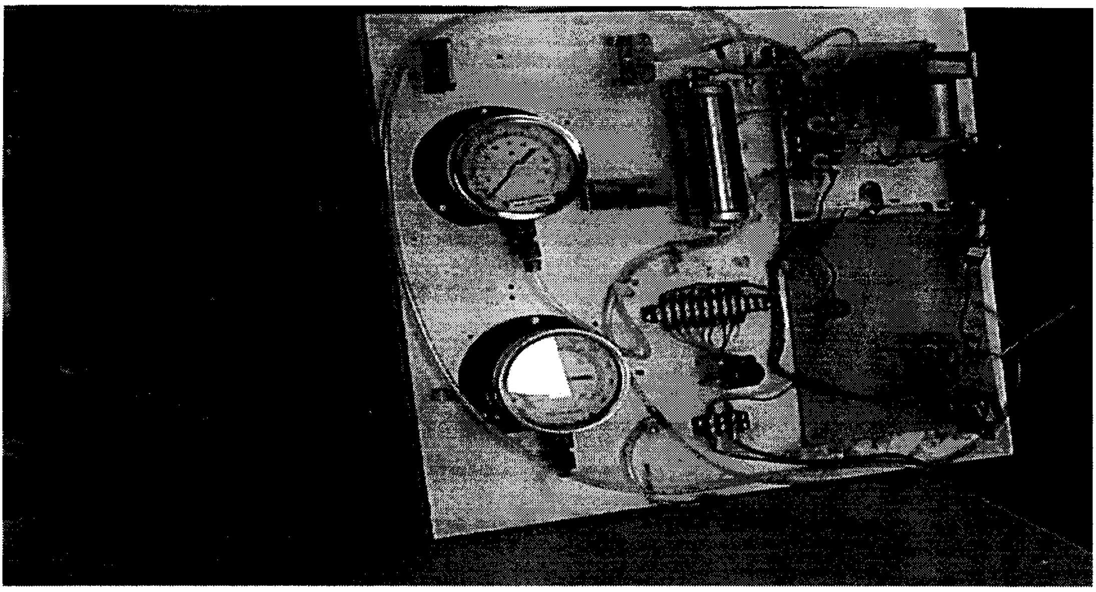

Figure 7.1 Water bubbler unit mounted on the board for testing and learning purposes (ZESCO ltd)

The **TMS-1000 unit** is an electronic data acquisition unit designed to measure environmental and meteorological parameters .The TMS-1000 is used to collect data from various hydrological or meteorological sensors, and log the data into memories, transforming the raw data into information.

It has flexibility to read many kinds of analogy and digital signals. Then all electronic plugs in cards are ensembled on a shock mount card to sustain shock and vibrations. Operates on the temperature range of –10 to 60 degrees. It has a rugged watertight thermoplastic enclosure hence it is able to withstand harsh industrial conditions. Its

7.3.1 What must be included to the existing system.

The additional sensors to be included should be for Temperature, wind speed and humidity measurements. Handar Inc supplies examples of such sensors.

The **temperature sensor** this is the resistance measurement type .the principle of measurement is that a sensor with a variable –resistance measuring element, such as the thermistor, can be read by the data acquisition system using a resistance bridge. The output voltage ranges from 0 to 1.0V being linear with the temperature changes. It is a single ended voltage sensor with the twelve volts needed to power the sensor.

Temperature is an indicator of hotness or coldness on a particular day. During hot days water bodies and landmasses tend to lose more water, due to increased ultra radiation. Thus temperature has a direct effect to the rate at which water is lost from the soil, plants and water reservoirs through eva-transpiration.

The **relative humidity sensor** this is the single–ended voltage measurement .The principle of measurement is that the connected sensor generates an analogy voltage output within any of the specified ranges as given in the manufacture's table. The sensor provides a voltage output from 0.0 to 1.0V proportional to the relative humidity. The twelve-volt power is needed to run the sensor.

Humidity is the measure of the amount of water vapour in the atmosphere. Hence wet days with high water vapour in the atmosphere, plants tend to lose less water to the atmosphere .the potential eva-transpiration is slowed down leading to the increase in time before the plant could require a moisture replenishment for its normal growth.

The **wind speed sensor** the principle of measurement is that the data acquisition system provides one frequency input, which can either determine the frequency or count the pulses up to the present total. The intended use of the input is for a wind speed sensor that generates an AC or chopped pulse train. That is feed into the DAS.

Wind speed in conjunction with increase in temperature accelerates the speed at which water droplets form of vapour are swept away from the surface of the soil, plant or water bodies.

Hence increased wind speed operating with low humidity, high temperatures and long sunshine hours leads to rapid water loss from water bodies from water bodies.

The proposal also look at adding value to the system by looking at information technology related application in line with third (3) generation radios and modems.

- Telephone and Fax usage.
- E-mail and Internet application.

These facilities would help greatly for the people based in some of stations like Itezi tezi *where at moment telephone communication is a problem. At the same time it would enhance* the operations of ZESCO Ltd, as employees shall communicate and acquire information easily.

The Automatic link establishment radios and modem using the 1045 FED-STD have the facilities which enables the usage of HF propagation communication as another channel of transmitting data, voice and have low speed e-mail and internet services.

7.4.0 The implementation strategy

7.4.1 Radios and modems

The implementation should involve the acquisition of new radios and modems to replace the existing ones and enjoy the benefits of the new technology. There are local agents within the country for the following manufactures

- Motorola supplied by Hazida communications, C.C.Systems, Northcom, Mobite
- Kenwood supplied by Hazida communications, C.C.System, Mobitel
- Codan supplied by Itercel ltd, Aeradio Ltd
- Barrents supplied by Aeradio

In appendix B are some of the manufactures with the prices of radios and modems.

7.5 Sustainability

Management of the telemetry network resides with ZESCO LTD in Lusaka. One key area is the operation, maintenance and the repair of all the telemetry equipment. The continued, effective functioning of the telemetry network and its equipment is maintained through the application of standard operating procedures, a planned program for the periodic inspection, testing, and preventive maintenance.

7.6 Costing

With the automated system in place, it cut down many operational expenses. In the past data used to be collected at the end of the month from the observer living at the site. If a problem arose at the station or there was a flood coming, it was very difficult to know due to our poor telecommunication infrastructure. What it meant is that someone had to get it the car drive to site and get a reading. However, with the automated system, operational personnel are able to get these readings on a daily basis and as such, it is easy to plan. The equipment is more accurate than a human observer. At certain times, they could just extrapolate the readings because no one is there to supervise them.

Before traveling, you have to work out the cost of the trip. This includes transport, fuel, food, incidentals and accommodation arrangements. Fuel costs at K4000.00 per litre. If you to travel to the furthest destination which is about 1,300 km one way plus field allowances for three members of staff on the trip at about K150000.00 per night for a minimum of three nights per visit. An example of fuel cost analysis in a month would look like this:

Vehicle: Nissan Patrol

Mileage: 193738 to 197755

Total Km: 4017

Liters Used: 607.17

Km/Lt: 6.62

Other expenses would include the servicing and maintenance of the vehicles

7.7 Key current benefits

Automated telemetry provides the water-data analysts with provisional stage and discharge information in a timeframe that meets water-management needs. This technology permits field offices to monitor the operation of the hydrological stations continuously. Time visits to stations to coincide with times of maximum needs for data (such as during floods), and to service equipment at the stations.

The data collected are archived at the hydrology data base office. This is a computerised database known by the acronym HYDATA. The HYDATA system contains the data and a number of programs that can be used to analyse and produce statistical summaries of the data contained therein. The data provides hydrological information needed to help define, use, and manage the nations water resources. The data from individual stations are commonly used for the purposes beyond the original purpose for an individual station. The possible uses *include the following:*

- Scheduling power production
- Enhancing the public safety by providing data for forecasting and managing floods
- Operating and designing multipurpose reservoirs
- Allocating water for municipal, industrial, and irrigation uses
- Administering agreements or resolving conflicts on interstate rivers.
- Defining and apportioning the water resources at our international borders

Undertaking scientific studies of long-term changes in the hydrological cycle The collectio of data to meet future needs often represents a great challenge than does collection of data fc current needs because the future needs are seldom known precisely and, in fact, may b impossible to anticipate. Some applications of data require long-term records to achieve specified accuracy. The more records you have the better it is to predict because you wi have solid reference points.

The adoption of the Codan radios whose prices is not very high and has technology feature for telephone/fax and email/Internet and all ALE features in operation will ensure th manned station like Itezi-tezi with poor telecommunication networks will have such service Note: most of the UN agencies use the Codan radio and have connected them to som gateways for e-mail and access to the Internet

Finally at the end the project has made it possible to acquire the knowledge and technic insight on the design and operation of HF telemetry systems.

7.8 Conclusion

The performance of the Telemetry network could be described as fair. The objectives c improving the availability, quality and accessibility and utilization of hydrological are bee partly attained.

The Hydrology department as the custodian of data collected, process the raw data and come up with the information which is used for decision making and future prediction c forecasting. The collection of data to meet future needs often represents a great challeng than does collection of data for current needs because the future needs are seldom know precisely and, in fact, may be impossible to anticipate.

The are certain technicalities which have made it difficult to attain full availability and real-time application. These include

- *The data acquisition systems had propriety software and the hardware was not of the* standard type. The server side software (at the master station) was also written specifically for the HF controllers.
- The HF controllers (data modems) had originally design fault making them prone to lightening even when grounded.
- When the controller started failing it was not possible to get the replacement as both the manufacture of the HF controllers data acquisition equipment went bankrupt and the firms that took over stopped the manufacture of the equipment.

The above problems resulted from the initial conditions which specified that, the Canadian contractor specify the equipment and all the equipment be bought from
Canadian companies

This raises the question of sustainability, which as outlined seems to be a problem due to the nature of some of the equipment, which was specifically tailor-made, and the manufactures have winded up. This is one of the reasons attributed to the call to change the radios and modems.

The quality of data collected is high when the remote station is operational. The innovation and improvement to be done should consider standardizing of equipment.

The utilization of the gained information using the Telemetry leads to predictive maintenance and prevention. Learning from the past experience of reactive maintenance, we can tell that it erodes into the bottom line of our business - prolonged plant down time, customer dissatisfaction and hindered development in the country.

Automation enables any producer to monitor assets and be able to plan and carry out predictive maintenance, gradual upgrading and therefore maintain efficient performance of the system. And Telemetry is automation, when put to good use any organization should be able to take good care of water reservoirs and environment

The main benefits included reduction in time and error judgment for data collection due to scheduled and upon request collection. Low operational cost attributed to automation and enhanced scheduling of power production and public safety by providing data for forecasting and managing floods. The social consideration is to enhance communication

8.0 REFERENCES

1. A.B.Carlson. Communication systems, (McGraw hill ed.) New York, 1986
2. K Sam Shanmugam, Digital and Analogy communication systems (John Wiley& Sons, ed.) pg (9-11) Singapore 1985
3. S.Katz, Armature radio systems, pg (10-12), May 1993.
4. CanacTelecom, Vol 3 Remote Data acquisition pg (A1-1 to A1-2, A3-1to 9,26-28,A6-1 to 12)
5. Canac Telecom, Vol.4 HF radio systems, pg (2-3 to 6-15), 1993.
6. IPS Radio & Space services. file://Introduction to HF RadioPropagation.htm, pg (2-3,4-6,11-13), 2000.
7. The Electrical Engineering handbook /editor-in-chief, R.C.Dorf, 1993 {Conrad H.Hoeppner, Telemetry (John Hopkins University) pg (1578-1585), Susan A.R.Garrod, D/A &A/D converters (Purdue University) pg (771-781)}
8. Paul Horowitz/W. Hill, The Art of electronics (Cambridge University press, 2nd ed.), pg (683,617,723-730), 1989
9. George Kennedy, Electronic communication, (Macmillian/McGraw-Hill, 4th ed.) pg (262-266), 1992
10. A.K.Maini, Electronics and communication simplied (Khanna Publishers 19th ed.) Delhi, pg (637-653), 1997.
11. A.K.Maini Handbook of Electronics (Khanna Publishers 2nd ed.) pg636-638)
12. Samuel Y. Liao, Microwave Devices and circuits (Prentice Hall, 3rd ed.) pg (19-23), 1990
13. Handar Inc Environmental Measurement Solution (Handar inc) pg (1-1 to1-9, 4-5 to 4-9), 1994.
14. John Woody, PC almode magazine, December 1995.
15. David Risley, hardware central /tutorial modem standards, 2003
16. W. Chekwe. Personal communications, Lusaka, 2003
17. G. Siwila. Personal communications, Lusaka, 2003.
18. F. Phiri. Personal communication, Lusaka 2003.

Appendix A

Table A.1

KASAKA TELEMETRY STATION

TELEMETRY DATA

FEBRUARY '02

Date	Gauge Plate	Telem Rdg	Differ in m	% Error
1	7.788		7.788	
1	7.725		7.725	
1	7.727		7.727	
2	7.727		7.727	
2	7.715		7.715	
2	7.729		7.729	
3	7.73		7.73	
3	7.739		7.739	
3	7.725		7.725	
4	7.715		7.715	
4	7.795		7.795	
4	7.764	7.236	0.528	2.64
5	7.738	7.231	0.507	2.535
5	7.739	7.227	0.512	2.56
5	7.735	7.245	0.49	2.45
6	7.734	7.226	0.508	2.54
6	7.732	7.229	0.503	2.515
6	7.73	7.254	0.476	2.38
7	7.732	7.234	0.498	2.49
7	7.725	7.238	0.487	2.435
7	7.726	7.26	0.466	2.33
8	7.727	7.228	0.499	2.495
8	7.768	7.198	0.57	2.85
8	7.675	7.202	0.473	2.365
9	7.721	7.22	0.501	2.505
9	7.705	7.204	0.501	2.505
9	7.691	7.201	0.49	2.45
10	7.728	7.225	0.503	2.515
10	7.719	7.209	0.51	2.55
10	7.705	7.214	0.491	2.455
11	7.728	7.226	0.502	2.51
11	7.716	7.218	0.498	2.49
11	7.717	7.239	0.478	2.39
12	7.72	7.226	0.494	2.47
12	7.71	7.214	0.496	2.48
12	7.7	7.214	0.486	2.43

13	7.67	7.185	0.485	2.425
13	7.668	7.175	0.493	2.465
13	7.656	7.174	0.482	2.41
14	7.653	7.152	0.501	2.505
14	7.654	7.183	0.471	2.355
14	7.645	7.175	0.47	2.35
15	7.638	7.142	0.496	2.48
15	7.631	7.151	0.48	2.4
15	7.61	7.136	0.474	2.37
16	7.613	7.124	0.489	2.445
16	7.62	7.146	0.474	2.37
16	7.604	7.125	0.479	2.395
17	7.595	7.107	0.488	2.44
17	7.588	7.107	0.481	2.405
17	7.578	7.095	0.483	2.415
18	7.561	7.071	0.49	2.45
18	7.553	7.069	0.484	2.42
18	7.539	7.058	0.481	2.405
19	7.532	7.04	0.492	2.46
19	7.558	7.036	0.522	2.61
19	7.54	7.039	0.501	2.505
20	7.545	7.05	0.495	2.475
24	7.408	6.912	0.496	2.48
25	7.4	6.905	0.495	2.475
25	7.386	6.888	0.498	2.49
25	7.369	6.879	0.49	2.45
26	7.37	6.882	0.488	2.44
26	7.352	6.858	0.494	2.47
26	7.332	6.849	0.483	2.415
27	7.336	6.837	0.499	2.495
27	7.329	6.828	0.501	2.505
27	7.305	6.822	0.483	2.415
28	7.301	6.816	0.485	2.425
28	7.29	6.795	0.495	2.475
28	7.29	6.796	0.494	2.47

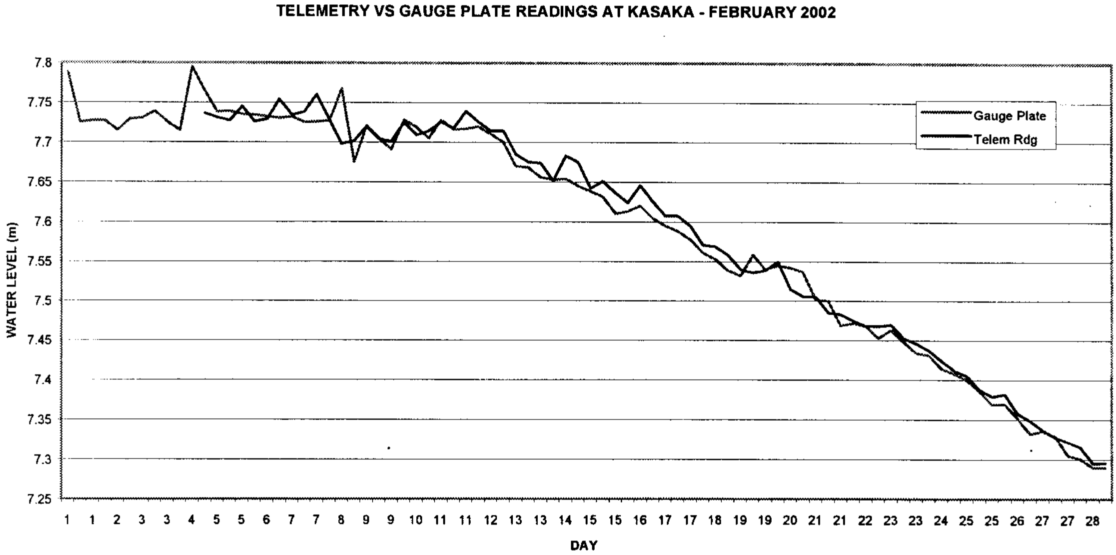

Figure A.1

Appendix B

Motorola

Motorola provides the Micom-2B SSB transceiver.

Basic cost	US$6,350
ALE added	US$2,30
Capacity	3000bps

Kenwood

Kenwood provides the TRC 80 transceiver.

Basic cost	US$2,500
TNC Hub	US$400
Modem (Codan)	US$2150
Capacity	300bps

Codan

Codan provides the Codan 9360 radio and the 9002 modem.

Basic cost	US$3,200
Modem (Codan)	US$2,150

Capacity	300bps

Racal (Canada)

Racal of Canada provides the Javelin RC 9125 HF transceiver.

Basic cost	US$10,500
Power supply	US$1,400
Antenna	US$1,315
Capacity	3600bps

Comment.

Much of the information on the above quotations was obtained from the 1999 study on the International Research Development Centre (IRDC). A guide to using low cost radio Communication systems to telecommunication in developing Countries - An African perspective. The details on the Javelin were obtained from the factory in Canada and quotations they supplied ZESCO Ltd. Details about the Codan were obtained from the National Airports and the local agents, Intercel and Aeradio here in Lusaka.

Appendix C

Glossary

Antenna - Conductive structures specifically designed to couple or radiate electromagnetic energy. The antenna is usually used to both transmit and receive electromagnetic energy. The size and shape of antennas are determined, in large part, by the frequency of the signal they are receiving

ASCII (American Standard Code for Information Interchange) -- This is the de facto world-wide standard for the code numbers used by computers to represent all the upper and lower-case Latin letters, numbers, punctuation, etc. There are 128 standard ASCII codes each of which can be represented by a 7 digit binary number: 0000000 through 1111111, plus parity.

Baud rate actual rate of signal changes per second between two modems. At one signal per second, 300 baud translates to 300 bits per second (bps). However, depending on the signal's code, a baud rate may have more than one bps rate

Bit Frame is the structure on which all of the logic elements are mounted. There is one bit frame for each control stage.

Bit Stream A continuous transfer of bits over some medium. The flow of information, between a sender and receiver in digital communication.

Bytes are typically a sequence of eight bits put together to create a single computer alphabetical or numerical character. The size of a file being transmitted on the Internet is normally measured in Bytes, unlike transmission rates that are conventionally measured in bits.

Cyclic Redundancy Check. A CRC is a type of check value designed to catch most transmission errors. A decoder calculates the CRC for the received data and compares it to the CRC that the encoder calculated, which is appended to the data. A mismatch indicates that the data was corrupted in transit

Data Acquisition -The automatic collection of data from sensors, instruments and devices: in a factory, laboratory or in the field, by this process events in the real world are translated to machine-readable signals. The term usually refers to automated systems in which sensors are attached to machinery.

Data-can be defined in many ways. Information science defines data as unprocessed information. Data is converted into information, and information is converted into knowledge.

Database a collection of information organized and presented to serve a specific purpose. (A telephone book is a common database.) A computerized database is an updated, organized file of machine-readable information that is rapidly searched and retrieved by computer.

Data logger an electronic memory device which accepts information from instruments and records it for future use, usually in a form which can be read with the help of a personal computer

Direct Memory Access/Addressing. DMA is a method of transferring data from one memory area to another without having to go through the central processing unit. Computers with DMA channels can transfer data to and from devices much more quickly than those in which the data path goes through the computer's main processor.

Decile If a set of numerical values is ordered from lowest to highest and divided into ten equal parts, then the values separating the ten parts are called deciles. Hence there are nine deciles, which separate the ten sections. The upper and lower deciles are the 90% and 10% levels, respective

Directivity for antennas, directivity is the maximum value of gain in a particular direction. (Isotropic point source has directivity = 1). For directional couplers, directivity is a measure (in dB) of how good the directional coupling is and is equal to the isolation minus the coupling.

Daemon, a networking program that performs a housekeeping or maintenance utility function without being called by the user. A daemon sits in the background and is activated only when needed, for example, to correct an error from which another program cannot recover.

Ecology the study of the relationships between living organisms and their environment the study of the interrelationships between organisms and their environment.

Hydrology the study of the waters of the earth, especially with relation to the effects of precipitation and evaporation upon the occurrence and character of water in streams, lakes, and on or below the land surface.

Hardware the mechanical devices that comprise a computer system, such as the central processing unit, monitor, keyboard, and mouse, as well as other equipment like printers and speakers.

Hex (hexadecimal) the base 16 numbering system, sometimes used as a short way of representing binary numbers. The digits 0-9 are used, plus the letters A-F that stand for numbers 10 to 15.

ISA (Industry Standard Architecture.) The original specification for the EXPANSION SLOTS used on the first IBM PC. Nowadays replaced by its successor - the PCI SLOT

Link quality analysis (LQA): In adaptive high-frequency (HF) radio the overall process by which measurements of signal quality are made, assessed, and analyzed.

Modem -Modulator-demodulator - a device or program that enables a computer to transmit data over analogue telephone lines. Computer information is stored digitally, whereas information transmitted over telephone lines is transmitted in the form of analogue waves. A modem converts digital data from computers into analog data that can be transmitted over the telephone lines.

Noise electrical signals from natural or man-made devices that interfere with a receiver's ability to receive radio signals.

PCI (Peripheral Component Interconnect) is an interconnection system between a microprocessor and attached devices in which expansion slots are spaced closely for high-speed operation. Using PCI, a computer can support both new PCI cards while continuing to support Industry Standard Architecture (ISA) expansion cards, an older standard.

Polarisation In an ionised medium in the presence of a magnetic field, a radio wave is split into two circularly polarised components, each propagating independently. In the ionosphere a radio wave is split by the earth's magnetic field into ordinary (o) and extra-ordinary (x) waves.

Radiation is energy that is radiated or transmitted in the form of rays or waves or particles

Random Access Memory is the temporary memory a computer uses to store data and process information. The more RAM a computer has, the more data a computer can manipulate. The contents of RAM are cleared when you turn off the computer. ; An integrated circuit memory chip allows information to be stored or accessed in any order and all storage locations are equally accessible

Signal an electric quantity (voltage or current or field strength) whose modulation represents coded information about the source from which it comes

Software A computer program, which provides the instructions, which enable the computer hardware to work. System software, such as Windows, operate the machine itself, and applications software, such as spreadsheet or word processing programs, provide specific functionality.

Sensor a device that responds to a physical stimulus, such as thermal energy, electromagnetic energy, acoustic energy, pressure, magnetism, or motion, by producing a signal, usually electrical

Transceiver - A device that combines both functions of the transmitter and receiver, thereby providing both output and input interfaces

Telemetry-The capability of transmitting or retrieving data over long distance communication links, such as satellite, radio or telephone. The use of telecommunication devices to automatically record measurements from a distance