A STUDY

ON THE VARIOUS CAUSES OF SIGNAL TO NOISE RATIO REDUCTION IN POWER LINE CARRIER (P-L-C) SYSTEM WITH SPECIAL REFERENCE TO BANGLADESH

BY

MD. SHAMSUL ALAM

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA

MARCH, 1985

A STUDY

ON THE VARIOUS CAUSES OF SIGNAL TO NOISE RATIO REDUCTION IN POWER LINE CARRIER (P-L-C) SYSTEM WITH SPECIAL REFERENCE TO BANGLADESH

BY

MD. SHAMSUL ALAM

A THESIS

SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGG.
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF
MASTER OF SCIENCE IN ENGINEERING (ELECTRICAL AND ELECTRONIC)

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA

MARCH, 1985

THIS IS TO CERTIFY THAT THIS WORK WAS DONE BY ME AND IT HAS NOT BEEN SUBMITTED ELSEWHERE FOR THE AWARD OF ANY DEGREE OR DIPLOMA.

SIGNATURE OF THE SUPERVISOR

SIGNATURE OF THE CANDIDATE

A STUDY
ON THE VARIOUS CAUSES OF SIGNAL TO NOISE RATIO REDUCTION IN POWER LINE CARRIER (P-L-C) SYSTEM WITH SPECIAL REFERENCE TO BANGLADESH

ACCEPTED AS SATISFACTORY FOR PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING(ELECT. & ELECTRONIC).

EXAMINERS

20/3/85
DR. A.B.M. SIDDIQUE HOSSAIN
ASSOCIATE PROFESSOR OF
E.E.E. DEPT., BUET.
DHAKA.

CHAIRMAN & (Supervisor)
Head of the Deptt.

20/3/85
DR. S.F. RAHMAN
PROFESSOR AND HEAD,
E.E.E. DEPT., BUET.
DHAKA.

Co-supervisor
MEMBER

20/3/85
DR. A.M. ZAHOORUL HUQ
PROFESSOR,
E.E.E. DEPT., BUET.
DHAKA.

MEMBER

২০/৩/৮৫
DR. MAHFUZUR RAHMAN KHAN
PROFESSOR,
E.E.E. DEPT., BUET.
DHAKA.

MEMBER

20.3.85
DR. A.R. KHAN
[illegible] PROFESSOR,
DEPT., OF APPLIED PHYSICS
AND ELECTRONICS
DHAKA UNIVERSITY
DHAKA.

EXTERNAL MEMBER

ACKNOWLEDGEMENT

The author expresses his heartfelt and deep sense of gratitude and indebtedness to his supervisor Dr. A.B.M. Siddique Hossain, Associate Professor, Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology, Dhaka for his sympathetic encouragement and valuable guidence throughout his supervision of the work.

The author also expresses his gratefulness, indebtedness and thanks to Dr. A.M. Zahoorul Huq, Professor, Department of Electrical & Electronic Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka for his great interest and helpful suggestions throughout the progress of this work.

The author gratefully acknowledges the help extended to him by Dr. S.F. Rahman, Professor & Head, Department of Electrical and Electronic Engineering, BUET, Dhaka, Mr. Kazi Abdur Rouf, Chairman, Bangladesh T & T Board and Dr. Mahfuzur Rahman Khan, Professor, Department of Electrical & Electronic Engineering, BUET, Dhaka.

Acknowledgements are made to Mr. Bazlur Rahman, Chief Engineer, load dispatch, BPDB, Mr. Giash Uddin Mollah, S.E. (grid & carrier and Mr. Alamgir, Asstt. Engg.(carrier),BPDB, L.H. Bhuya and Mr. M. Mannan, Divisional Engineer, Microwave Maintenance for their valuable help in the investigation of noise.

The author wishes to express his appreciation to many friends and colleagues who have helped in carrying out the measurements.

ABSTRACT

All modern power systems, now-a-days, have a central load dispatch centre (LDC) where all informations are transmitted from different metering points located in power stations and substations by using the power line carrier (PLC) system. With the proposed installation of telemetering system in BPDB in the near future, it is imperative that all possibly improvements be made on the existing PLC system for the successful operation of the proposed telemetering system. A study on the various causes of reduced signal power, causes of excessive noise level and thus poor signal to noise ratio (SNR) with special reference to Bangladesh Power Development Board (BPDB) has been carried out. Brief description of the BPDB PLC system, description of various types of noises, interference, response of receiver to different types of noise and attenuation in cables and networks have been discussed with facts and figures.

Measurements for noise and interference, signal strength in cables and switching networks and grounding resistance of protective devices have been made on some of the links of the BPDB PLC system and the results are compared with standard ones. Other related informations collected from different metering stations have been tabulated. Much of the information provided in this thesis is based on empirical methods of calculation

and in some cases a limited number of measurements have been made of some of the important factors affecting carrier transmission. Methods of making some of the necessary measurements have also been covered.

Conclusion is made on the basis of the experimental results and informations from field survey. Efforts are made to find out some of the causes of poor SNR in the existing PLC system and some defects have been properly identified. Some useful recommendations have also been put forward based on the study.

CONTENTS

Page

Chapter 1. INTRODUCTION

Chapter 2. NOISE, INTERFERENCE AND DISTORTION IN POWER-LINE CARRIER COMMUNICATION SYSTEM

Chapter 3. NOISE AND ATTENUATION IN CABLES AND SWITCHING NETWORKS IN POWER LINE CARRIER COMMUNICATION SYSTEM.

Page

Chapter 4. TECHNIQUES AND METHODS FOR MEASURING

Chapter 5. MEASUREMENTS AND RESULTS

Chapter 6. CONCLUSIONS AND RECOMMENDATIONS

APPENDICES

CHAPTER - 1

INTRODUCTION

1.0 Preliminaries

Carrier current provides a means for the transmission of many forms of communication including telephony, telegraphy, telemetery, metering indications, control impulses, etc., and various other types of information. In Power Line Carrier (P-L-C) system, this transmission of intelligence takes place by the existing High-voltage power lines simultaneously with the transmission ;of electrical energy and without mutual interference.

Power-line carrier facilities are used primarily to provide organisation owned communication services for power-system operation. On large power systems, it is not possible to provide all communication needs by means of power-line carrier because of the limited frequency spectrum available. However, high-voltage transmission lines provide a very reliable medium for communication, and in general, power-line carrier is used for the more important services.

Power transmission lines of any voltage can be used for communication purposes; however, lines operating at 33 kv and higher are most prevalent. Lower voltage lines are usually tapped or looped through a greater number of stations between terminals, which increases the cost of maintaining a suitable path for communication signals.

Communication over power lines is accomplished by superimposing carrier frequencies on the transmission lines in somewhat the same manner as is done on open-wire telephone lines, except for the method of connecting the carrier transmitters and receivers to the line conductors.

Power-line carrier frequencies fall between the limits of 30 and 200 kc. While 30 kc is not an absolute lower limit, the bandwidth obtainable at lower frequencies with standard line coupling and tuning equipment is not adequate for most practical needs. The upper limit is due to the extensive use of frequencies between 200 and 415 kc for aircraft navigation radio facilities.

Carrier equipment has been applied to power lines since the early 1920's. The first applications were made for voice-communication purposes, but it was soon recognized that power-line carrier channels could provide circuits for many other vital services on power systems. Today, the applications of power-line carrier include the provision of channels for such functions as protective relaying, telemetering load-frequency control, supervisory control, fault location, and many other miscellaneous services, in addition to the original voice-communication application. It can safely be said that power-line carrier has become indispensable to the operation of most large power systems.

With the increased applications of power-line carrier, involving the extension of channels over greater distances than ever before, and with the modern practice of interconnection and integration of individual power systems into large groups, the problems of successfully applying and operating carrier equipment have increased many times. Yet modern power-line carrier equipment, with its greatly improved selectivity and sensitivity, its reduced bandwidth, and its use of modern systems of modulation, is capable of providing extremely reliable channels for all the modern applications of carrier, even in the face of today's difficult application problems.

Basically, a power-line carrier system consists of three distinct parts:

1. The terminal assemblies, consisting of the transmitters, receivers, and associated components;
2. The coupling and tuning equipment, which provides a means of connecting the terminals to selected points on the high-voltage system;
3. The high-voltage system itself, which must provide a suitable path for transmission of the high-frequency energy between the terminals.

All three of these basic parts of a power-line carrier system must be suitable for their intended purpose, if reliable and trouble free operation of the power-line carrier system is to be obtained.

Generally, the user is not concerned with details of design of the carrier terminal, except insofar as conservative use of components, physical size, appearance, etc., are involved. It is fundamentally the responsibility of the manufacturer of carrier equipment to employ design techniques which reliably provide the performance specified with regard to power output, harmonic reduction, selectivity, sensitivity, etc. However, selection of the most modern terminals cannot assure the user of trouble-free operation of the over-all carrier system unless a satisfactory high-frequency transmission path is provided. The characteristics of this path, consisting of the high-voltage system and the coupling equipment at each terminal, are basically under the control of the user of the carrier equipment rather than the manufacturer. Hence, responsibility for successful operation of a carrier system necessarily lies with the user, insofar as provision of a suitable transmission path is concerned.

It is felt that by far the majority of the difficulties that have been encountered in recent years in the successful operation of power-line carrier channels can be ascribed to lack of satisfactory radio-frequency (r-f) transmission paths. It is believed that many of these difficulties could have been avoided if users had realized their responsibility to provide satisfactory paths, and if they had had ready access to information which would enable them to examine critically, from a carrier-application standpoint, the paths they were using. It is the purpose of this thesis to provide a summary of the information on the characteristics of high-voltage power-transmission systems at power-line carrier frequencies, and to point out methods of treatment of such systems to improve these characteristics. Information on coupling is included, since it is an integral part of any high-frequency transmission path. However, the application of the transmitting and receiving equipment is not covered from the functional standpoint, except insofar as the transmission requirements of the high-frequency path are affected by differences among the various functions.

Much of the information provided in this thesis is based on empirical methods of calculation data obtained from different metering station and in some cases only a limited number of measurements have been made of some of the important factors affecting carrier transmission. Methods of making some of the necessary measurements have been covered in this thesis. Results and other tabulated data obtained from this work are compared with standard ones and some recommendations have been put forward based on the study.

1.1 Brief description of P-L-C system (BPDB)

In any electricity supply grid it is important to have a good, reliable communication system between the different substations and powerstations. In the medium tension grid (i.e. 33kV) of the BPDB the VHF system is mainly used. This system is convenient for shorter distances and for grids with many substations as it is the case in the 33 kV grid.

In the 132 kV grid the distances are too ;long for VHF. Besides, the capacity of VHF is very limited. Further, in the 132 kV grid we have different kind of information, beside telephone, which has to be transmitted and this cannot be done by VHF. This information includes protection signals, metering signals and controlling signals. To transmit all these signals including telephone, the Power Line Carrier system is used (PLC).

1.1.1 Principle of operation

The idea behind the PLC system is, to use the high tension Power-line on the transporting midium for telephone calls instead of installing a separate set of wires between the stations. It is obvious that due to the hazardous voltage telephone cannot be connected directly to the powerline. It is necessary to install some protection and coupling devices between the power line and the telephone. To let the telephone signal pass through these devices we have to alter it in a special way. This is done by 'packing' the telephone signal in the frequency range of about 50Hz to 4 kHz on a so called 'carrier' signal in the long wave radio range (100 kHz to 500 kHz). The RF-carrier frequency is modulated by the AF-speech signal.

By this provision, a wider range for the communication is achieved. The resulting signal from the modulation can easily be put on the Power line and also be taken off from these again. The following Fig. 1.1 illustrates the Principle of such a PLC link.

1.1.2 Coupling Capacitors (CC)

This high voltage capacitor is connected between the PLC-set and the power line. It prevents the dangerous high voltage of usually 132kV from damaging the PLC-set and threatening men life. Only the harmless RF signal can pass the coupling capacitor. The CC is working as a High Pass filter.

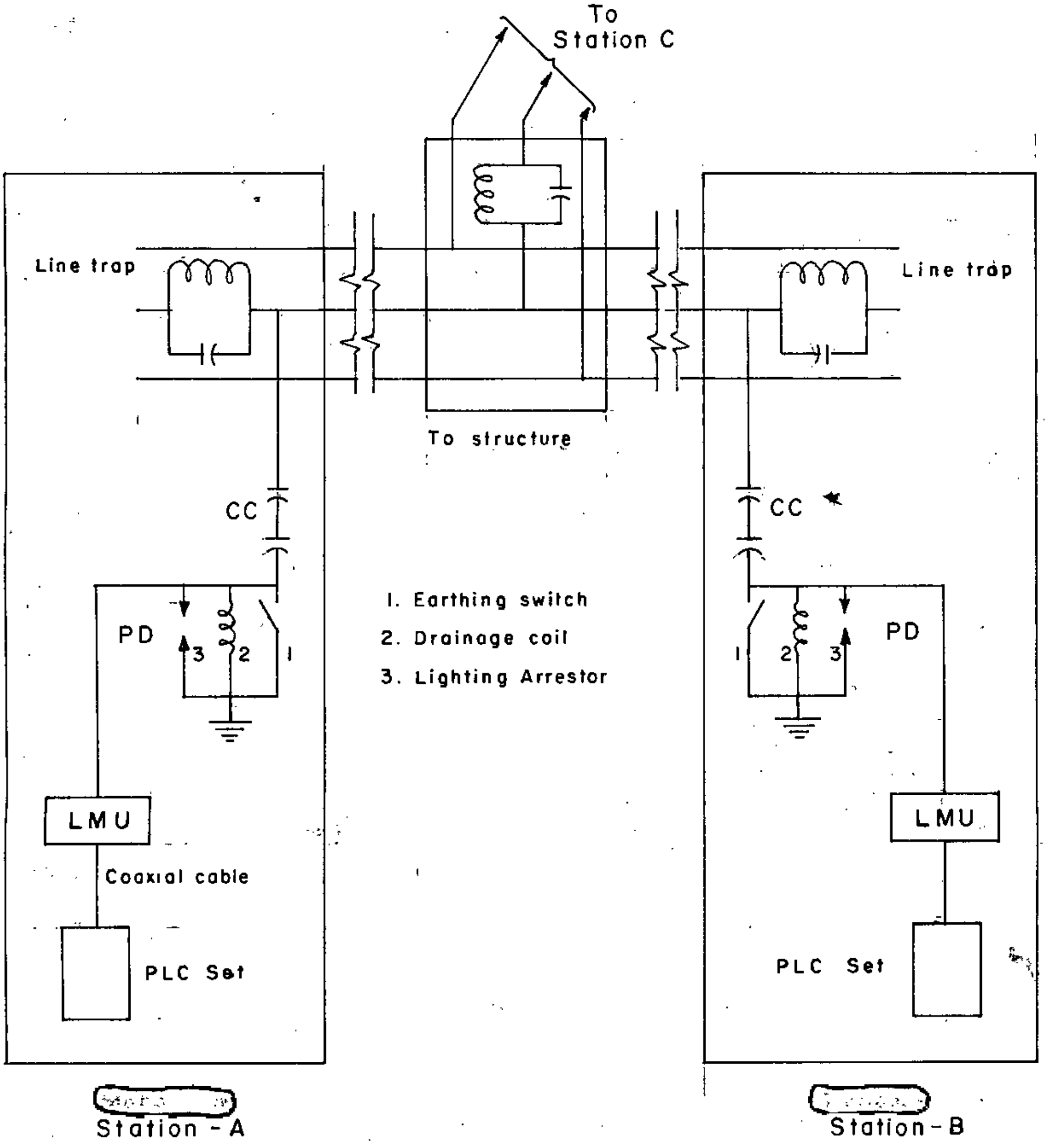


Fig. 1.1 PLC Net work

1.1.3 Wave trap (WT)

This is a high current coil connected between power line and substation. It prevents the RF signal from entering into the powerside (switchyard) of the substation. Only the 5o Hz power can pass the wave trap. The WT is working as a Low Pass filter.

1.1.4 Protective devices (PD)

Because the voltage after the coupling capacitor still can reach hazardous values, different measures of protection have to be taken. We are connecting the following protective devices:

Earthing Switch: During any maintenance work between the LMU and the coupling capacitor this switch has to be closed to short-circuit any voltage to earth. Closing of this switch will interrupt the communication.

Drainage Coil: This device shortens the remaining 50 Hz potential (coming from the power transmission) after the CC to earth. It works as a low pass filter.

Lightning Arrestor: When lightnings strike the powerline, excessive voltages may occur after the CC. which the drainage coil cannot drain. To ground these peaks, the lightning arrestor is built into the circuit.

1.1.5 Line Matching Unit (LMU)

This is used for impedance matching and electrical coupling between power line and PLC-set. It also works as a band pass filter.

1.1.6 PLC - set:

This is the active part of the whole system. In the PLC set the modulation of the RF carrier with the speech signal is done. Also amplification of the signal, to get enough transmitting power, is a task of the PLC-set. Since there is communication in both directions, the PLC-set has also to receive a signal from the opposite station. Amplification and demodulation are done in the receiver section.

After demodulation the speech signal has to be prepared for the connected telephone equipment. The power supply provides the necessary energy to the electronics.

1.1.6.1 Transmitter:

The following figure 1.2 shows the block diagram of this section.

'1' is the Mixer - point. Here the speech signal is fed to the transmitter, coming from the voice section. Other inputs on this print are foreseen for protection and metering signals. All the signals connected to this mixer print are mixed together and adjusted to a proper voltage level.

'2', here the signal, coming from '1' is amplified. In addition the so called Pilot frequency is produced on this point and added to the speech signal. This pilot is always transmitted, even when there is no telephone call on the line. It is used for the supervision of the PLC link. Though, if the pilot cannot be detected in the opposite station, due to some fault on the link, an alarm is issued.

Further the pilot is used to carry the dialing pulses produced in the moment of dialing. This is done by means of

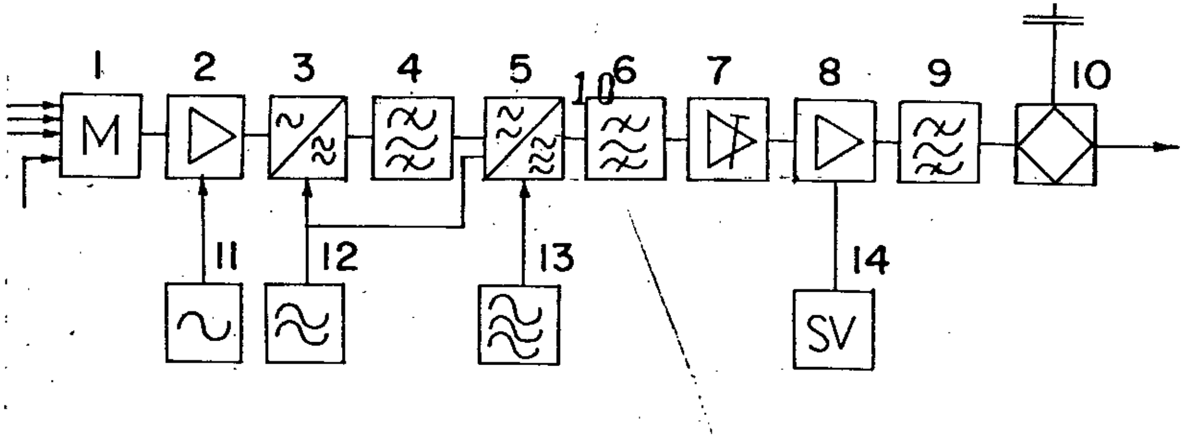


Fig. 1.2 Transmitter

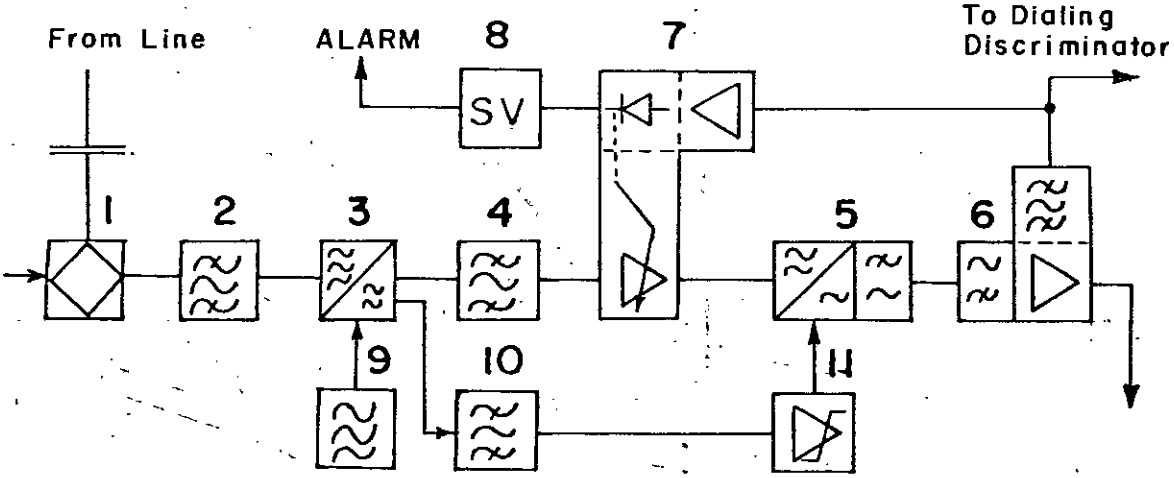


Fig. 1.3 Receiver

changing the pilot frequency from normally 3570 Hz to 3630 Hz in the rythm of the dialing pulses (square wave of 10 Hz). For instance for dialing a five the pilot oscillator shifts its frequency five times from 3570 Hz to 3630 Hz and back.After amplification the combined pilot, speech and the telemetering/ teleprotection signals, together forming the AF-band, are fed to: '3' . Due to some theoretical considerations it is better to divide the modulation of the RF-carrier with the AF-band into two steps. This means, we first modulate a so called intermediate frequency with AF-band and in a second stage we modulate the RF-carrier with the result of the first modulation. This intermediate frequency (IF) is procduced in the oscillator '12'. Throughout the system it is 17 kHz. From '12' the IF-carrier is fed to '3', where the modulation of this IF-carrier with the AF-band is performed.The modulation of two signals with different frequencies results in one signal consisting of two different frequencies. One frequency is the addition of the two modulated frequencies and the other one is the subtraction. As an example, if we modulate the IF-carrier of 17 kHz with the pilot signal of 3570 Hz we shall get the following signals:

ADDITION: 17 kHz = 20.57 kHz
SUBTRACTION: 17 kHz = 13.43 kHz

Since the AF-band is not one single frequency but a frequency band, we get - after the first modulation - the addition and subtraction of the 17 kHz and the AF-band. The AF-band includes frequencies from 300 Hz to 4 kHz. After the modulation we receive the following:

ADDITION : 17 kHz + 0.3 ... 4.0 kHz = 17.3 ... 21.00 kHz
SUBTRACTION : 17 kHz - 0.3 ... 4.0 kHz = 16.7 ... 13.0 kHz

These two frequency bands are called the Upper and the Lower Sideband and are available at the output of '3'. Since we need only one of the two sidebands, we feed the output of '3' to a filter '4'. It has been decided to use the lower sideband and therefore '4' is a bandpass filter with the range from 13.0 kHz to 16.7 kHz. the upper sideband from 17.3 kHz to 21.0 kHz is cut off. The lower sideband is fed to '5'. In this stage the second modulation is done. The RF-carrier, produced by the oscillator '13', is modulated with the IF-signal. Before the modulator we add (mixing) again the 17 kHz IF-carrier to the IF-signal because we have lost it during the first modulation, and we still need it in the receiving section of the opposite station. The IF-signal includes now the frequency band from 13.0 .. 17 kHz. As the result of the second modulation we again get the addition and the subtraction of the RF-carrier and the IF-signal. Proceeding our example from above let us assume an RF-carrier frequency of 329 kHz. For each link this RF-carrier frequency has to be different. Otherwise the different links would interfere with each other. When we now modulate the RF-carrier with the IF-signal band we shall get:

ADDITION : 329 kHz + 13.0 ... 17kHz = 342.0 ...346.0 kHz
SUBTRACTION : 329 kHz - 13.0 ... 17kHz = 316.0 ...312.0 kHz

Again we cut off the upper sideband with a bandpass filter '6' and the resulting frequency band from 312.0 kHz to 316.0 kHz is fed to the adjustable preamplifier '7'. From there we go to the power amplifier '8' after which the RF-signal is available with about 15 W power level. In the following transmitterfilter '9' any unwanted frequencies (distortion) are eliminated. In the Hybrid '18', the transmitter signal is passed to the coaxial cable and fed to the line matching unit LMU.

1.1.6.2 Receiver:

The following figure 1.3 shows the function of this second basic part of the PLC-set. The task of the receiver section is to reverse the alterations we have done to the AF-signal in the opposite transmitter section. The same way the transmitting signal is going out to the power line, the receiving signal is coming in: Via coupling capacitor, protective devices, line matching unit and the coax cable to the hybrid. The transmitting and the receiving signals are not affecting each other because they consist of two different frequency ranges, usually 4, 8 or 16 kHz apart. The hybrid '1' separates the incoming receiving signal from the outgoing transmitting signal and routes it to the input filter '2'. This bandpass lets only pass signals in the specified receiving range. After the filter the signal is passed to the first Demodulator which is nothing else than a modulator as we learned in the transmitter description. The oscillator '9' supplies the RF-carrier.The result of this demodulation is again the addition and subtraction of the two signals:

ADDITION : 325 kHz + 308.0 ...312.0 kHz = 633.0 ...637.0 kHz
325 kHz - 308.0 ...312.0 kHz = 17.0 ... 13.0 kHz

Now it is obvious that we have to cut off the upper sideband. This is done with the bandpass filter '4', which is a very sharp filter and makes out the selectivity of the whole receiver. The remaining signal is again the IF-signal in the range of 13.0 ... 17 kHz. Parallel to the filter '4' there is an other filter for separating the IF-carrier of exactly 17 kHz which we have added in the opposite transmitter '11'. We need this IF-carrier later in the second demodulation. After the filter '4' an amplifier with an automatic gain control follows in the chain. This means that the gain of that amplifier is adjusted continuously according to the level of the received signal. The control voltage for the gain of this amplifier is derived from the pilot amplitude at the output of the receiver section. By theis provision we always have a constant signal level at the output of the receiver, regardless of the attenuation caused by power line, climate and coupling. The next stage of the receiver is the second demodulator where the conversion from the IF-frequency ;to the AF-band is performed. The output of the AGC-amplifier is fed to '5'. As IF-carrier we use the 17 kHz filtered out on '10'. This 17 kHz IF-carrier is passed through a limiter amplifier '11', where the sine wave signal is limited to a certain amplitude. From there this limited 17 kHz-signal gets to '5' for the second demodulation. Again this modulation or demodulation results in the addition and the subtraction:

ADDITION : 17 kHz + 13.0 ... 17 kHz = 30.0 ... 34 kHz
SUBTRACTION : 17 kHz - 13.0 ... 17 kHz = 4.0 ... 0 kHz

The lowpassfilter '6' on the same module suppresses the upper sideband, leaving the AF-band (0 ... 4 kHz) only, which then passes to ithe next module: The AF-signal is passed through a highpass filter to cut off frequencies below 300 Hz. After amplification the pilot of either 3.57 kHz or 3.63 kHz is filtered out. This pilot is passed to the dialing discriminator of the voice section. Further the pilot is rectified and used to drive the supervision circuit and - as already mentioned above - to control the AGC-amplifier '7'. The AF signal on '6' is then passed to the voice section.

1.2 Signal and noise in P-L-C system:

Information is transmitted and received as electrical signal in P-L-C systems. But information which is produced by a source in general, is not electrical. So a transducer is required which converts the information or massage to a desirable time varying electrical signal which is better for further processing by the system. Similarly another transducer at the destination converts the out put signal to the appropriate massage form.

But in course of electrical signal transmission, certain unwanted and undesirable effects take place. One is attenuation which reduces the signal power. However, distortion, interference and noise change the signal shape. In a broad sense any unwanted signal perturbation may be classified as noise.

Noise occurs in P-L-C systems in various ways. On the low voltage transmission lines is caused chiefly be defective insulators and loose hard wire and on the high voltage transmission lines by corona discharge. All circuits are subjects to the noise effects of atmospherics, line faults, switching surges and faulty apparatus. Noise increase subtantially in bad weather as the combined result lightning, corona, from drops of water particles, snow or ice on the conductor and leakage over insulators.

Background noise is generally greater at the lower frequencies but lightning stroms may produces high noise levels through out the entire spectrum. Noise during thunderstroms can produce a value of ten times or more than the fair weather noise. All these factors must be considered for best utilization of the P-L-C systems.

The proper characteristics of the noise must be considered for each application and receiver band width as well, since the noise response is usually a function of band width.

It is not ordinarily possible to reduce appreciably the noise level present at a given receiving point in a carrier system. Therefore the only practictical way to improve the signal to noise ratio is to raise the signal level at the receiving point. It is not usually feasible to raise signal levels by increasing the transmission power, because appreciable gains in terms of decibels, require large increases in power. For example, to raise the signal level from a 10-watt transmitter by 20 db requires a increase to 1000 watts, or 100 times the original power. A much more practical solution is to reduce the channel attenuation by every means available and noise from different source should be controlled with in the reasonable limit.

1.3 Transmission media and their characteristics:[3-5]

The behavior of a carrier signal being propagated along a multiconductor power-transmission line is governed by the same physical laws that have been developed into the classic equations normally applied to isolated two-conductor communication transmission lines. A true analysis of propagation along the multiconductor line, however, is much more difficult because of the multiplicity of self- and mutual impedances which exist.

Several conducting paths exist on a power line, including at least three power phases and a ground path, which usually consists of one or two ground wires and earth. When a carrier voltage is impressed upon an input circuit consisting of any two of these paths, a wave of carrier energy will proceed down the line, apparently beginning the same as on the theoretical two-conductor communication circuit. Except with special cases of symmetry, however, the energy is not confined to the intended route. Mutual coupling between conductors causes a continuing interchange of energy which results in changing proportions of current as the signal progresses down the line.

Various theories have been applied to obtain better concepts of the complex phenomena associated with wave propagation on the multiconductor lines. The natural mode concept is particularly helpful in predicting the distribution of carrier-frequency current among the power conductors and in explaining many apparentlystrange aspects of carrier behavior. A transmission line with n conductors has n natural modes which, when combined in appropriate proportions, can represent any current or voltage distribution among the n wires. No mutual coupling exists between modes, all conductor impedances are equal for a given mode, and the attenuation to a carrier signal in each mode may be considered independently as a linear function of distance.

On a transposed power line the three phases approach electrical symmetry for any basic configuration. A phase-to-phase carrier circuit on any two of the three phases, therefore, approaches balanced circuit behavior. On untransposed lines, e.g., single-circuit with the three phases in the same horizontal plane, phase-to-phase carrier signals are balanced only when applied to the two outside conductors. The unbalanced wave propagated when a carrier signal is applied on adjacent phases may be perceived as having two components, one of which is the same as the previous balanced arrangement and another which involves all three phases. Despite the lack of symmetry, a carrier signal on adjacent phases has lower attenuation because the added three-phase component has less loss per unit length of line than the pure phase-to-phase component. However, a small additional loss is experienced at the receiving terminal because there is energy on the uncoupled phase which cannot be recovered. Every carrier signal coupled phase-to-ground has, in addition to interphase components, a true phase-to-ground component consisting of carrier-frequency current flowing in the same direction in all three phases and returning through ground wires or earth. The attenuation per unit line length of this component is very high in comparison with those not directly involving ground currents, so that, within a short distance from a transmitter, the phase-to-ground component is essentially lost. This [illegible] fixed loss at the sending end is very significant if one is to obtain consistent estimates of phase-to-ground carrier attenuation. Energy on uncoupled phases which cannot be recovered at the receiving end of a line is also significant.

Because of electrical symmetry, phase-to-ground carrier on either phase of a transposed line will be propagated in a manner similar to that on the center phase of an untransposed line. Phase-to-ground carrier on an outside conductor of the untransposed line, because of different component distributions, is attenuated more within a given line length than the previous examples.

The value of impedance to which carrier terminals and coupling equipment are adapted in an effort to achieve minimum mismatch attenuation is called the characteristic impedance of a carrier circuit.

1.4 Objective of the thesis:

All modern power system, Now-a-days have central load dispatch centre (L-D-C) where all informations are transmitted from different metering points located in power stations and sub stations by using the power line carrier system. With the proposed installation of tele-metering system in BPDB in the near future, it can be assumed that the existing or modified P-L-C system will be used for all data transmission to the load dispatch centre at Shiddhirgonj. Because of the addition of more information to be transmitted, which will reduce the available power for each signal, and the great importance of the P-L-C link for BPDB; it is imperative that all possible improvement be made on the P-L-C system for the successfull operation of the proposed telemetering system.

Therefore a study possibly for the first time in our country, on the [illegible] causes of reduced signal power and thus poor signal to noise ratio (SNR) in the present P-L-C system of BPDB will be very significant and timely.

Measurements for noise and interference are made on some of the links of the P-L-C system of BPDB. and the results are compared with those given by consultative committee for international telephone and telegraph (CCITT) and consultative committee for international radio communication (CCIR) and other related informations collected from different metering stations are also tabulated.

Conclusion is made on the basis of the results and informations. Efforts are made to find out some of the causes of poor SNR in the existing P-L-C system and some defects have been properly identified. Some recommendations have also been put forward based on the study.

1.5 Contents of the Thesis:

An introduction to the topic of the thesis with a brief description of the P-L-C system of BPDB has been given in Chapter-1. Description of various types of noises, interference in P-L-C system and response of receiver to different types of noise are given in Chapter-2. A discussion about noise, interferance and attenuation in cables and networks is made in Chapter - 3..

Chapter-4 gives a brief description about methods of measuring noise, SNR and grounding resistence of protective devices. Some measurements for noise, signal strength in cables and switching networks and grounding resistence of protective device in P-L-C system of BPDB are made in Chapter-5. Based on these measurements and survey reports , discussion is made in this Chapter.

Conclusions and recommendations of the whole work are given in the last chapter that is Chapter-6. A brief discussion about future P-L-C system of BPDB is also given in Chapter-6 along with necessary comments.

1.6 Brief Literature Review

Transmission of a signal as well as the rate at which it may be transmitted is characterized greatly by the noise present in the system. The rate of transmission of intelligence (signal) is also characterized by the time required. for energy change in the system. But these facts were not very clear till 1948 when Claude Shannon(1) gave a mathematical relationship between system capacity, signal strength and noise strength. System capacity means the maximum amount of information that may be transmitted in one second.

Carrier equipment has been applied to power lines since the early 1920's. The first applications were made for voice-communication purposes, but it was soon recognized that power-line carrier channels could provide circuits for many other vital services on power systems. Today, the applications of power-line carrier include the provision of channels for such functions as protective relaying, telemetering, load frequency control, supervisory control, fault location, and many other miscellaneous services, in addition to the original voice-communication application. It can safely be said that power-line carrier has become indispensable to the operation of most large power systems.

Importance of the study of noise attenuation and interference in P-L-C systems was felt essential after shannon's formula for system capacity was derived. Large number of Acientific papers in this field appeared during the past three decades. The main contributors R.C. Cheek(8), J.D. Moynihan(27), B.J. Dpstlin(15), F.C. Krings(22), J.L. Eoofeotyh(22),AIEE Committee Report(36), G.E. Adams(16), D.E. Jones(20), P.W. Waddington(20), J. Reichman, and J.R. Leslie are from the Westinghouse Electric Corporation, General Electric Company and Hydroelectric Power Commission of Ontario, Canada. Many other related text books, handbooks and journals on the P-L-C system are listed in the reference.

In Bangladesh, the Swedish Dev. Agency carried out some survey work in 1982 on the existing BPDB P-L-C system and Mr. Emdadur Rahman Khan(37) made a study on the noise and interference in Telecommunication system with special reference to Bangladesh for his M.Sc. Engg. thesis in the Electrical and Electronic Engg. Dept. of BUET.

CHAPTER - 2

NOISE, INTERFERENCE AND DISTORTION IN POWER-LINE CARRIER COMMUNICATION SYSTEM.

2.0 Preliminaries

In this chapter discussion will be made about what are meant by noise, interference & distortion, their types and how they affect communication in P-L-C system.

2.1 Noise, Interference and Distortion

In course of electrical signal transmission, certain unwanted and undesirable effects, take place e.g. distortion, noise and interference which alter the signal shape. So, at the receiver end the signal is received as contaminated signal. These undesired signal pertubation may be classified as noise. Therefore signal to noise ratio is one of the basic criteria of the performances of any communication or signaling circuit. However there are good reasons and adequate basis for seperating the three effects.

2.1.1 Distortion

It is the alteration of the signal due to imperfect response of the system to the desired signal itself. Distortion disappears when signal is turned off. For example, the gain of an amplifier may change with frequency or input signal level causing so called frequency distortion or amplitude distortion. Similarly, the phase of the output signal may change with frequency causing phase distortion. These will be discussed in the subsequent chapters.

Improved system design or compensating networks can reduce distortion. Theoretically perfect compensation is possible but practically, some distortion must be accepted, though the amount can be held within tolerable limits in all but extreme cases.

2.1.2 Interference

Interference is the contamination of the desired signal by extraneous signals, usually man made, of a form similar to the desired signal. It may be a deterministic signal or a random signal. For example, multiplexing in communication systems may be considered, In this case many channels are multiplexed by using different frequency carriers (Frequency division multiplexing) for transmission over a common link. But due to incomplete filtering , information from one channel may enter in another channel causing interference which is called crosstalk in this case. Information theory says that a known signal carries no information and so it is meaningless to transmit. Hence all meaningful communication signals must be of nondeterministic nature, that means, information carrying signals must be random. Here the type of interference cited is also random. Of course, it may also be deterministic e.g. in communication system, an interfering sine wave may be generated from an external uncontrolled source, which is deterministic in nature. However, actually speaking, the amplitude, frequency or phase of the said sine wave are subjected to unpredictable changes. So this may also be considered as random type of interference.

Unlike distortion, interference remains if the desired signal is turned off. The cure for interference is obvious i.e. the elimination of the interfering signal or its source. Again a perfect solution is possible, though not always practicable.

2.1.3 Noise

Noise means the random and unpredictable electrical signals which come from natural causes, both internal and external to the system. Obviously these are unwanted signals. What makes noise unique is that it can never be completely eliminated, even in theory. It will be shown that non-eliminable noise poses one of the basic problems of electrical communication. The case of thermal noise may be cited. Such noise is due to the continual notion of the electrons in thermal equilibrium with the molecules, in a conductor. This type of noise causes a random voltage to develop across a resistor. Another example of noise is shot noise which aries due to discrete nature of electron flow and is found in most active devices. Unlike distortion, noise remains even if signal is turned off.

From the forgoing discussions, it is clear that noise, interference and distortions are undesirable signals.

Each of them interfer with the desired signal. For easier analysis, all of them may be termed an noise. That means any undesirable signal is termed as noise.

2.2 Effect of Noise on Signal

It is clear from the previous discussion that noise arises in P-L-C systems in various ways. It may be due to nonlinearity of an amplifier, due to incomplete filtering, inherent thermal and shot noise etc. It may also be due to the coupling between conductors in a cable, coupling by the common power source and common grounding. External interference may also cause noise. These noises are augmented by occasional rather violent bursts caused by circuit - breaker operation, disconnect - switch arcs, nearby lightning discharges & corona discharges. Actually, noise may occur in various ways. These noises or unwanted signals finally add with the desired signal at the receiver. As a result, the receiver output will be a mixture of the two signals. So, if the received signals are audio signals , then the ears will receive both the wanted signal and noise. The effect of noise may be like a hiss, click, crash, pitch, loudness, etc. It may also be an intelligible signal. Just annoyance will be felt by receiving such unwanted signals i.e. noise. For person to person communication, the annoyance will be more if the noise is intelligible. Also, the intelligibility of the signal will be deteriorated due to the presence of noise. Similarly, if the received signal is a video signal, then the picture of intelligence will be deteriorated in addition to the annoyance felt by the eyes. In case of telegraph system and data transmission, noise is a threat to the accuracy of the received information.

Now how much deterioration of the signal will be caused by the noise depends on signal and noise strengths. If the signal power is appreciably higher than noise power, then effect of noise will hot be perceptible. Thus the criterion of performance of a system is determined by the ratio of signal to noise power. This ratio is called the signal to noise ratio (SNR). The higher the SNR, the better is the performance of a system.

In a power line cerier communication channel, poor signal to noise ratio may result in unsatisfactory service of a degree varying from barely perceptible background noise to complete masking and total loss of intelligibility of the speech signal. In telegraphic type of channels poor signal to noise ratio can cause misoperation ranging from an occasional spike on a telemetered chart record to incrrect tripping of a circuit breaker through a carrier remote tripping system.

For example incase of audio system SNR should be higher than 30 dbm and in case of vidio system SNR should be higher than 50 dbm.[6]

2.3 Common type of Noise

Noise due to all causes can be divided into two broad classifications: random noise and impulse noise. The properties of these two types of noise are markedly different, and their relative effects vary in a different manner from each other when receiving equipment characteristics vary. Hence, the two will be discussed separately. Both types are present simultaneously on power lines, but it is indicated that impulse noise always predominates to a greater or lesser extent.

2.3.1 Random Noise

Random noise is noise with a continuous frequency spectrum resulting from the random occurrence of an infinite number of elementary discharges or fluctuations that are not in themselves separately distinguishable. The audio output of a communication receiver to which true random noise is applied is a soft hissing or rushing sound.

Noise approaching true random noise in its characteristics may appear on power-line carrier channels as a result of thermal agitation in the power-line conductors, pick-up of distant atmospheric discharges or static by the power-line conductors acting as antennas, and tube or resistor noise in carrier receivers. The aggregate of the almost infinite number of small random discharges that occur constantly on an extensive power system also probably approaches

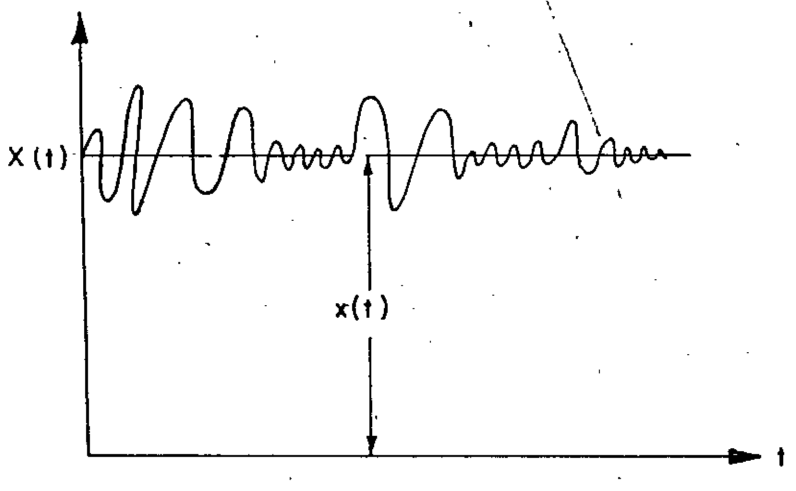


Fig. 2.1 Typical noise wave form

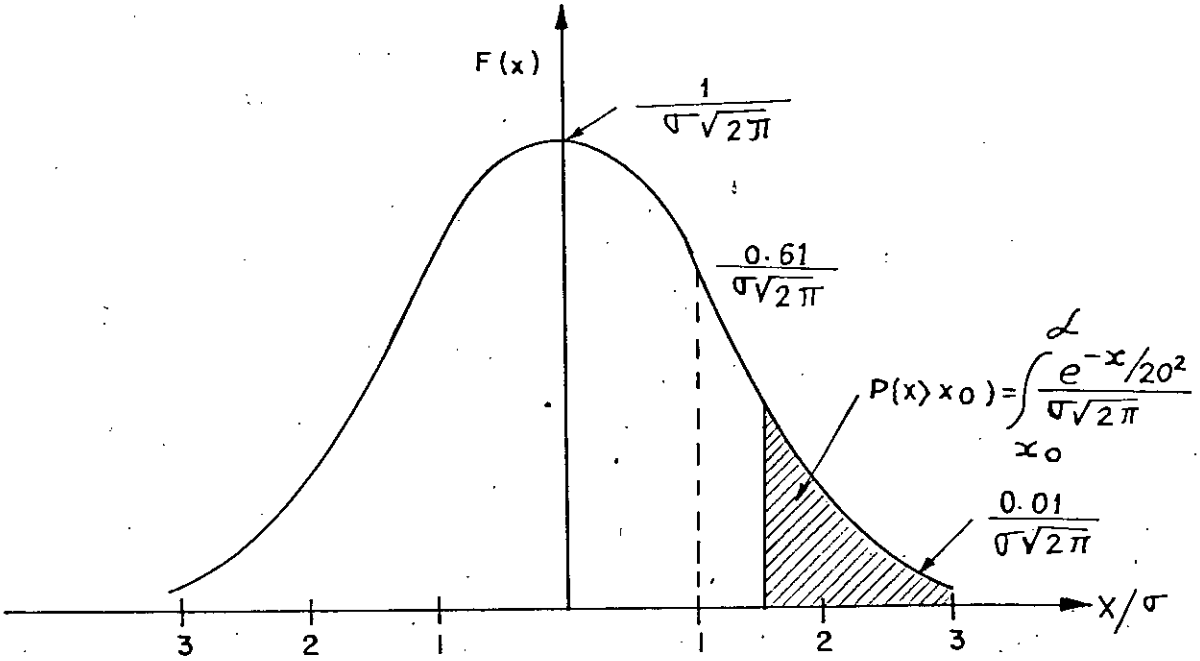


Fig. 2.2 The Gausian Probability distribution

random noise in its characteristics if these random discharges are considered separately from the large, separately distinguishable, and more or less regular pulses which predominate.

Superposition of large no. of events occuring in a random manner causes a noise wave form. For example, thermal noise, stated earlier, arises from the random motion of electrons in a conductor. Since the nature is random, it is not possible to give any precise statement regarding the effect at any particular instant but since the number of events concerned is very large, the average behaviour is well defined and the satisfactory description of noise waveform can be made in statistical terms. A typical noise waveform is shown in fig. 2.1

In the Fig. 2.1 fluctuation of the noise voltage about the mean value $\overline{x(t)}$ is shown. An obvious measure of the magnitude of the noise is the r.m.s. value of the waveform. In practice it is simple to work with the mean square value which is given by

$$\overline{x^2(t)} = \text{Lt} \, \frac{1}{T} \int_{-T/2}^{T/2} x^2 dt \qquad (2.1)$$

It is also required to know the probability of occurence of a particular value and this can be given by probability distribution function. For example, probability of x lying between x and x + dx is given by F(x)dx where F(x) is the probability distribution functions. But for all noise phenomena it is found that Gausian distribution is the most practical one. It is given by

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-x^2/2\sigma^2\right) \qquad 2.2$$

where $\sigma^2 = \overline{x^2(t)}$ and σ is the standard deviation.
For this distribution, standard deviation is equal to mean value. The distribution is shown in Fig. 2.2. Obviously, the probability that x exceeds x_o is given by

$$p(x > x_o) = \int_{x_o}^{\infty} F(x)\,dx \qquad 2.3$$

Also, from the theory of probability, the total area under the curve is unity i.e.

$$p(x > -\infty) = \int_{-\infty}^{\infty} F(x)\,dx = 1 \qquad 2.4$$

In many communication systems, two noise signals are required to be combined. The answers depends considerably on whether the two signals are statistically independent or not. Noise signal generated by seperate sources can be regarded as independent i.e. probability of particular value of one signal is not affected by the presence of the other. The probability that two such signals have values in specified ranges is then equal to the product of the seperate probabilities that the individual signals are each in their specified range. Let

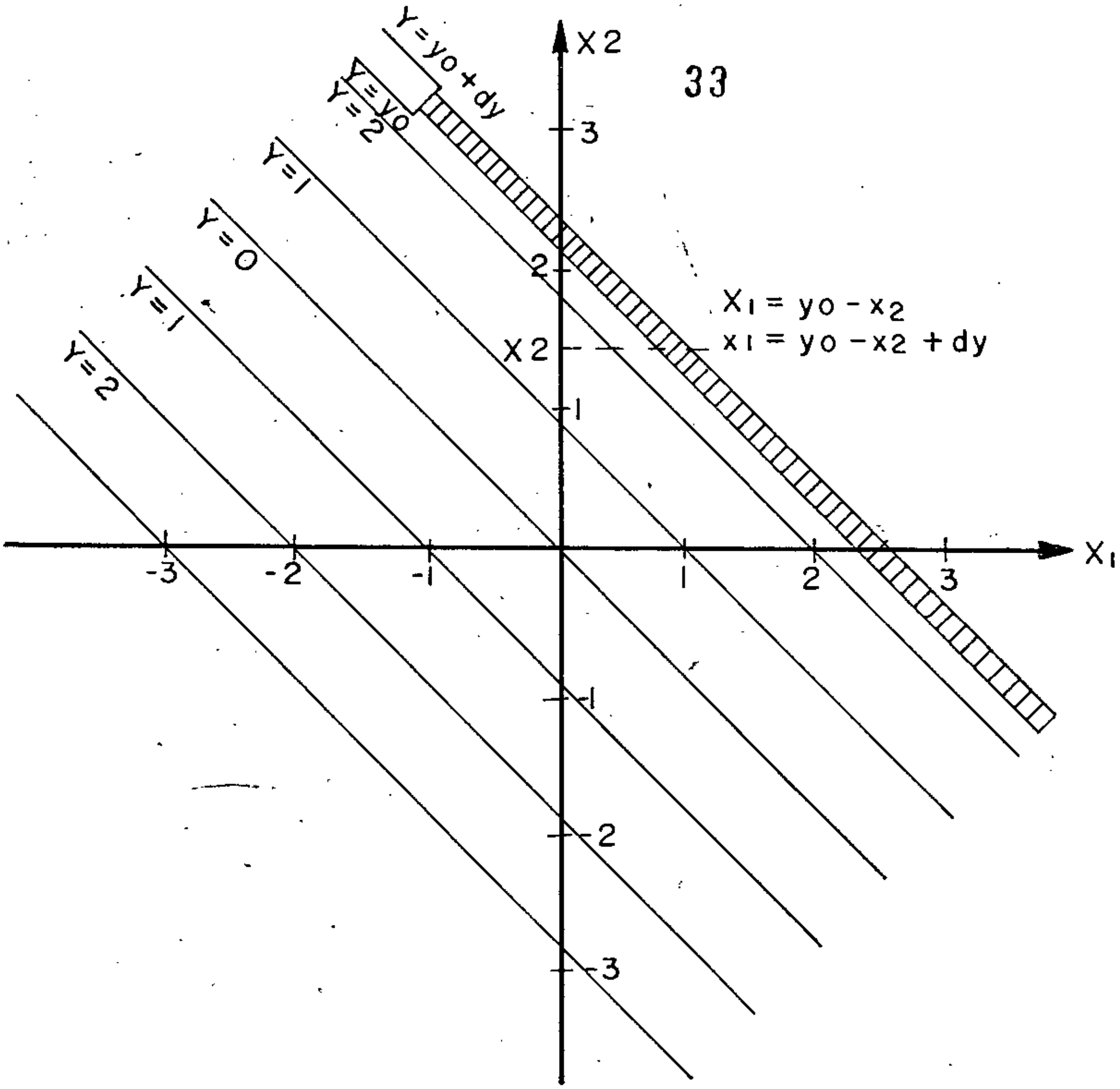


Fig. 2.3 Summation of two noise signals $Y = X_1 + X_2$

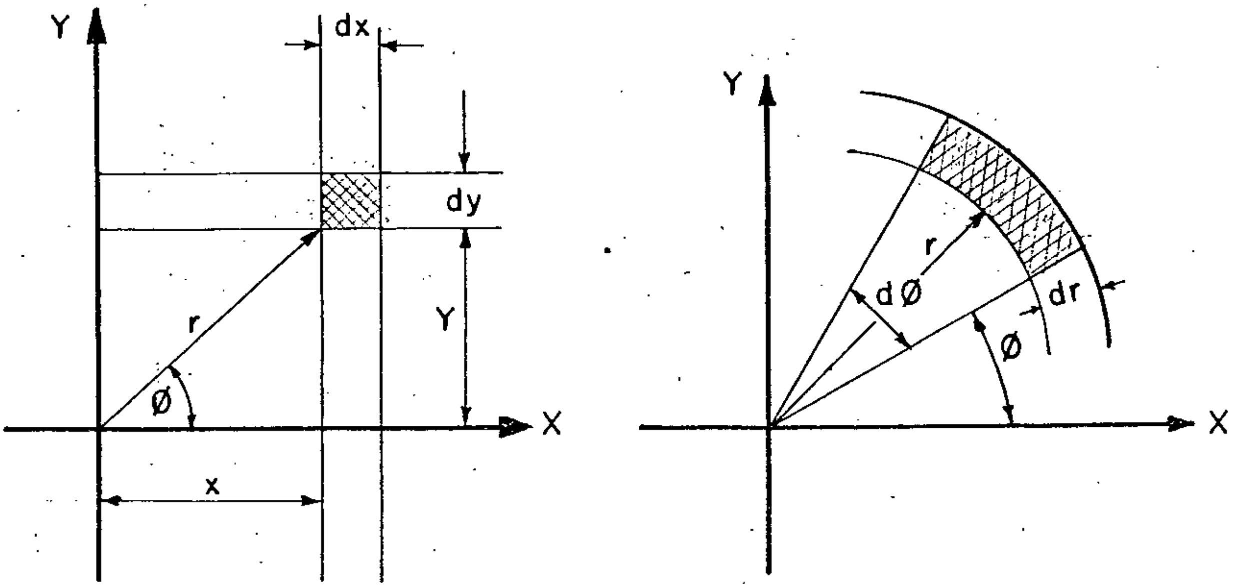


Fig. 2.4 Representation of band limited noise

(a) In terms of in phase and quadrature components

(b) In terms of magnitude and phase.

x_1 and x_2 be the two independent noise signals and have Gausian distributions. Let σ_1 and σ_2 be the r.m.s values respectively and let the two signals are added giving the noise signal y. At every instant

$$y = x_1 + x_2 \qquad 2.5$$

The value of y can thus be read off from the figure 2.3. This figure will be used to find the probability that y lies between the values y_o and $y_o + dy$ i.e. in the shaded area. If the value of x_2 is first fixed, then the corresponding permissible range of x_1 is between $y_o - x_2$ and $y_o - x_2 + dy$ and the probability of this is $F_1(y_o - x_2)dy$ where F_1 is the Gausian function with r.m.s value σ_1. Now, let x_2 is allowed to have any value and the probabilities are added for all possible values. This means multiplication of $F_1(y_o-x_2)dy$ by $F_2(x_2)dx_2$ and integration over the permissible range of x_2. This step is only permissible since x_1 and x_2 are independent. The probability that y lies between y_o and $y_o + dy$ is therefore,

$$p(y_o < y < y_o + dy) = \int_{-\infty}^{\infty} F_2(x_2)F_1(y-x_2)dy\ dx_2 \qquad 2.6$$

$$= \int_{-\infty}^{\infty} \frac{1}{\sigma_2\sqrt{2\pi}} \exp\left(\frac{-x_2^2}{2\sigma_2^2}\right) \frac{1}{\sigma_1\sqrt{2}} \exp\left(\frac{-(y-x_2)^2}{2\sigma_1^2}\right) dydx_2$$

$$p(y_o < y < y_o + dy) = \frac{1}{\sqrt{2\pi}\ (\sigma_1^2 + \sigma_2^2)} \exp\left\{\frac{-y^2}{2(\sigma_1^2 + \sigma_2^2)}\right\} dy \qquad 2.7$$

This shows that the probability distribution of y is also Gausian and that the mean square value of y is $(\sigma_1^2 \pm \sigma_2^2)$ The mean square value of a noise waveform obtained by adding two independent noise waveforms is therefore the sum of the mean square values of these two waveforms. This result can be extended to any number of noise waveforms. Since, power is proportional to mean square value, it can be said that noise power adds if the waveforms are statistically independent.

2.3.2 Impulse Noise [8]

Because impulse noise is the predominant type of noise on power lines, it will be discussed in somewhat greater detail below.

Impulse noise consists of sharp, discrete, well-separated impulses, each identifiable with a specific electrical discharge. The repetition rate of the impulses may be random or regular. If the repetition rate is irregular, the noise contains all frequencies in the spectrum and the amplitudes of the individual frequency components vary only gradually over a given band of frequencies. If the pulses are uniform and have a regular repetition rate, their frequency spectrum contains discrete frequency components separated by a frequency equal to the repetition rate, that is, it consists of the fundamental and harmonics of the repetition frequency.

It is reasonable to expect impulse noise on power lines to have a more or less uniform repetition rate because of the cyclic nature of the power voltage that gives rise to the electrical discharges. However, random pulses also can be expected as a result of switch operations, faults, and lightning discharges on or near the power line. In a carrier communication channel, typical power-line noise produces a harsh, raspy buzz upon which are superimposed strong clicks or pops of random occurrence, indicating that regular as well as random pulses are present in the channel.

A convenient type of pulse to use in a mathematical analysis of the effect of impulse noise in reception is a unit pulse occuring at $t = 0$. Such a pulse has infinitesimal duration and infinite amplitude, such that its time integral is unity. The frequency spectrum of the unit pulse can be deduced from its Fourier integral representation

$$i(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{j\omega t} \, d\omega \qquad \ldots \qquad 2.8$$

which shows that all frequencies are present in such a pulse and further that all frequency components have the same amplitude.

In reference 4 it is shown that if an impulse is of such short duration that the system to which it is applied does not respond appreciably before the impulse is completed, its operational form is simply Ap, where A is the force-time area of the pulse. This is an important result, not only because of the usefulness of such a representation in an analysis of the effect of impulse noise upon receiving equipment, but also because it demonstrates the fact that the response of a receiver to a sharp pulse, or to a continuous train of well-separated sharp pulses, is independent of the actual amplitude or shape of the individual pulses at the input to the receiver and is dependent only upon their areas.

2.4 Band Limited Noise

In practical communication system noise, together with the signal, will be transmitted by frequency selective networks and only those frequencies within the passband of the system will appear at the output. So, it is required to know the nature of noise waveform restricted to a particular band of frequencies, extending from e.g. $f_o - B/2$ to $f_o + B/2$. This is the situation for a system of midband frequency f_o and bandwidth B Hertz. Thus white noise is actually transmitted as band limited noise. If only the noise is present, the output appears similar to a carrier wave of frequency f_o modulated by a noise signal containing frequencies between 0 to B/2 (for AM). Such noise can be expressed in the form

$$f(t) = x(t) \text{ Cos } w_o t + y(t) \text{ Sin } w_o t \quad \ldots \qquad 2.9$$

where x(t), y(t) are noise signals with independent Gausian distributions. (Details may be found in the references). x, y can be regarded as the amplitude of the inphase and quadrature components respectively. The probability that x lies between x and x + dx is given by

$$p_x = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right) dx \qquad \ldots \qquad 2.10$$

σ being the r.m.s. value of x. The distribution of y is identical in form.

The probability that x lies between x and x + dx and that y simultaneously lie between y and y + dy is given by

$$p_{xy} = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) dxdy \qquad .. \ 2.11$$

since the two probabilities are statistically independent. This expression gives the probability that the pair of values x, y lies within the shaded area in the Fig. 2.4(a)

An alternative expression for f(t) is given below:

$$f(t) = r \cos(w_o t + \phi) \qquad .. \qquad 2.12$$

in which r, ϕ are respectively the amplitude and phase of the modulated carrier. Since $x^2 + y^2 = r^2$ and $y/x = \tan \phi$, the probability of a pair of values r and ϕ can be predicted

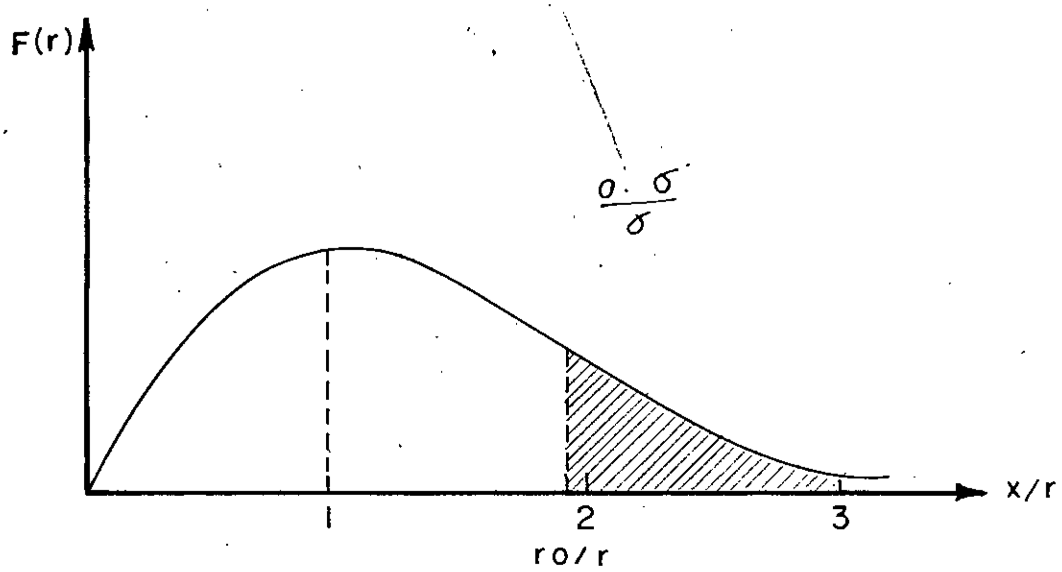


Fig. 2.5 The Rayleigh Probability Distribution.

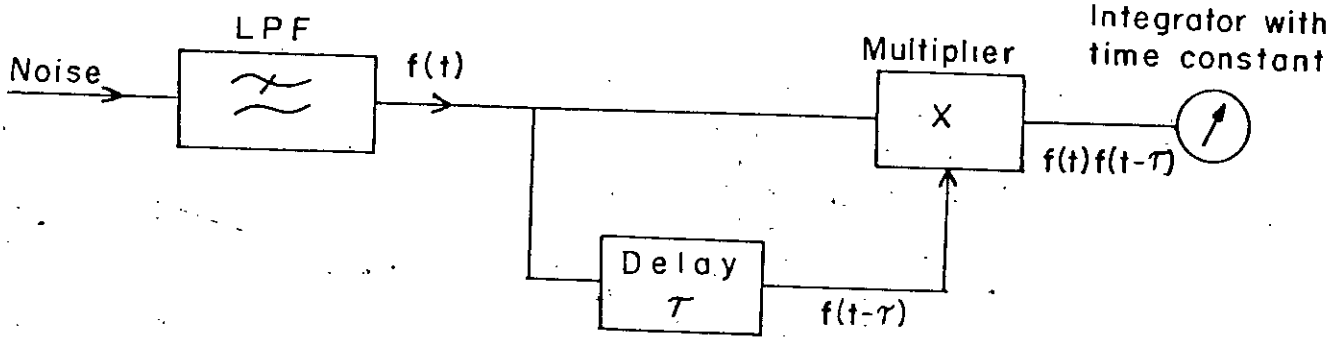


Fig. 2.6 Circuit designed to measure the autocorrelation of a noise signal.

from the expression for the probability of the pair x, y. The product dxdy equals to $rdrd\emptyset$ and so the joint probability can be written as follows:

$$p_{r\emptyset} = \frac{1}{2\pi\sigma^2} \exp\left(\frac{-r^2}{2\sigma^2}\right) rdrd\emptyset \qquad \ldots . \quad 2.13$$

This is now interpreted as the probability that the pair of values r, $\emptyset$ lie in the shaded region of Fig. 2.4(b). The angle $\emptyset$ only appears in the differential, which means that all values of $\emptyset$ are equally likely. The possible range of $\emptyset$ is form '0' to 2π so that the probability of a value between $\emptyset$ and $\emptyset + d\emptyset$ must be $d\emptyset/2\pi$. The joint probability is the product of $d\emptyset/2\pi$ and $(r/\sigma^2)\exp(-r^2/2\sigma^2)drd\emptyset$, so that the probability of a value of r between r and r + dr must be (r/σ^2) $\exp(-r^2/2\sigma^2)dr$. This is called the Rayleigh distribution and is shown in Fig. 2.5. . Band limited noise can then be regarded as modulated carrier of random phase, all values being equally limely and with an amplitude which has a Rayleigh probability distribution. The carrier frequency is the midband frequency, f_o.

From, Raylieigh distribution,

$$p(r > r_o) = \int_{r_o}^{\infty} \frac{r}{\sigma^2} \exp(-r^2/2\sigma^2)\,dr = \int_{r_o/\sigma}^{\infty} x.\exp(-\tfrac{1}{2}x^2)\,dx$$

$$= \exp(-r_o^2/2\sigma^2) \qquad \ldots \quad 2.14$$

The amplitude must be positive and so it is expected that $p(r>0)$ is to be equal to unity. This is confirmed by the equation for $p(r>r_o)$. (i.e. eqn. 2.14).

2.5 Frequency Analysis of Noise Waveform

Any known type of waveform is composed of spectra of sinusoidal signals. But noise signal is random and so nonsterministic i.e. time waveform is not known exactly. As a result analysis by using Fourier transform is practically difficult. Random signals can be analysed easily by using autocorrelation function. Let the time waveform be f(t) and the Fourier transform is evaluated for a time interval - T/2 to T/2. Mathematically,

$$gT(w) = \int_{-T/2}^{T/2} f(t)\ \exp\ (-jwt)\,dt \quad \ldots\ldots \quad 2.15$$

Now, power spectrum G(w) is defined by $G(w) = \underset{T\to\infty}{\mathrm{Lt}} \frac{|g_T(w)|^2}{T}$. 2.16

The term power is appropriate since f(t) is either voltage or current, $|g_T(w)|^2 \times dw$ will be proportional to the power associated with the frequencies in the interval of w to w + dw. Now, convolution theorem states that if $g_1(w)$ and $g_2(w)$ are the Fourier transform of time function $f_1(t)$ and $f_2(t)$ respectively, then the product $g_1(w)g_2(w)$ is the transform of the time function

$\int_{-\infty}^{\infty} f_1(x)\ f_2(t-x)dx.$ Let $g_1(w) = g_T(w)$ and

$$g_2(w) = \int_{-T/2}^{T/2} f(-t)\ \exp(-jwt)dt = \int_{-T/2}^{T/2} f(t)\ \exp(jwt)dt = g_T^*(w)$$

since f(t) is a real function.

$$\text{So, } g_1(w)xg_2(w) = \int_{-\infty}^{\infty} \left| \int_{-\infty}^{\infty} f_1(x)f_2(t-x)dx \right| \exp(-jwt)dt$$

$$\text{or, } g_T(w)g_T^*(w) = \int_{-\infty}^{\infty} \left| \int_{-T/2}^{T/2} f(x)f(x-t)dx \right| \exp(-jwt)dt.. \quad 2.17$$

This is by the given definition of $g_1(w)$ and $g_2(w)$. Since, by given definition g_1, g_2 relates with f(t), and since f(t) vanishes beyond the interval - T/2 to T/2, the limit of the inner integral becomes - T/2 to T/2, Thus,

$$G(w) = \underset{T \to \infty}{\text{Lt}} \frac{|g_T(w)|^2}{T} = \underset{T \to \infty}{\text{Lt}} \frac{g_T(w)\ g_T^*(w)}{T}$$

$$= \int_{-\infty}^{\infty} \left| \underset{T \to \infty}{\text{Lt}} \frac{1}{T} \int_{-T/2}^{T/2} f(x)f(x-t)dx \right| \exp(-jwt)dt \quad ..2.18$$

which shows that G(w) is the Fourier trensform of R(t) given by

$$R(t) = \underset{T \to \infty}{\text{Lt}} \frac{1}{T} \int_{-T/2}^{T/2} f(x)f(x-t)dx \qquad 2.19$$

i.e. $G(w) = \int_{-\infty}^{\infty} R(t) \exp(-jwt)\, dt$ and

$$R(t) = \tfrac{1}{2} \times \frac{1}{\pi} \int_{-\infty}^{\infty} G(w) \exp(jwt)\, dw.$$

The function $R(t)$ is called the autocorrelation function of the noise waveform. Putting $t = 0$, $R(t)$ becomes,

$$R(0) = \underset{T \to \infty}{\mathrm{Lt}} \frac{1}{T} \int_{-T/2}^{T/2} f^2(x)\, dx = \frac{1}{2\pi} \int_{-\infty}^{\infty} G(w)\, dw$$

$$\text{i.e.} \quad \overline{f^2(t)} = \int_{-\infty}^{\infty} G(w) \frac{dw}{2\pi} \quad \ldots \quad 2.20$$

(using equation 2.1).

Let $f(t)$ be a voltage developed across a one Ohm resistor. Thus $\overline{f^2(t)}$ is the average power dissipated in the resistor and the integral in equation 2.20 is the integrated power of the various frequencies represented. $G(w)$ can thus be regarded as a power density per unit frequency interval.

Autocorrelation function is useful in noise analysis since it can often be more easily calculated than the power spectrum. It can be measured by the circuit given in Fig. 2.6. Noise signals that arise in telecommunication systems have the properties which are independent of the choice of the time origin and it is easily shown that the output of the integrator will be proportional to $R(\tau)$. A series of readings can be taken for different values of τ and the autocorrelation function can then be plotted.

2.6 Noise due to Radio Interference

Radio noise performance of any system can be described as a function of three broad parameters:

(i) The generation of radio noise energy by corona on the conductors.

(ii) Line hardware

(iii) The propagation of the radio noise energy along the transmission line.

If the undesired interference signal is added to the desired FM signal, the spectral beats of both signals fall into every message channel, and is called interference noise.

Let the desired FM signal be $A_c \sin | w_c t + B_A(t) |$ and the undesired FM signal be $B_c \sin | w_d t + B_B(t) |$. Combining both signals, the output from the frequency discriminator is given by, if $B < A$,

$$e_o = (1/2\pi) \frac{dB_A}{dt} + (1/2\pi) \sum_{n=1}^{\infty} (B_c/A_c)^n \mathrm{Cos}\, n \,|\, (w_c - w_d)t + (B_A - B_B) \,|\, \times$$

$$\frac{d}{dt} \,|\, (w_c - w_d)t + (B_A - B_B) \,| \quad .. \qquad 2.21$$

The first term in eqn. 2.21 is the signal and the 2nd term is the interference. Three important factors in the interference

(1) Carrier frequency difference between the desired and undesired signal $(w_c - w_d)$.

(2) The desired to undesired signal ratio.

(3) The sidebend spectrum of the desired and undesired signal (the term $B_A - B_B$).

Now, the power spectrum of the desired signal is given by

$$S_A(f) = \frac{A_c^2}{2} \times \frac{1}{\sqrt{2\pi}\,\sigma A} e^{-(f-f_c)^2/2\,\sigma_A^2} \quad .. \qquad 2.22$$

where σ_A = effective frequency deviation of the desired signal.And for undesired signal,

$$S_B(f) = \frac{B_c^2}{2\sqrt{2\pi}\;\sigma_B}\, e^{-(f-f_d)^2/2\,\sigma_B^2}$$

$$= \frac{B_c^2}{2\sqrt{2\pi}\;\sigma_B} e^{-(f-f_c-f_o)^2/2\,\sigma_B^2} \quad .. \qquad 2.23$$

where, $f_d - f_c = f_o$ and σ_B = effective frequency deviation of the undesired signal. Now, power spectrum of the resultant noise is given by (for FM case)

$$S_{FM}(f) = \frac{2f^2}{A_c^4} \int_{-\infty}^{\infty} S_A(x)\; S_B(f+x)\; dx \quad .. \qquad 2.24$$

After the evaluation of the integral, equn. 2.24 becomes,

$$S_{FM}(f) = \tfrac{1}{2}\,(B_c/A_c)^2 \; \frac{f^2}{\sqrt{2\pi}\,\sigma}\; e^{-(f-f_o)^2/2\sigma^2} \quad .. \qquad 2.25$$

where $= A_A{}^2 + B^2$

The derivation of the above expression may be found in references[21]. If desired and undesired carriers are of same freq. (i.e. $f_o = 0$), then $S_{FM}(t)$ has a maximum value at a base band frequency of $f = \sqrt{2}\sigma$.

Interference in microwave systems are produced by antenna coupling. It may also happen by microwave signals in another link.

Sources of r-f interference may be calasified as (1) In-channel interference (2) Image channel interferance (3) Adjacent channel interference and (4) Single frequency interference.

2.6.1 Noise due to Corona

Radio noise would then have been created primarily by conductor corona. Which is distributed along the line on the surface of the conductor of the power line.

Corona discharges cause a modulation of the noise voltage envelope by superinposing additional noise impulses in cadence with the positive peaks of the power frequency voltage.[12]

This conductor corona is influenced by many variables in addition to the line geometry, such as conductor surface condition, precipitation, temperature, humidity etc.

2.7 Conducted Interference

The previous discussion covers noises that are generated within the cable itself. But outside interferences may also present within the cable. Such interference may enter into the cable in two ways viz. (i) by conduction (ii) by radiation. Interference by conduction i.e. conducted interference will be discussed in this section. The following section will cover radiated interference.

Equipment must be connected to other equipment, equipment must be connected to common power system, and equipments also must be connected to common grounds. Signal from one equipment, thus, can enter into the another equipment by such connection. This is called conducted interference. Thus conducted interference is that interference which enter into a circuit by conduction. Cable pairs of a multipaired cable are connected to various equipments in the exchange. Unwanted signals from these equipments can enter directly into the cable by conduction resulting conducted interference. These unwanted signals must be removed as much as possible by proper filtering. Also, the conducting medium may be made in such a way that it does not pick up unwanted energy. Of course, if the interfering signal falls in the voice band, then some times it becames very difficult to eliminate it and ultimately it appears at the receiver as interference.

2.8 Radiated Interference

The interference that enters in the cable (or equipment) by radiation is called radiated interference. The magnitude of interference that appears in the circuit depend on the following factors:

(1) Physical length of the exposed conducting medium

(2) The intensity of unwanted signals or fields to which the conducting medium is exposed.

(3) Particular types of interfering fields involved.

(4) The impedance of the termination to which the particular conducting medium connects.

Shielding is the only practical method of suppressing interference which is radiated directly from a source. A perfect shield will not allow the passage of either electrostatic or electromagnetic energy. Shielding partially reflects the interfering signal, and absorb the rest. The absorbed portion is attenuated as it passes through the metal shield.

2.9 Importance of Receiver Characteristics in Evaluating Effects of Noise[8]

The ultimate harmful effects of noise of any kind occur in the end device connected to the output circuit of a receiver, for example, a telephone receiver or a telemetering instrument. Because the noise is radically modified in passing through the tunned circuits and the detector of a receiver, it is necessary to consider the effect of receiver characteristics upon noise in any evaluation of the relative importance of the various parameters that may be used to describe the noise.

The tuned circuits of the receiver have a major modifying effect upon noise in its passage through the receiver, because only those frequency components of the noise that are accepted by the tuned circuits are detected and passed on to the end device. It is evident, therefore, that the selectivity of the receiver is an important factor in evaluating the ultimate effect of noise of a given type.

The most commonly used measure of selectivity is the width of the experimentally determined receiver selectivity curve between the two points at which the gain is 3 decibels down from the midband value G_o. A more specific measure is the power bandwidth, which is defined as

$$B_o = \frac{\int_0^\infty G^2(f)\,df}{G_o^2} \quad \ldots \qquad 2.26$$

where G(f) is the response of the receiver as a function of frequency. The power bandwith B_o is the width of an ideal (rectangular) response curve which would result in the same noise power output if substituted for the actual response curve G(f) with random noise applied to the receiver. It is shown that the power bandwidth of a cascade amplifier with "n" single-tuned circuits is, for ordinary values of Q,

$$B_o = \frac{\pi f_o (2n - 2)!}{Q 2^{2n-1} (n-1)!^2} \quad \ldots \qquad 2.27$$

where f_o is midband frequency and n is the number of tuned circuits. The Q of all the tuned circuits is assumed to be the same. By application of Stirling's formula,[7] this expression reduces to (approximately)

$$B_o = \frac{f_o}{2Q}\sqrt{\frac{\pi}{n-1}} \quad .. \qquad 2.28$$

For $n \geqslant 5$, the power bandwidth approaches to within a few percent the bandwidth specified on the basis of 3-decibels drop in gain.

2.9.1 Response of a Receiver to Random Noise

If the individual components of random noise have the same amplitude e at all frequencies, the mean square output of a receiver to which it is applied is

$$E^2 = \int_0^\infty G^2(f)e^2 df \quad .. \qquad 2.29$$

which from equation 2.27 can be expressed as

$$E^2 = e^2G_o^2B_o \quad ... \qquad 2.30$$

so that

$$E_{rms} = eG_o\sqrt{B_o} \quad ... \quad ... \qquad 2.31$$

Actually e will not have the same value at all frequencies, but due to the random nature of the amplitude distribution, the result is the same when the analysis is made on a statistical basis with e equal to the mean value of the component voltages.[9]

Thus, the rms noise output of a selective amplifier to which random noise is applied is proportional to the square root of the bandwidth of the amplifier.

The peak and the average values of the envelope of random noise are both statistically related to the rms value, and these relations are independent of the frequency interval. Hence, the peak and the average values of random noise also are proportional to the square root of the bandwidth.

2.9.2 Response of a Receiver to Impulse Noise

In the case of a sharp impulse applied to a receiver, which usually contains a number of tuned circuits, all of the tuned circuits oscillate but the envelope of the oscillation is different for each. Consider the case of a receiver having n singletuned circuits preceding the detector. For a sharp pulse applied at t = 0 in series with the inductance of the input circuit (for example, from an untuned coupling coil) the envelope of the oscillatory voltage applied to the detector by the nth tuned circuit is approximately:

$$E(t) = 2A_o a G_o \frac{e^{-at}(at)^{n-1}}{(n-1)!} \qquad \ldots\ldots \qquad 2.32$$

in which A_o is the integrated volt-time area of the original pulse, $a = \pi f_o/Q$, and G_o is the over-all gain of the stages considered for a continuous-wave signal at the midband frequency f_o, to which all the circuits are assumed to be tuned.

It is evident from Figure2.7 that the effect of the tuned circuits is to lengthen the pulse and to reduce its peak value. Also, the peak value occurs at a longer and longer time after application of the pulse as n is increased beyond a single stage. This peak occurs at

$$t = \frac{n-1}{a} \quad .. \qquad 2.33$$

at which time the amplitude of the envelope is

$$E_{max} = 2A_o a G_o \frac{e^{(1-n)} (n-1)^{n-1}}{(n-1)!} \quad .. \qquad 2.34$$

and from equations 2.28 and 2.34 again by application of Stirling's Formula,[7]

$$E_{max} = 2 \sqrt{2} A_o G_o B_o \qquad 2.35$$

Hence, the peak value of the envelope is directly proportional to the bandwidth, the gain of the receiver, and the area of the original impulse.

The peak value of the response of a receiver to impulses is an important factor in the operation of carrier communication channels. In an automatic simplex carrier assembly a transfer unit performs the switching operations between the transmit and the receive conditions and vice versa. The transfer unit responds to noise peaks when the exceed a certain preset level, normally

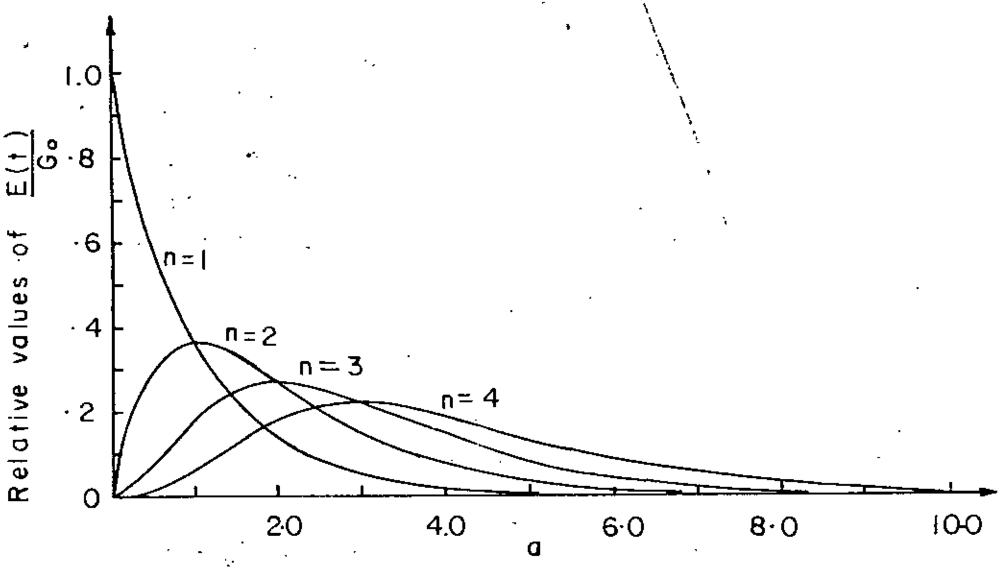


Fig. 2·7 Effect of number of tuned circuits.

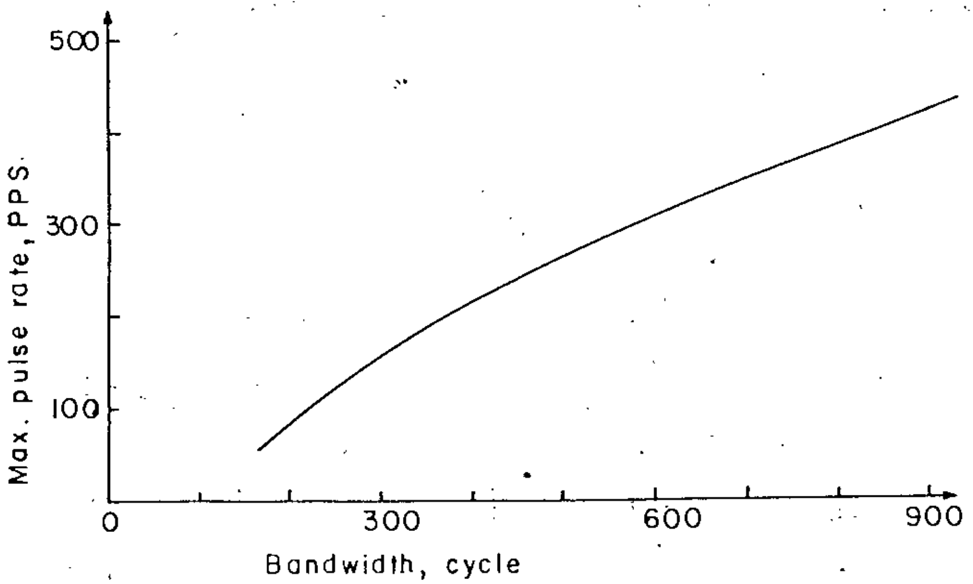


Fig. 2.8 Max. Pulse repetition rates

well below the minimum received carrier signal level, and under these conditions the carrier transmitter may be intermittently or permanently blocked. In other types of communication channels, impulse noise produces a masking or distracting effect which is roughly a function of the peak value of the noise at the output of the receiver and also of the repetition rate.

The average value of the envelope of the receiver detector output is the most important factor in evaluating the effect of repetitive impulse noise in the operation of carrier channels for telegraphic types of functions, for example, for relaying, telemetering, and supervisory control. Such functions usually involve use of a polarized d-c relay in the detector circuit. The detector itself is normally a linear diode or a linear plate detector. The average value of the response of such a system to sharp impulses can be found by first integrating equation 2.32 with respect to time as follows:

$$\int_0^\infty E(t)\,dt = 2A_o a G_o \times \int_0^\infty \frac{e^{-at}(at)^{n-1}\,dt}{(n-1)!} = 2A_o G_o \qquad .. \; 2.36$$

Then, if the pulses have a repetition rate of m per second, and provided that the repetition rate is such that the wave trains in the tuned circuits do not overlap appreciably, the average response is

$$E_{av} = 2mA_o G_o \qquad \ldots \qquad 2.37$$

which is independent of the bandwidth.

Since the spectrum of a unit impulse contains all frequencies with equal amplitudes, it follows that the noise energy in a given interval is proportional to the interval. Hence, the rms value of receiver response with impulse noise is proportional to the square root of the bandwidth, as with random noise. The rms value of the response is of less importance than peak and average values in evaluating the harmful effects of noise in powerline carrier applications, as previously indicated.

2.9.3 Response of Receiver to Combination of Random and Impulse Noise

In the preceding discussions, the assumption of purely random noise or purely impulse noise has been made throughout. Also, the impulses were assumed to be sharp and well separated in the case of impulse noise. If the noise is a composite type, made up of random noise and impulse noise with neither markedly predominant, the peak value of the noise at the receiver output can be expressed as

$$E_{max} = k_1 B_o^{\beta} \quad .. \qquad 2.38$$

where β has a value between 0.5 and 1.0. The average value of the output can be expressed as

$$E_{av} = k_2 B_o^{\gamma} \quad ... \qquad 2.39$$

where γ has a value between 0 and 0.5.

If the noise consists of sharp impulses, the separation of the impulses determines for a given bandwidth whether equations 2.35 and 2.37, which were derived on the assumption of a single sharp impulse, are applicable. If the repetition rate is sufficiently high to cause appreciable overlapping of the resulting wave trains in the receiver, the conditions for composite random and impulse noise, equations 2.38 and 2.39 apply. An idea of the bandwidths and pulse rates at which this begins to occur is given by Figure 2.8 , which shows for a 100-kc amplifier the pulse repetition rates at which the response to each individual pulse (equation 2.32) is down to 1 percent of its maximum value before the next pulse occurs.

It was reported[14] that the noise field in the vicinity of 3-phase transmission lines has an average pulse repetition rate on the order of 20 pulses per second, the pulses resulting primarily from corona discharges on the negative half-cycles of the 60-cycle voltage. Although at least 60 pulses per second might reasonably be expected, the erratic nature of the corona bursts produces an effective pulse rate below this figure.
It is therefore possible to conclude from Figure 2.8 that in carrier receivers of the usual bandwidths, the reponse to noise consisting predominantly of impulses is as given by equations 2.35 and 2.37 Thus, increasing carrier communication receiver selectivity should reduce proportionally the peak value of the response to impulses of the type found in power lines, up to the maximum selectivity

that can be used in such receivers. In telegraphic channels, however, where the average response to noise is most important, increased selectivity cannot be expected to reduce materially the effects of impulse noise until the extremely sharp selectivity is reached at which the wave trains resulting from the pulses begin to overlap. Further increases in selectivity should provide reductions in average response approaching proportionality to the square root of the resulting bandwidths.

2.10 Quasi-peak Value of Impulse Noise[8]

The quasi-peak value is based on the use of a detector output circuit which has a fast charging time (1 millisecond) and a relatively slow discharging time (600 milliseconds).[10,8] These time constants result in a reading which is near the peak value of the response of the detector to pulses occurring at a rate of approximately 15 or more per second, It has shown that quasi-peak readings are approximately proportional to the masking or distracting effects of noise.in aural reception of modulated signals. Hence, it is logical to expect quasi-peak readings of conducted carrier-frequency noise to be indicative of the probable effects of such noise on carrier communication channels of the duplex or manual simplex types. In the automatic simplex type, as has already been pointed out, the actual peak value is of more importance because it is the factor that determines whether the transfer unit operates.

With irregular pulses, or pulses of high amplitude that occur infrequently, the quasi-peak reading is somewhat less than the absolute peak value reached. When transfer unit operation is not involved, however, the masking effect of such peaks is not as great as if they were repetitive at a rapid rate, and the quasi-peak value is correspondingly lower than the maximum value.

2.11 Susceptibility of Receiving Equipment to Line Noise[1]

The narrower the pass band of the receiver, the less energy it will pass through it, and the less will be the effect of the noise. This is true of random noise, sometimes called white noise (on the analogy to light), which is evenly distributed over the spectrum. The noise power is proportional to the band width, and the effective noise voltage measured as rms, average, peak, or quasipeak is proportional to the square root of the bandwidth. With impulse noise, the situation is more complicated. A steep-front impulse contains all frequencies, and is thus evenly spread over the bandwidth, but the tuned circuits when hit with a pulse tend to ring or oscillate at their natural frequencies, and the higher the Q, corresponding to a narrower bandwidth, the more the ringing effect.

Most power-line noise consists of a mixture of random and impulse noise. The peak may be said to vary as $(\text{bandwidth})^B$ where B is between 1/2 and 1, and the average to vary as $(\text{bandwidth})^a$ where a is between 0 and 1/2. The quasipeak value will behave somewhat like the peak value.

Line noise is primarily an amplitude effect, and as might be expected, amplitude modulation (AM) of the various types of modulation, is the one most susceptible to noise interference.

However, the advantages claimed for frequency modulation (FM) are considerably reduced for power-line carrier as compared with broadcasting. The large number of channels demanding space in the carrier spectrum make it desirable to limit a communications channel to 6 kc, the same for FM as for AM. This necessitates a deviation ratio of unity or less, and at these low ratios the noise discrimination is much reduced. Moreover, if the noise rises above the signal, it may take control of the channel, and exclude the signal.No results of detailed studies of noise interference with narrow-band FM are available, but the consensus of opinion is that with fair signal-to-noise ratio, FM will show up to advantage, and will suppress some of the noise, so that the audio signal-to-noise ratio is better than for AM under the same noise conditions.

Single side band (SSB) is basically a form of AM, but has several important advantages. First, the bandwidth need be only half that for AM which reduces the noise accepted, and second, for a given transmitter power, all the output capability, instead of one fourth, as with AM, can be concentrated in the intelligence. A third advantage is with corona modulation. Since this occurs directly in proportion to the signal, with AM the audio noise output will be constant as the carrier is constant. Thus, weak speech may be swamped. With SSB as the speech goes down, the signal goes down also, and so does the audio noise; therefore, weak speech has less chance of being masked.

For telegraphic functions, working on keyed carrier, reduction of bandwidth is of some help, but not as much as for telephonic functions. As has been shown, the average noise value is the determining factor, and for mixed noise the effect varies from the zero power to the 1/2 power of the bandwidth.

Frequency-shift transmission is capable of operating over much greater attenuation. This, in effect, means with a lower actual signal-to-noise ratio than conventional on-off continuous wave transmission. This is partly due to the extremely narrow bandwidth, but more to the use of a limiter and balanced discriminators, which tend to cancel the effects of noise voltages.

CHAPTER - 3

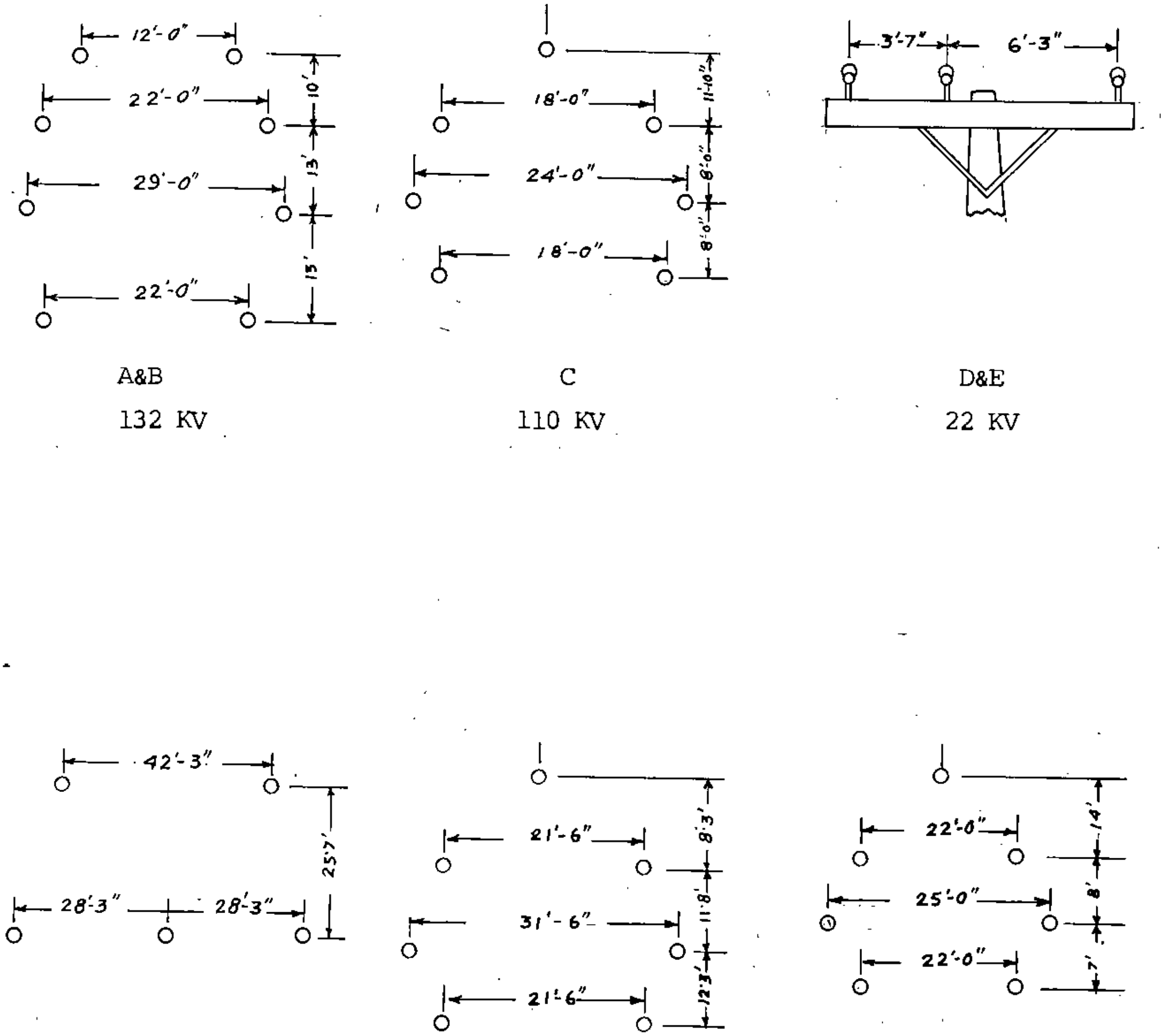
NOISE AND ATTENUATION IN CABLES AND SWITCHING NETWORKS IN POWER LINE CARRIER COMMUNICATION SYSTEM

3.0 Preliminaries

In the chapter discussion will made about noise, interference and atteuation in cables and switching networks of power line carrier communication system.

It was discussed in previous chapter that noise generally fall into two categories ; random noise which has a continuous frequency spectrum and impulse noise which consists of sharp well - separated impulses due to specific electrical discharges. Power line noise is predominately of the impulse type, the impulse peaks being well above the general level, but the space in between the pulse is occupied by random noise.

Noise on the lower - voltage transmission lines is caused chiefly by deffective insulators and lose hardware on the high voltage line by radio interference which is mainly conona discharge. All circuits are subject to the noise effects of atmospherics, line faults,switching surges and faulty apperatus. Noise increases subtantially in bad weather as the combined result of lightning. Corona from drops of water or particales of snow or ice on the conductor and leakage over insulators. Background noise is generally greater at the lower frequencies but disturbances and lightning storms may produce high noise level through out the entire spectrum.



A&B
132 KV

C
110 KV

D&E
22 KV

F&G
220 KV

H
132 KV

I
66 KV

Fig. 3.1: Details of typical line configuration.

Attenuation is a measure of the loss of energy between the transmitting and receiving terminal and depends on many factors: frequency, conductor size and spacing, line configuration, presence of ground wires, parallel circuits, transpositions, ground resistivity, mismatching modes of propagation and weather condition. The type of coupling used and the phase to which it is applied control the total attenuation from terminal to terminal.

3.1 General Nature of Conducted Carrier-Frequency Noise[15]

A summary of the quasi-peak to average noise voltage ratios obtained at all locations (figure 3.1) is given in Table 3.1 for frequencies of 30,100, and 200 kc. In all cases the ratio exceeds the figure of 1.8, which has been used as a criterion for the predominance of impulse noise[8].

Table 3.1: Ratio of Quasi-Peak to Average Noise Voltage

Location	Kv	Frequency, Kc		
		30	100	200
A	132	2.0	4.0	4.0
B	132	2.0	2.25	2.04
C	110	4.12	5.0	5.0
D	222	2.36	2.8	2.34
E	22 (Fair Weather)	5.0	3.03	2.66
E	22 (Thunderstorm)	5.84	2.9	2.31
F	220	3.5	2.9	3.4
G	220	2.6	2.9	3.8
H	132	2.5	2.45	2.86
I	66	1.94	2.35	3.42
J	66	2.5	2.0	2.5

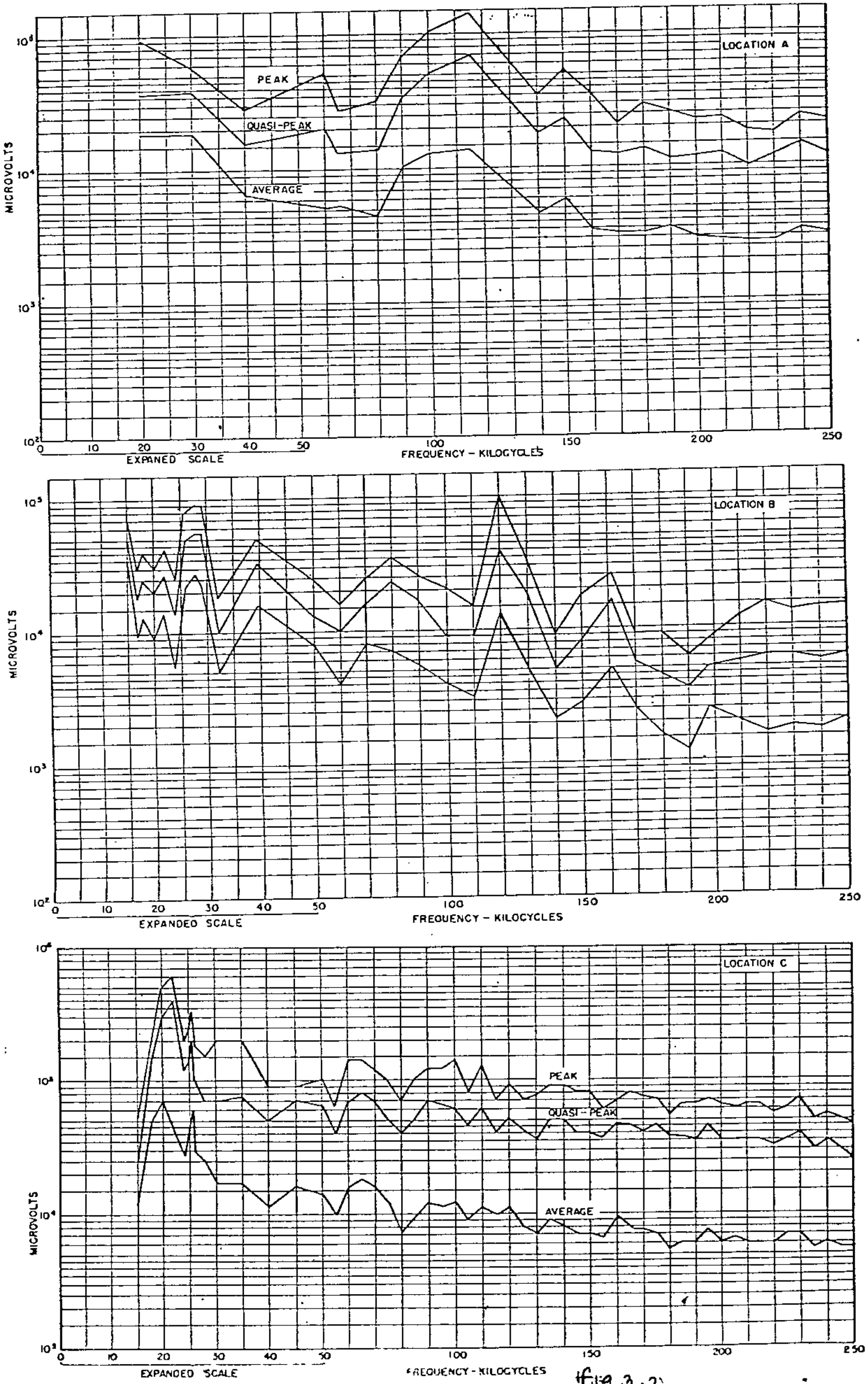

LOCATION A
PEAK
QUASI-PEAK
AVERAGE
MICROVOLTS
10⁵
10⁴
10³
10²
0
10
20
30
40
50
100
150
200
250
EXPANED SCALE
FREQUENCY - KILOCYCLES
LOCATION B
MICROVOLTS
10⁵
10⁴
10³
10²
0
10
20
30
40
50
100
150
200
250
EXPANDED SCALE
FREQUENCY - KILOCYCLES
LOCATION C
PEAK
QUASI-PEAK
AVERAGE
MICROVOLTS
10⁶
10⁵
10⁴
10³
0
10
20
30
40
50
100
150
200
250
EXPANDED SCALE
FREQUENCY - KILOCYCLES

Fig 3.27

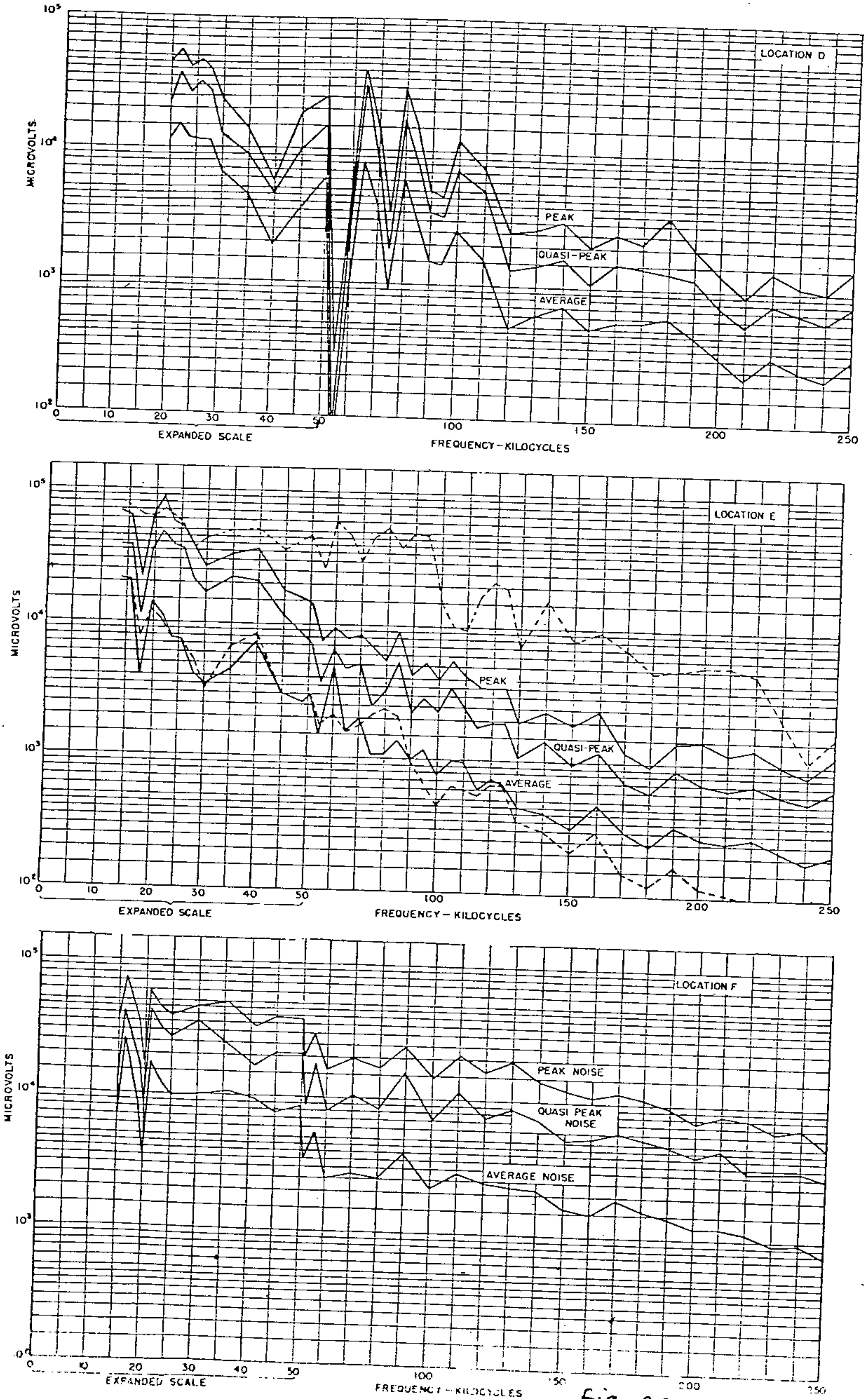

LOCATION D
PEAK
QUASI-PEAK
AVERAGE
MICROVOLTS
10⁵
10⁴
10³
10²
0
10
20
30
40
50
100
150
200
250
EXPANDED SCALE
FREQUENCY-KILOCYCLES
LOCATION E
PEAK
QUASI-PEAK
AVERAGE
LOCATION F
PEAK NOISE
QUASI PEAK NOISE
AVERAGE NOISE

Fig-3.2

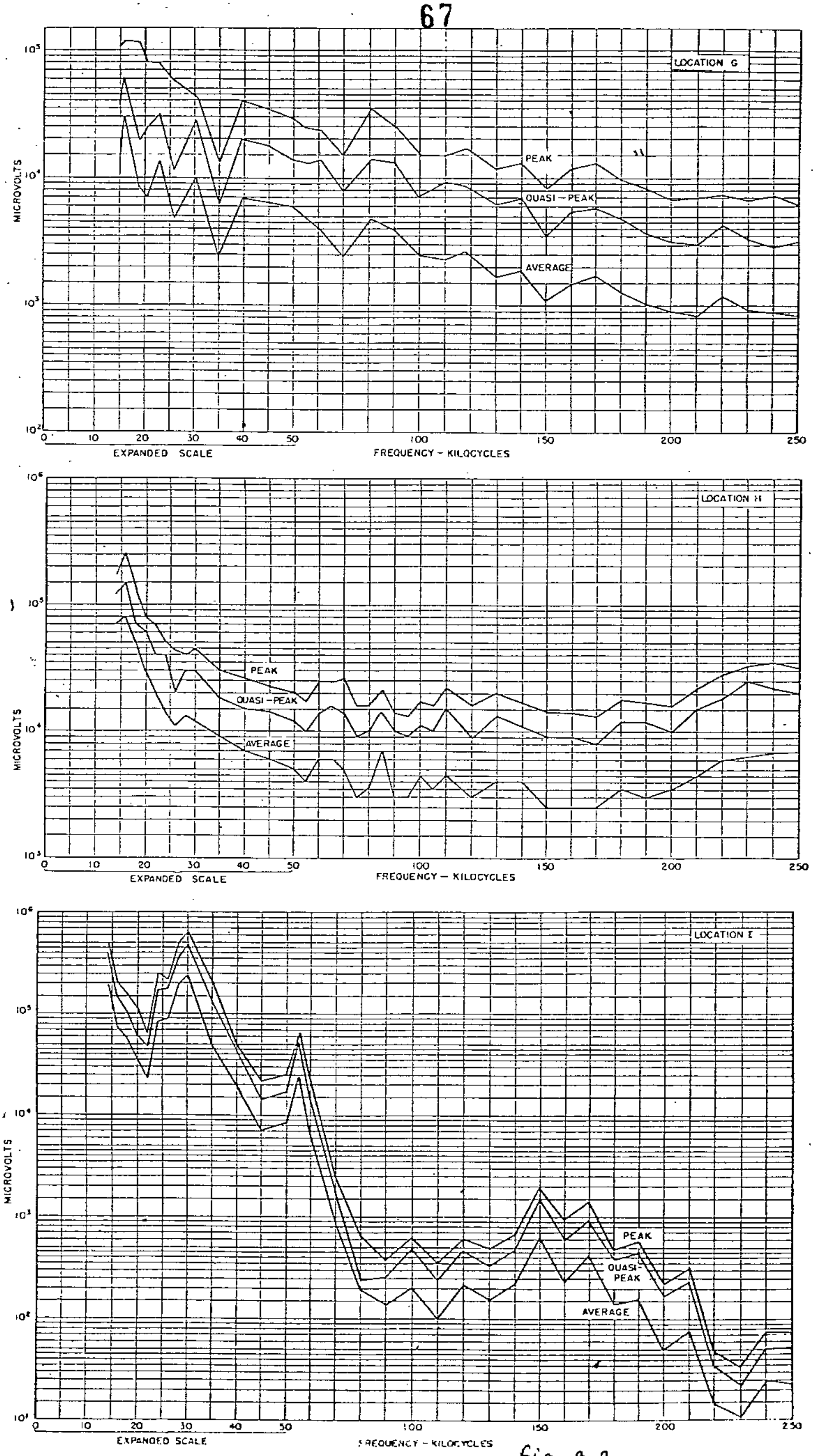

LOCATION G
PEAK
QUASI-PEAK
AVERAGE
MICROVOLTS
10⁵
10⁴
10³
10²
0
10
20
30
40
50
100
150
200
250
EXPANDED SCALE
FREQUENCY - KILOCYCLES
LOCATION H
PEAK
QUASI-PEAK
AVERAGE
MICROVOLTS
10⁶
10⁵
10⁴
10³
EXPANDED SCALE
FREQUENCY - KILOCYCLES
LOCATION I
PEAK
QUASI-PEAK
AVERAGE
MICROVOLTS
10⁶
10⁵
10⁴
10³
10²
10¹
EXPANDED SCALE
FREQUENCY - KILOCYCLES

Fig 3.2

3.2 Variation of Noise Voltage with Frequency[15]

Curves of the peak, quasi-peak, and average noise voltages over the frequency range of 15 to 250 kc at all locations (Fig./3.1 studied are shown in Figure 3.2. All the curves show a general increase in noise level with decreasing frequency. This indicates that the rather general practice of reserving frequencies at the low end of the carrier spectrum for long-haul channels, to take advantage of the lower attenuation at these frequencies.

The peaks and valleys that occur in the curves of Figure3.2 are believed to be at least partly attributable to the presence of stub lines at or near the test locations, because in some cases they occur with a degree of regularity with respect to frequency. If the assumption that stub lines are responsible for these effects is correct, it appears that noise is affected by such stub lines in much the same manner as signals, and that a large portion of the noise at a given location arrives from distant sources.

3.2 Variation of Noise Voltage with Weather Conditions and Switching Operation[15]

The dotted curves of Figure3.2(e) show the results of a ? series of peak and average voltage measurements made during a heavy thunderstorm, as compared with the solid curves which show results of measurements made at the same location during bright and clear weather. In some portions of the spectrum the peak

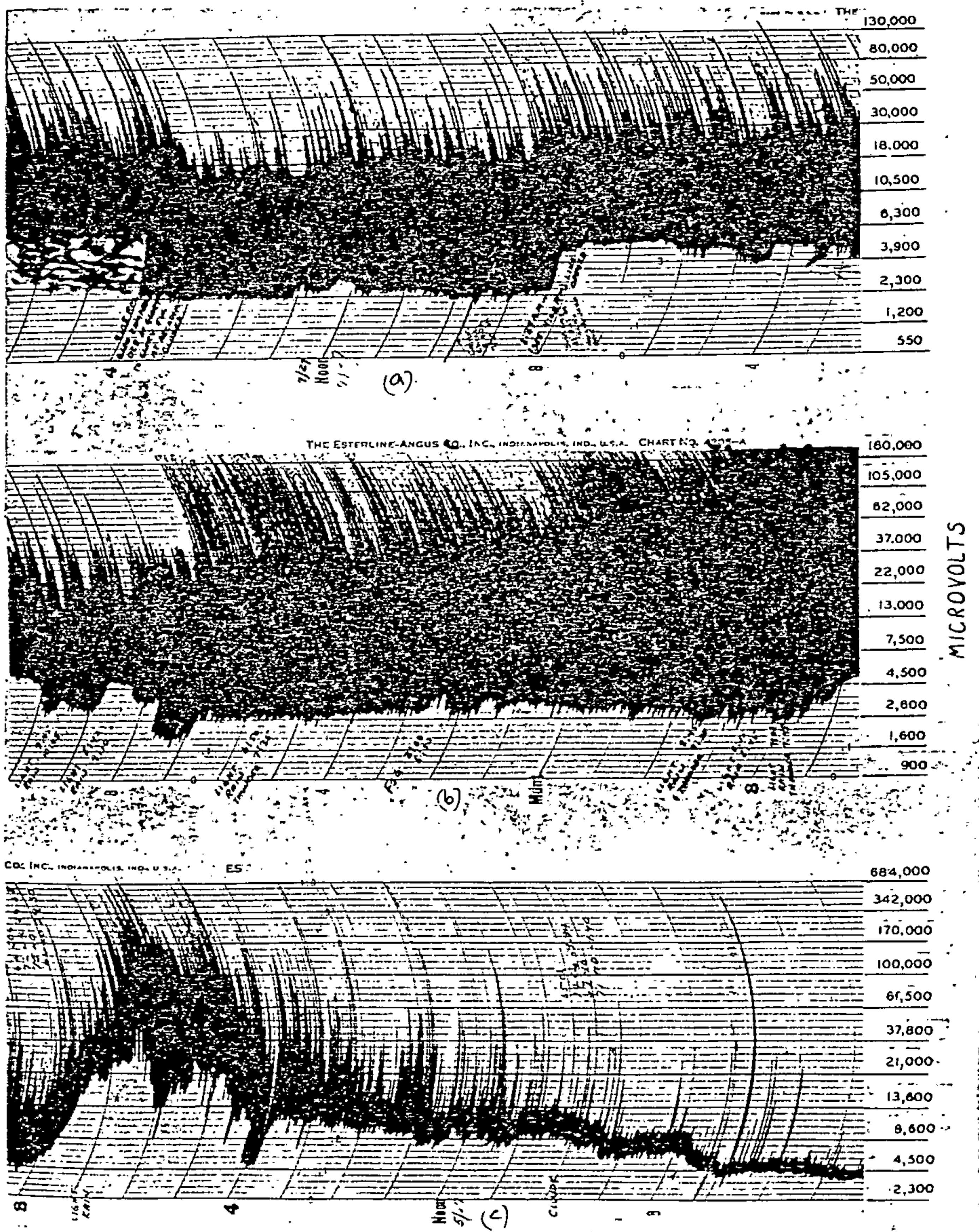

THE ESTERLINE-ANGUS CO., INC. INDIANAPOLIS, IND., U.S.A. CHART NO.
MICROVOLTS
130,000
80,000
50,000
30,000
18,000
10,500
6,300
3,900
2,300
1,200
550
4
7/27
Noon
8
4
(a)
160,000
105,000
62,000
37,000
22,000
13,000
7,500
4,500
2,600
1,600
900
8
4
Mdn
8
(b)
CO. INC. INDIANAPOLIS, IND. U.S.A.
684,000
342,000
170,000
100,000
61,500
37,800
21,000
13,600
8,600
4,500
2,300
8
LIGHT RAIN
4
Noon
5/
(c)
CLOUDY
8

Fig 3.2

values during stormy weather were as much as ten times the fair-weather values. Readings of average voltage during stormy conditions followed very closely the curve taken for fair weather conditions. These results indicate that the major increase in the noise level during stormy weather resulted from the presence of extremely large impulses of entirely random occurrence. The repetition rate of these pulses was apparently too low to affect the average value of the noise response appreciably.

Typical chart records are shown in Figure 3.3 . to determine the range of time and under a variety of weather conditions. Figure3.3(a) is of interest because it shows a marked drop in noise level coincidental with a switch operation and restoration of the original noise level when the system returned to the previous setup. Fair weather prevailed throughout this sample record.

A marked increase in quasi-peak noise during thunderstorms is indicated by Figure3.3(b), in which the chart pen continually ran off scale during thunderstorm conditions. Much lower values are indicated during subsequent light rain without thunder, however, indicating that the increase in noise level was more closely associated with lightning discharges than with rain itself.

A gradual increase in noise level with increasing cloudiness and subsequent light rain, followed by a return to lower values with clearing weather, is indicated by Figure3.3(c).

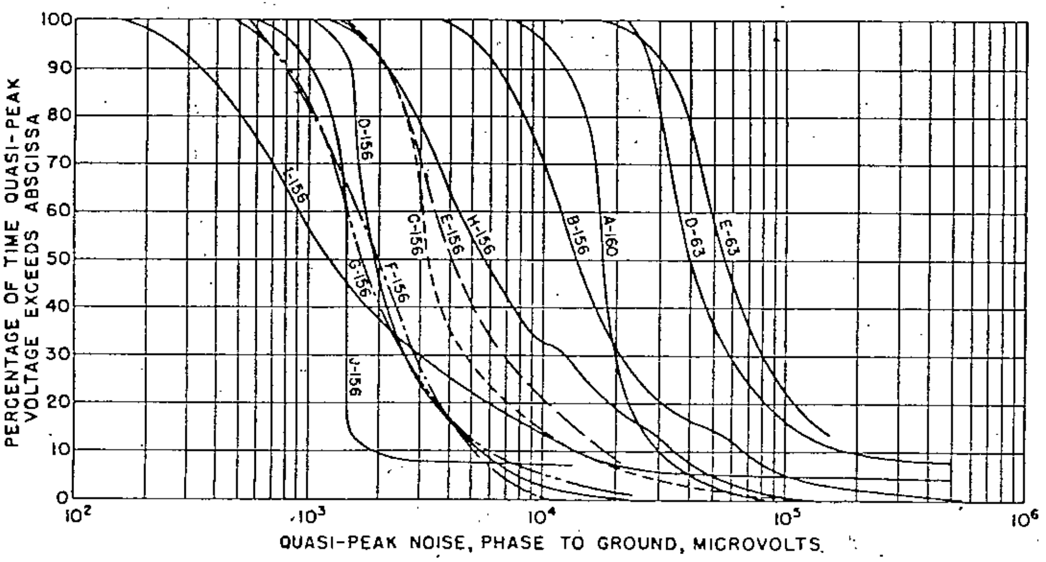

PERCENTAGE OF TIME QUASI-PEAK VOLTAGE EXCEEDS ABSCISSA
100
90
80
70
60
50
40
30
20
10
0
10^2
10^3
10^4
10^5
10^6
QUASI-PEAK NOISE, PHASE TO GROUND, MICROVOLTS.
I-156
D-156
G-156
F-156
C-156
E-156
H-156
B-156
A-160
D-63
E-63
J-156

Fig - 3.4

Fog and light rain without thunder appeared to coincide with noticeable but not extreme increases in recorded noise..

3.3 Variation of Noise with External Sources[15]

The high noise level recorded for a portion of the time in figure3.2(I)was caused by intermittent operation of are furnaces. The chart record for this location shows frequent sudden increases in noise level from low steady values to very high and fairly constant levels, followed by equally sudden drops back to the lower values. Because of the low minimum values, it is believed that the noise generated on the transmission lines themselves associated with this location was much lower than is indicated by analysis of the chart record including this externally generated noise.

3.4 Variation of Noise Voltage with Time[15]

The continuous chart records were analyzed as follows: The total recording time at each location was divided into half-hour intervals, and the maximum quasi-peak value reached in each of these intervals was noted. The maximum value was taken as the maximum excursion of the recorder pen, exclusive of the six highest excursions in any half-hour period. High isolated peaks of relatively infrequent occurence were thus eliminated, on the basis that these would not seriously affect carrier channel operation in any of the usual applications. The number of time intervals during which the noise exceeded specific values was then plotted as a percentage of the total number of time intervals for each case.

The curves of Figure3.4 show that the general noise level at a given location, is not a function of system voltage alone. Further evidence of the inverse variation of quasi-peak noise levels with frequency are the curves for noise. These curves constitute more conclusive evidence than Figure 3.2 of the increase of noise with reduced frequency because the data for these curves were taken over sufficiently long intervals to be representative of the normal distribution of the noise levels with time.

3.5 Radio Interference[1-6]

The corona which is distributed along the line on the surface of the conductor has been considered to be the source of the radio interference. This conductor corona is influenced by many variables in addition to the line geometry such as conductor surface condition, precipitation, temperature, humidity, etc.

A strong electric field exists in the region adjacent to the transmission-line conductor during normal operation. This electric field varies periodically with time in the same manner as the applied voltage.

The electric intensity E_{prin} in the region immediately adjacent to the antenna of a radio receiver induces a voltage in the antenna circuit. This is an interference voltage or noise signal. After passing through the mixer and intermediate-frequency (i-f) sections of the receiver, the noise signal is detected, amplified, and then converted to sound by the speaker

The over-all characteristic of the mixer and i-f sections is bandpass in nature, i.e., only a small range of frequencies from $f=f_a$ to $f=f_b$ and centered about $f=f_o$ is transmitted without appreciable attenuation.

If $|Y|$ is the absolute value of the overall transfer function of the mixer and i-f sections, and if the spectral density of the noise signal does not vary strongly with frequency over the passband of the receiver, the mean square value of the output of the i-f stage is given by

$$< (\text{i-f output})^2 > = U_q |(k(f_o)| \int_{f_a}^{f_b} |Y|^2 df \quad .. \qquad 3.1$$

Thus, the mean square value of the i-f output is given by the triple product of the field factor U_q, the test-cage current spectral density factor at the frequency f_o to which the receiver is tuned, and a third factor which depends upon the transfer characteristics of the receiver.

This mean square value of the i-f output can be used as a measure of the noise signal or of the interference level of the line. Such a use or the mean square value or the noise power is very common in communication engineering.

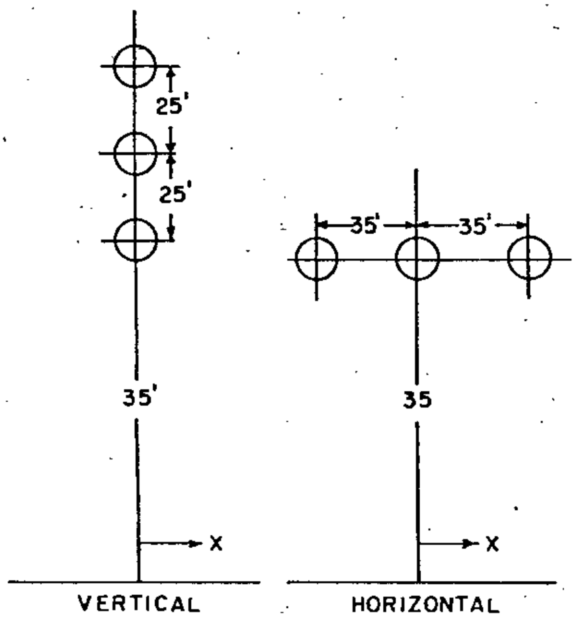


Fig. 3.5 Cross sectional view of Transmission lines.

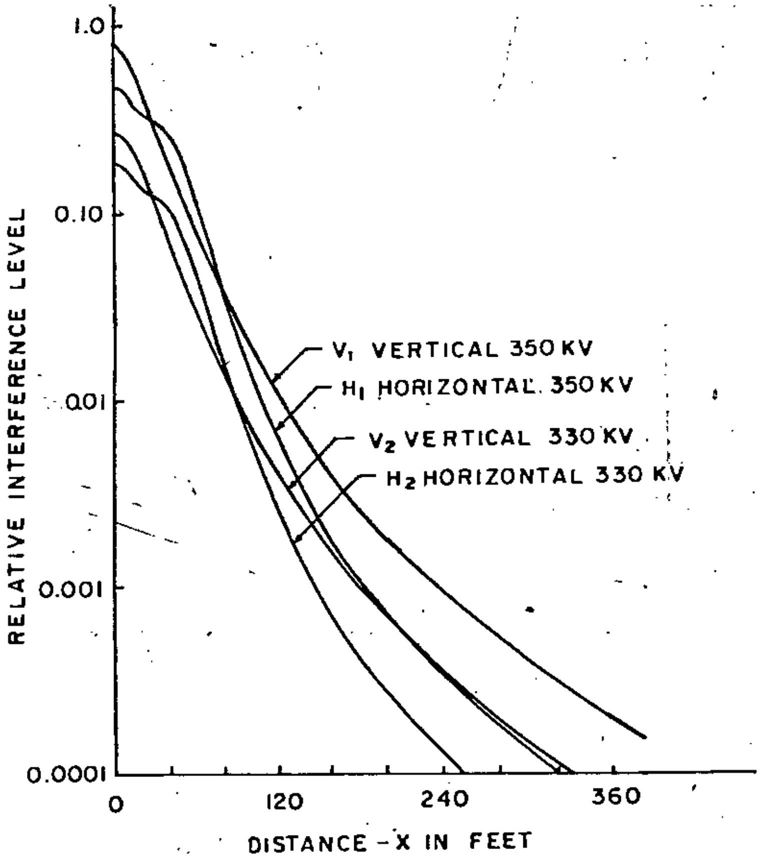


Fig. 3.6

Horizontal and vartical power line configuration is shown in figure 3.5 . In figure 3.6 , The relative interference level is shown for different configuration as well as different system voltage.

At the center of the line, the interference level of the vertical arrangement is greater than that of the horizontal by roughly 50 percent. For lateral distances from the center of the line between about 25 and 80 feet, very little difference exists between the interference levels of the two arrangements. For distances greater than about 80 feet, the interference level of the vertical line is appreciably greater than that of the horizontal.

3.6 Noise and Interference in Telephone Exchange

Various types of machineries and equipments are used in the exchanges. These are the sources of interference e.g. d-c rotating machineries like electric motor, generator, drill etc. generates interference due to arcing produced in the process of commutation. Similar type of interferences occur in motors containing slip rings. Oxidation is another perennial source of interference in rotating machineries. Oxidation film is generally formed irregularly causing variations in the sliding control resistance which in tern causes the d-c current to vary, resulting in r-f interference. The oxidation film also sets up a rectifier condition which makes transients possible since the resistance vary non-linearly, depending on whether the brush is positive or negative.

In machines where rotor and stator are not electrically connected, interference develops because of the discharges of the electrostatic energy which builts upon the seperate moving parts. This becomes important specially at high speeds, where, for example, the grease or lubricant between the inner and outer cases of a ball bearing acts as a dielectric. Energy buields up on both sides and eventually discharge takes place across the dielectric. Of course a conductive lubricant would eliminate this problem, however, this technique is not yet used commercially. Another successful technique is to ground the rotating shaft by use of slip ring. In case of commutator machines, capacitors are connected, to reduce interference, across brush holder and machine frame. It is obvious that machines containing no commutation or slipring produces negligible interference. Thus induction motors are best for this purpose.

3.7 Role of Grounding in Reducing Interference

The most general and the most important reason for grounding of any equipment, building, structures etc. is to make sure that no dangerous voltages are present on accessible parts of equipment, building etc. that will endanger the safety of persons who come in contact with it. Under this general reason, there are other reasons for grounding, one of the most important is the reduction of interference. Another is for the safety of the equipment. Power system is similarly grounded mainly for (1) protection of equipment (2) easy fault location and (3) safety to persons.

But in communication system, in addition to the safety of equipment and person grounding helps in two ways:

(i) reduces interference

(ii) save a conductor

Interference reduction by grounding of equipment body and chasis is obvious. If bodies of the equipments are at same potential and grounded, then all unwanted signals will go to ground. Saving of a conductor by grounding can be shown by assuming that a subscriber of an exchange A wants to make a connection to one of the subscriber at another exchange B. Obviously 1st group selector will be provided by exchange A and other group selectors will be provided by exchange B. Now to control the selectors in exchange B by the subscriber of exchange A, the battery terminals of exchange A must be extended to exchange B. For this purpose one terminal of the battery is grounded and the ground acts as one of the conductors to extend the battery to the other exchange. Thus grounding can save a conductor. Of course, ground contact resistance, Rg, must be very small. Otherwise switches will not function properly and coupling by Rg will also be appreciable. For proper grounding various factors are to be considered. Important factors are (1) ground rod, (2) depth, and (3) treatment of the soil.

3.8 Attenuation[1]

In carrier transmission, it is convenient to consider the transmission characteristic of a system in terms of attenuation, or the decrease of power along the transmission line. The ratio between the voltages, currents, or power at any two points is a measure of the attenuation of the circuit between these two points. However, it is not convenient in practice to express transmission losses or gains in terms of these ratios directly. The losses so expressed cannot be added to obtain the total loss, but must be multiplied. Consequently, this attenuation is expressed in decibels (db), which can be added directly

The total attenuation of a power-line carrier circuit consists of resistance and radiation losses in the transmission line itself; losses due to the power straying from the desired path; and losses due to coupling equipment and by-passes. If we express each of these losses in decibels, we can get the total loss over a channel by simple addition.

3.8.1 Line Attenuation

At carrier frequencies, the average power line represents a transmission circuit which is very long as compared to the wave length of the carrier signal being transmitted. Such a line can be represented as a very large number of resistors and inductors in series, and an equally large number of capacitors and resistors shunting the line.

In the theoretical case where the conductor size, condition, spacing, height from ground, shunt-path resistance, and ground resistance is constant, the configuration of the equivalent circuit is simple, and the characteristic impedance, loss, and other characteristics of the line can be calculated rather easily.

The line attenuation is affected by the method of coupling to the line. Phase-to-ground coupling is most commonly used. With this method, the signal goes out or one phase wire and may return over a variety of paths depending on ground resistance and configuration of the power line. Some energy returns through the ground path and some through the ground wire if there is one.

With phase-to-phase coupling, there is a definite return path over another phase wire and the losses are usually lower than for phase-to-ground coupling. This is partially due to lowered resistive losses in the path. Phase-to-phase coupling also reduces radiation of carrier energy into space, since the effectiveness of the transmission lines as an antenna decreases as the spacing between the outgoing and return paths gets smaller.

Higher voltage lines usually have lower losses, due to the longer insulation strings which reduce carrier leakage and dielectric loss in the insulation. As the carrier frequency increases, losses also go up due to increased radiation, effective conductor resistance, and dielectric losses. Table II shows typical attenuation data which can be used for estimating transmission-line attenuation.

In estimating the attenuation over a section of transmission line, the effect of environment and weather should be taken into account. Rain does not affect attenuation appreciably, Heavy rains may, by washing of insulators, actually decrease path attenuation.

Table3.2: Transmission-Line Attenuation

Line Voltage, Kv	Approximate Attenuation, Db per Mile									
	Phase-to-Phase Coupling					Phase-to-Ground				
	20kc	50kc	100kc	150kc	300kc	20kc	50kc	100kc	150kc	300kc
230	0.03	0.05	0.08	0.11	0.20	0.04	0.06	0.09	0.13	0.25
138	0.04	0.07	0.09	0.12	0.22	0.05	0.08	0.11	0.15	0.27
115	0.05	0.08	0.10	0.14	0.27	0.06	0.09	0.13	0.16	0.34
69	0.06	0.08	0.11	0.15	0.29	0.07	0.10	0.14	0.18	0.36
3.45	0.07	0.10	0.13	0.18	0.38	0.09	0.13	0.16	0.22	0.47
13,8	0.12	0.15	0.18	0.22	0.45	0.15	0.19	0.22	0.27	0.56

It has been definitely established that sleet on a transmission line increases the attenuation at carrier frequencies. It appears[18] that the attenuation over portions of line with heavy sleet can be as great as eight times (in db) the normal attenuation of those portions of the line. Losses in coaxial cable can be estimated from Table 3.3.

Table33: Approximate Losses in CoaxialCable

Frequency, Kc	Loss, Db per 1,000 Feet
20	0.20
50	0.32
100	0.50
150	0.60
300	0.90

3.8.2 Attenuation at Discontinuities

The characteristic or surge impedance of a transmission line is the impedance as measured at the input terminals, if the line has infinite length or if a finite length of the line is terminated in a resistive load equal in value to the characteristic impedance, the input impedance will vary in both magnitude and phase. At the point of improper termination, there is a reflection of The signal at this point with a resultant increase in attenuation. In addition to the reflection loss there is a loss in the device causing the discontinuity.

3.8.3 Attenuation due to Branch Circuits

I) Long Branch Circuits: When a carrier transmitter is coupled to a power system at a point from which several long unt~~f~~apped transmission lines radiate, the load impedance presented to the carrier equipment is the parallel of the characteristic impedances of the lines involved. The impedance-matching transformer in the line tuner can usually be adjusted so that this impedance is transferredc to load the transmitter properly, so that there is no reflection loss. However, the division of the energy among the several circuits in effect constitutes and attenuation of energy along the desired path, If the characteristic impedances of all the lines involved are the same, the losses at a transmitting terminal in this case are as shown in Table3.4. It should be noted that these losses are only correct for a transmitting terminal.

Table 34: Losses due to Long Branch Circuits at Transmitting Point

Additional Circuits	Db Loss
1	3.0
2	4.8
3	6.0
N	$10 \log(N+1)$

If one or more long untrapped lines radiate from an intermediate point in a carrier channel, or from a receiving point, there is a loss due to reflection as well as a loss due to division of the energy among the circuits. Treatment of this case as a shunt discontinuity, by methods previously outlined, yields the results given in Table 35.

Table 35: Losses due to Long Branch Circuits Remote from Transmitting Points

Additional Circuits	Db Loss
1	3.5
2	6.0
3	8.0
N	$20 \log (\frac{N+2}{2})$

II) Short Branch Circuits: As contrasted with the long branch circuits just considered, short untrapped spur lines (in general, lines less than 50 miles in length) may present shunt impedances differing radically from the characteristic impedance of the line. If the terminating impedance and the length of a spur line are known accurately, it is feasible to calculate the impedance such a spur line presents at its input terminals at a given frequency.

After installation of the equipment a carrier frequency cannot be chosen that maximizes the spur-line impedance, it may be necessary to install line traps to isolate the spur line from the carrier channel. In this case the effect of the spur line upon the attenuation is reduced to a low value, depending upon the characteristics of the line trap.

3.8.4 Attenuation due to Multipath Transmission:

A carrier circuit that includes two alternate paths may suffer attenuation due to out-of-phase arrival at a common point of signals travelling over the two paths. The magnitude of this attenuation is highly variable, depending upon the nature of the two paths, their relative individual attenuations, and the frequency used. The relative amplitudes and the phase of the two signals arriving at the junction of the paths determines the additional attenuation. Specific cases are as follows:

1. Equal Amplitudes, In-Phase Arrival: Reflection losses of 0.5 db at junction and at branch point due to impedance mismatch. Total attenuation from branch point to junction 1.0 db plus attenuation of one path.

2. Equal Amplitudes, Out-of-Phase Arrival: Cancellation of voltage at junction, infinite attenuation. This is an unlikely condition because two long alternate paths having exactly the same attenuation are rarely encountered. The attenuation may still be large in practical cases, however, as pointed out below.

3. Unequal Amplitudes, In-Phase Arrival: Total maximum loss 3.5 db at branch point due to reflection and division of energy, plus 3.5 db maximum at junction, plus attenuation of shorter path. These maximum losses are based on complete attenuation of the signal in the longer path.

4. Unequal Amplitudes, Out-of-Phase Arrival: Minimum loss at junction 3.5 db, increasing with decreasing difference in attenuation of the two paths, as shown in Table3.6. To this loss must be added 3.5 db loss at the branch point due to reflection and division of energy, plus the attenuation of the shorter path.

Table3.6: Attenuation due to Out-of-Phase Arrival of Signals at a Junction of Two Long Alternate Paths

Difference in Path Attenuation, Db	Attenuation at Junction, Db
0	Infinite
1	23.0
2	17.7
3	14.2
4	12.4
5	10.8
6	9.5
7	8.4
8	8.0
9	7.4
10	7.0
11	6.5
12	6.2

If both paths are short and of unequal length, the attenuation may be very great, particularly if one of the paths is 1/2 wave length longer than the other.

In general, if the frequency cannot be adjusted after installation to avoid out-of-phase arrival at a junction, it may be necessary to resort to the use of line traps to eliminate alternate paths.

3.8.5 Attenuation due to Carrier Propagation:

Several conducting paths exist on a power line, including at least three power phases and a ground path, which usually consists of one or two ground wires and earth. When a carrier voltage is impressed upon an input circuit consisting of any two of these paths, a wave of carrier energy will proceed down the line, apparently beginning the same as on the theoretical two-conductor communication circuit. Except with special cases of symmetry, however, the energy is not confined to the intended route. Mutual coupling between conductors causes a continuing interchange of energy which results in changing proportions of current as the signal progresses down the line.

Modal analysis can become complicated on multicircuit lines, but its best application appears to be for the longer lines of extra-high-voltage systems. These systems usually consist of a single-circuit 3-phase horizontal line. This type of line may operate in three modes:[11]

Mode 1. The current in the middle phase is roughly twice that in the outer phases and flows in the opposite direction.

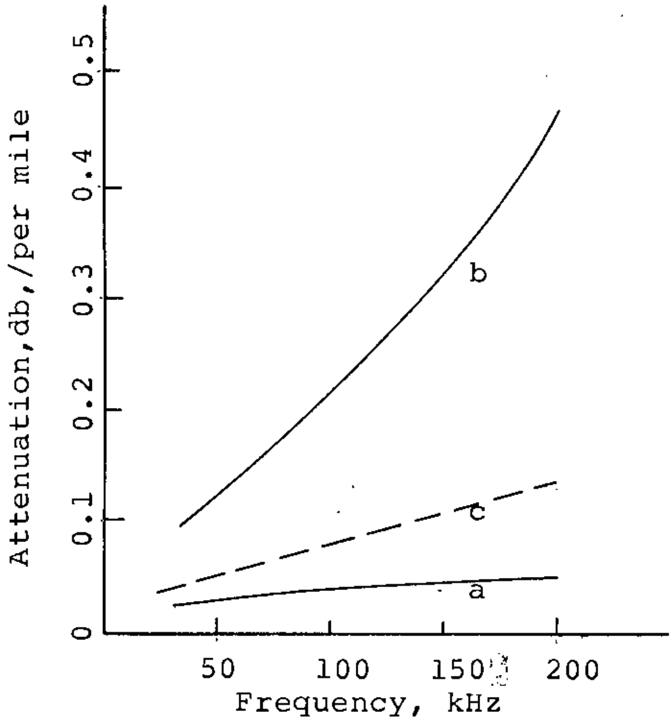


Fig. 3.7.

(a,b,c - different line length in miles around 100 miles).

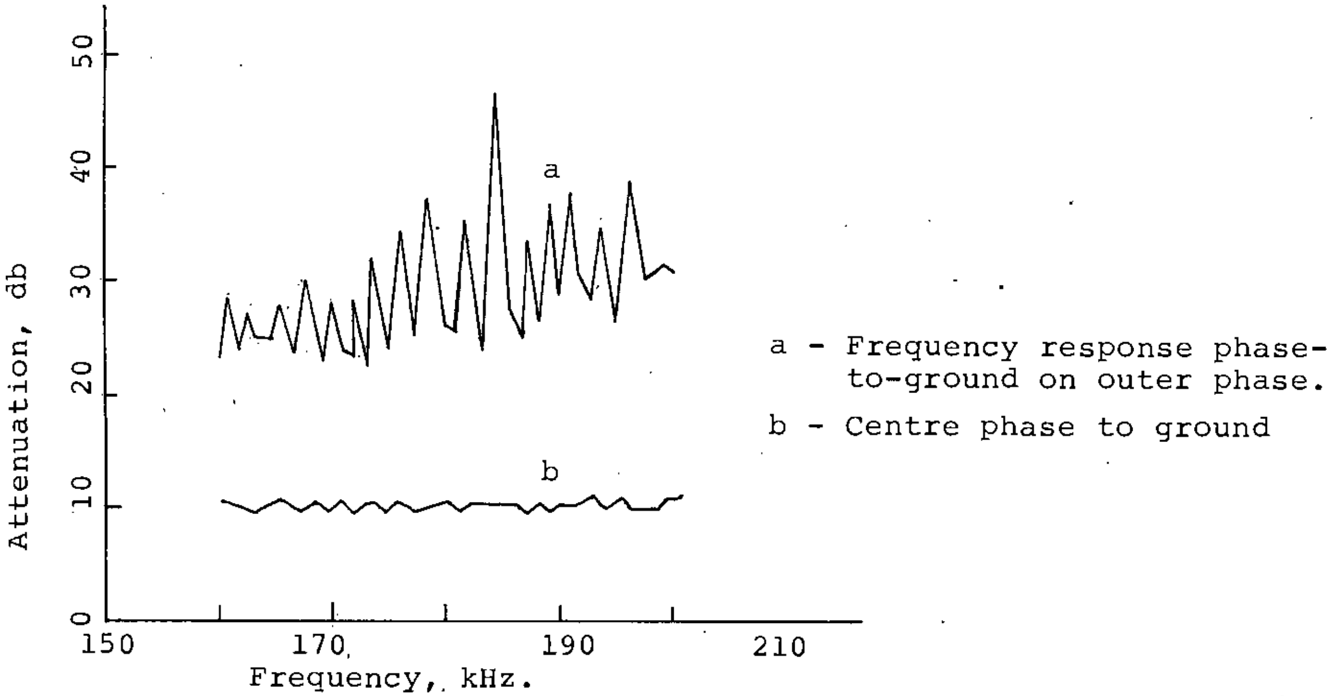


Fig. 3.8

The attenuation is least with this mode.

Mode 2. The currents in the outer phases are equal and opposed, while the middle phase does not contribute anything to the transmission. Attenuation is greater than for mode 1.

Mode 3. The currents flow in the same direction in all 3 phases and are approximately equal in magnitude. Owing to earth return, attenuation ;is higher with this mode.

Various forms adopted in practice for transmission over this type of line generally represent a combination of two or three modes. To achieve the lowest possible losses, the available transmission power should be fed to the line by mode 1. This becomes more important the longer the line and the higher the carrier frequency. At a certain distance from the transmitter, mode 2 and 3 components are attenuated to a low level. Therefore, with long lines and high carrier frequencies, only proper coupling using mode 1 will cause the signal to arrive at the receiving point. Because of electrical symmetry, phase-to-ground carrier on either phase of a transposed line will be propagated in a manner similar to that on the center phase of an untransposed line. Phase-to-ground carrier on an outside conductor of the untransposed line, because of different component distributions, is attenuated more within a given line length than the previous examples (Shown in fig.3.8).

The rate at which a signal is attenuated along the line depends not only on whether the coupling is phase-to-phase or phase-to-ground but also on the line configuration and the

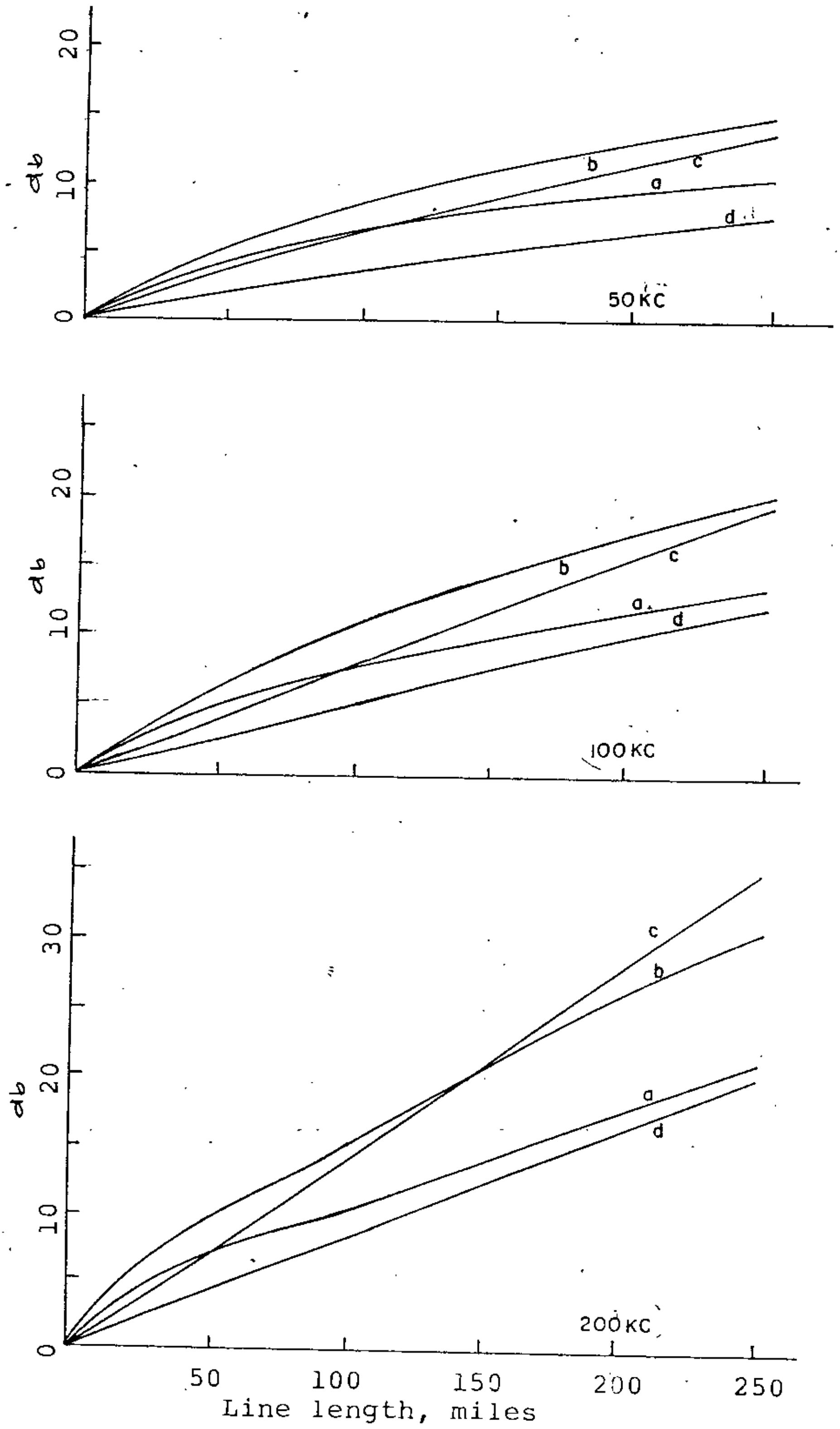


Fig. 3.9

Fig. 3.9(a): Centre phase to goround
(b): Outer phase to ground
(c) Phase-to-phase, outer phases
(d) Phase-to-phase, adjacent phases

choice of conductors. More accurate estimates can be made by the use of graphs such as Fig.3.9 . Unfortunately, this method requires separate charts for each transmission-line configuration and is further complicated when a section of line contains two or more configurations within its length. An interesting and useful point is that, on long lines, a carrier circuit coupled phase-to-ground can be almost as efficient as one coupled phase-to-phase.

3.8.6 Attenuation due to line configuration:[1,2]

On balanced two-conductor telephone lines, attenuation is approximately propertional to the square root of the frequency. On multiconductor power lines with much wider proportionate spacing, attenuation increases more steeply at higher frequencies, so that it is more nearly a linear function of frequncy than parabolic.

Lower voltage lines, i.e., 69 kv, etc., ordinarily have smaller conductors with correspondingly higher resistance and higher attenuation per unit length. Transmission lines in the 300 to 500 kv range usually have bundled conductors with lower resistance at carrier frequencies. However, the conductors are usually spaced wider in comparison with their height above ground, which tends to offset the lower attenuation trend of the larger conductor area. The proportionate spacing and height of any power transmission line are such that induced carrier-frequency current flows in the earth even when the carrier signal theoretically consists solely of interphase components. The magnitude of this current and the resulting carrier attenuation are functions of the ratio of conductor spacing to height and also of ground resistivity. (In Fig.3.10).

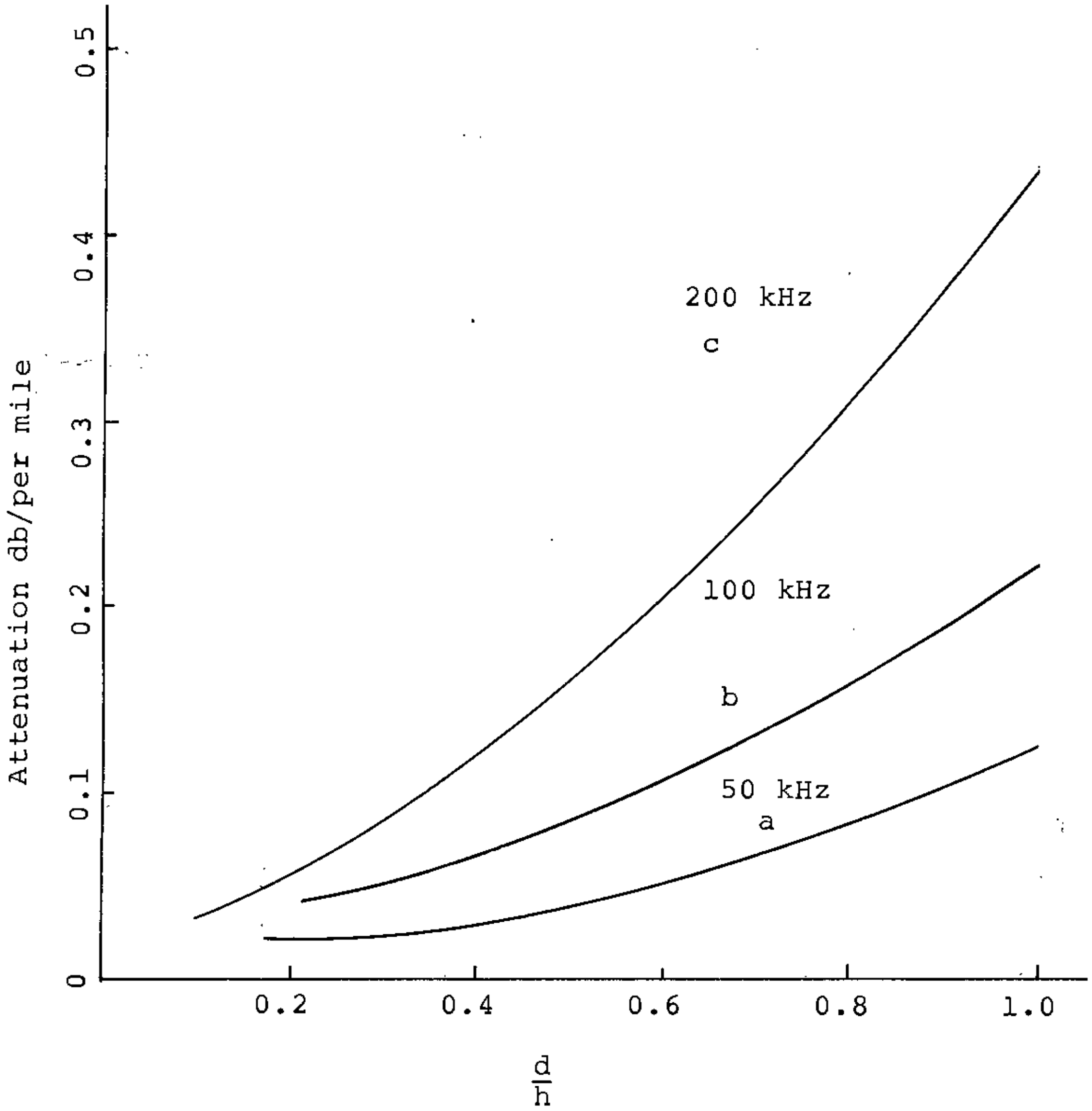


Fig. 3.10: Carrier attenuation due to proportionate line dimension
(d and h represent geometric mean spacing and height respectively).

3.9 Coupling and tuning:

The use of high-volatage power transmission lines for propagation of carrier signals for point-to-point communication requires efficient transfer of energy from the transmitter to the power line and from the power line to the receiver. Signals of a few millivolts at the carrier frequency must be separated from a circuit upon which is also impressed 60- cycle energy at a potential upto several hundred thousand volts.

3.9.1 Coupling Capacitors:

The capacitor is mounted on a metal base to provide convenient installation on the steel structure of a substation and to provide space and means for making connection to the lower terminal of the capacitor. The base unit usually contains a 60-cycle drain coil, and may also contain protective gaps, grounding switches, elements of a capacitor potential device unit, and all or portions of the coupling network.

A high-voltage coupling capacitor whose reactive impedance is very high at the power frequency but nominal at carrier frequencies is connected directly to the transmission-line conductor. FFor phase-to-phase coupling, two capacitors aree required.

3.9.2 Voltage rating of the Capacitor:

The voltage rating of a coupling capacitor is the nominal phase-to-phase voltage of the transmission line on which it sis to be used, although the actual potential across the capacitor is the phase-to-ground voltage. In addition to continuously withstanding this voltage, the capacitor insulation must withstand high voltage impulses caused by lightning and switching surges and is sometimes subjected to considerable over-voltages for extended periods. Tables3.7 and3.8 list capacitor requirements and values which are standard in the United States. Particularly at lower carrier frequencies, coupling efficiency is higher with higher capacitance. Also for any chosen tuning method, the bandwidth of the carrier channel will be broader with larger values of coupling capacitance.

Table3.7: Coupling Capacitor Voltage Ratings, Operating Voltages, Dielectric Test Voltages, and Minimum Creepage Distance*

voltage rating, kv	Maximum operating voltage, kv	Dielectric test voltage, kv Low-frequency withstand tests		Dielectric test voltage, kv Impulse withstand tests 1.5X40 sec full wave	Minimum creepage distance, in
		Dry 1 min	wet 10 sec		
2.4	1.6	15	13	45	7
8.32	5.5	27	24	75	10.5
14.4	9.0	50	45	110	14.5
14.4	9.0	36	30	95	14.5
23	15	65	60	150	19.5
34.5	22	85	80	200	26.5
46	28	110	100	250	33.5
69	42	165	145	135	45
115	70	265	230	550	76
138	84	320	275	650	88
161	98	370	315	750	103
230	140	525	445	1050	145
288	176	655	555	1300	77

* Taken from National Electrical Manufacturers Association Standards Publication.

Table3.8: Capacitance Ratings for Main Capacitance*

Circuit voltage, kv	Capacitance, μf** Low	High	NEMA creepage required, in.	BIL,*** kv
46	...	0.015	33.5	250
69	0.0032	0.010	45	350
115	0.002	0.006	76	550
138	0.0016	0.005	88	650
161	0.0013	0.0043	103	750
230	0.001	0.0030	145	1050
287.5	0.0008	0.0025	177	1300
345	0.00064	0.002	-	-

* Taken from National Electrical Manufacturers Association Standards Publication.

** The values of capacitance shall be within a tolerance of minus 10 per cent to plus 15 per cent. Values do not include bottom tap capacitance in potential device.

*** Basic impulse insulation level.

3.9.3. Method of coupling:

Line-to-ground coupling is favored on this continent, whereas line-to-line coupling is often used in Europe.

It was found[21] that several advantages of line-to-line copuling: lower attenuation, less variation of attenuation with weather, less radiation, less pickup of interference, and greater service reliability. Line-to-ground coupling has the advantage of lower initial cost and simpler maintenance since coupling equipment and wave traps are required on one phase only.

3.9.3.1 Effect of Coupling Methods on Interference Susceptibility:

It has been stated that line-to-line carrier transmission is less susceptible to interference than line-to-ground, because the two conductors form a "balanced line" similar to that used in standard telephone practice. Two of the possible sources of interference to a carrier channels are corona and impulsive noise.

Corona from the power line produces continuous background noise which is greatly intensified in wet weather. This noise may interfere with weak carrier signals on either voice or telemetering channels.

Impulsive noise may result from operation of disconnect switches in the station switchyard or lightning discharges near the line. These disturbances will usually be too brief to affect voice communication, but false operation of carrier control or telemetering devices may result.

3.9.3.1 Effect of Coupling Methods on Signal-to-Noise Ratio:[20]

In the case of corona noise, line-to-ground coupling produces about 2 db more attenuation but also about 2 db less noise than line-to-line coupling. Hence, as far as corona interference is concerned, the signal-to-noise ratio on a long line appears to be affected very little by the coupling method.

Momentary interference from disconnect switch operation was of large connect switch operation was of large amplitude and produced about the same degree of interference with either type of coupling in the installation tested.

With reference to lightning discharges, measurements during one storm showed that line-to-line coupling produced on the average, 6 db less noise than line-to-ground. Since line-to-line attenuation was also about 2 db less, the signal-to-noise ratio for line-to-line coupling was 8 db better than for line-to-ground. This factor may vary greatly, depending on the exact location of the storm with reference to the line. Also, lightning interference is usually of sufficiently low amplitude that it is serious only on very long carrier channels, or channels with low signal strength.

The effect of attenuation and interference, show little advantage for the more expensive line to line coupling in voice communication installation. For telemetering and remote control applications, an appreciable advantage was found for line to line coupling with respect to elimination of possible interference from lightning discharges only.

3.9.4 Line-tuning Units:

These serve to cancel or reduce the effects of coupling-capacitor reactance and to provide matching of impedances for maximum transfer of carrier energy. They are usually located in the switchyard beneath the coupling capacitors with which they are used. Connection to carrier terminal equipment, usually indoors, is made with coaxial cable. Line-tuning components may be located indoors in some instances. However, this procedure is inefficient and should be avoided where losses are critical and where coaxial-cable lengths exceeding approximately 100 ft are involved. Coaxial cables in general have nominal characteristic impedances of 50 to 75 ohms. Line-tuning units may be divided into two general categories: resonant types and broadband types.

3.9.4.1 Resonant Line-tuning Units:

These units employ reactive tuning elements to produce series resonance with the reactance of the coupling capacitor at one or more frequencies. In the single-frequency unit, this requires only one series inductance coil for tuning. The complete single-frequency line-tuning assembly also includes a protector unit and an impedance-matching transformer as shown in Fig.3.11(a)The inductance coil is usually variable by means of taps on the coil and a movable core. The coil is wound with Litz wire to provide an extremely high Q.

Two methods by which the coupling capacitor may be tuben to series resonance at two frequencies are shown in Fig.3.11(b) and(c). The circuit in Fig.3.11(b) is used when the two frequencies are to be directed over separate coaxial cables. A parallel-resonant trap unit in each branch is tuned to reject the frequency of the signal which passes through the opposite branch. The series inductance in each branch is adjusted to obtain maximum current of the desired-frequency signal. The circuit of Fig.3.11(c), may be used when it is desired to tune both frequencies into the same coaxial cable. The upper inductance is resonated with the coupling capacitor at the higher of the two frequencies. The branch of the lower portion which contains both a capacitor and an inductance is also series-resonated at the higher-frequency. The lone inductance in the opposite branch is finally adjusted to obtain maximum net current of the lower-frequency signal.

It is possible to tune a single coupling capacitor to resonance at three or more frequencies. However, this is seldom done

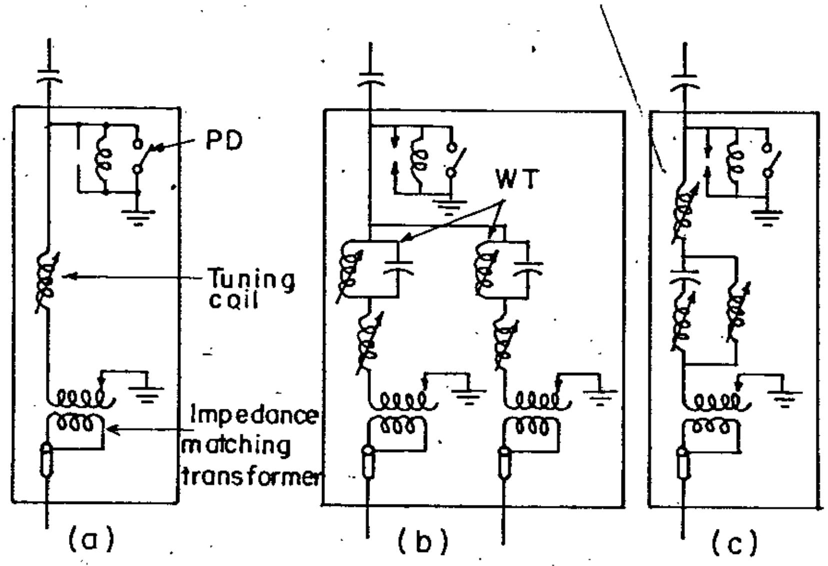


Fig. 3.11 Resonant line-tuning units. (a) Single frequency.
(b) Double frequency two coaxial cable.
(c) Double frequency, one cable.

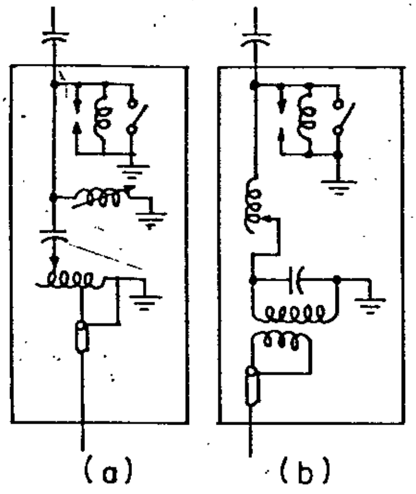


Fig. 3.12 Broadband line tuning units. (a) High pass T section.
(b) Bandpass half section.

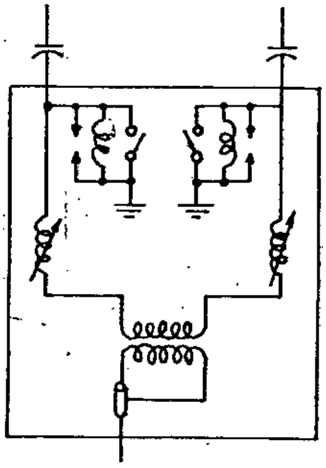


Fig. 3.13 Phase-to-phase sinle frequency line-tuning unit.

because the cumbersome circuitry required causes excessive loseses and produces undesirable antiresonances at frequencies often very near the desired resonant frequencies.

Impedance matching is a process of minimizing the standing-wave ratio on the coaxial cable. This is accomplished by selecting the impedance-matching transformer setting which causes the input cable current to approach the value obtained into a dummy resistive load of the correct value.

3.9.4.2 Broadband Line-tuning Units:

These use filter networks rather than series-resonant circuits to compensate for the reactance of the coupling capacitor. The coupling capacitor itself serves as one element of the filter, which is usually a constant-K highpass or bandpass arrangement such as the examples shown in Fig.3.12. The objective of broadband tuning is versatility; that is, several frequencies may fall within the passband of the filter without the necessity of individual tuning. The primary aim in the design of filters for broadband coupling units is to obtain maximum efficiency within the passband. Complex circuitry such as would be required to obtain high rejection outside the passband is not needed.

Some broadband tuning units are equipped with test terminals so that adjustments can be made for maximum carrier-frequency voltage at specified frequencies within the passband. Others are made with single-value elements set for average conditions and require no field adjustments. Measurements of input impedance are very useful in determining if a broadband coupling unit is functioning properly.

3.9.5 Phase-to-phase Tuning:

Phase-to-phase tuning requires two coupling capacitors and duplicates of all elements in the line-tuning assembly except the impedance-matching transformer. Ordinarily only one transformer is used as shown in Fig.3.13.The impedance-matching transformers in some broadband couplers form integral parts of the units. In such cases phasing leads or cables connect the two transformers together so that they may be driven 180° out of phase via a single coaxial cable.

3.9.6 Losses of Coupling Circuits:[22]

3.9.6.1 Theoretical Consideration of Broad-Band Coupling: For a band-pass filter having lower and upper cutoff frequencies of 50 and 200 kc respectively and working into a line resistance of 400 ohms, the coupling capacitor theoretically should have 0.006 mf of capacitance. Similarly, for a high-pass filter with a lower cutoff frequency of 50 kc and a line resistance of 400 ohms, the capacitor should have 0.008 mf. In other words, a high-pass filter requires one-third more capacitance than a band-pass filter for the 50 to 200-kc band. These values of capacitance are theoretically necessary at all values of line voltage. Unfortunately, the coupling capacitance value changes over a wide range as the voltage changes. For this reason, it is obviously necessary to use capacitance values other than the calculated theoretical ones.

3.9.6.2 Practical Considerations of Broad-Band Coupling:

The load impedances encountered in power-line carrier applications include 200, 100, 50, and even 25 ohms, as well as

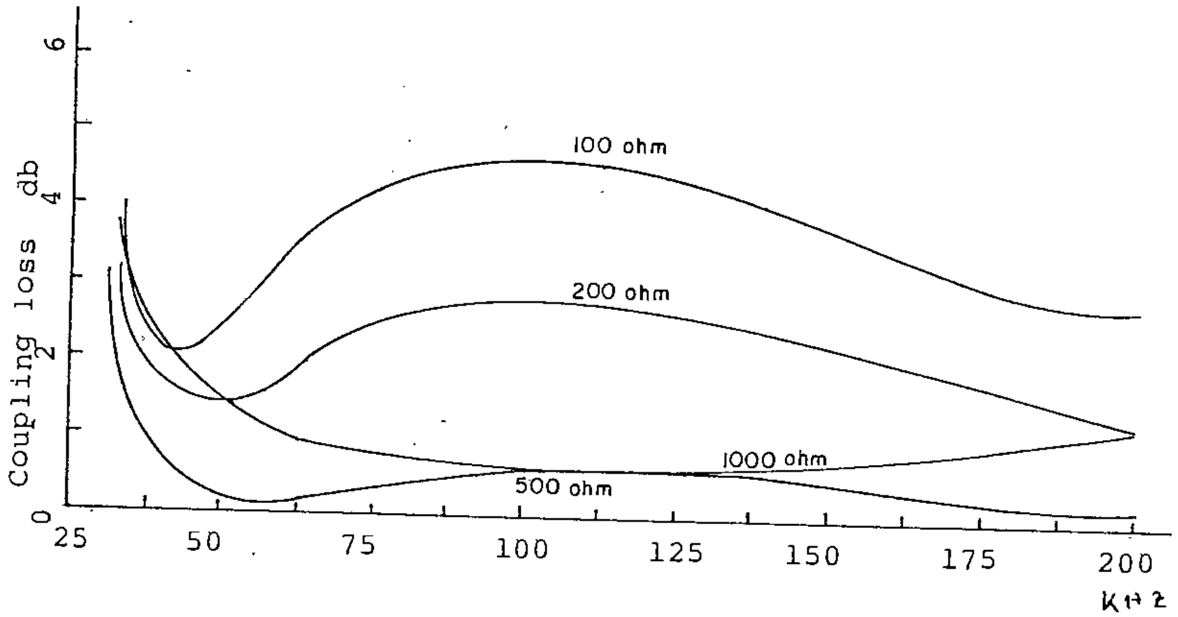


Fig. 3.14: Band-pass coupling performance for 0.006-mf capacitance.

the 400-ohm level used in the theoretical consideration of broad-band coupling. It is apparent that decreasing the line impedance the these values would require corresponding increases in capacitance as shown in Table3.9. In addition, these values would be needed at all line voltages.

Table3.9: Capacitance Increases in Broad-Band Coupling.

Line Impedance, Ohms	Capacitance for Band-Pass Filter, Mf	Capacitance for High-Pass Filter, Mf
400	0.006	0.008
200	0.012	0.016
100	0.024	0.032
50	0.048	0.064
25	0.096	0.128

The characteristic or image impedance of a filter is a function of the series and shunt elements of the filter. To make the image impedance match a line impedance, the filter element elements of the filter. To make the image impedance match a line im impedance, the filter elements must be changed or a matching transformer must be used. It is easy to make come of the elements adjustable but the coupling capacitor element is not adjustable. The matching transformer is an excellent solution for matching the filter to the carrier equipment but is obviously not economically feasible between the coupling, capacitor and the transmission line. In other words, the filter network has an inherent image impedance which theoreticallyshould be matched to the transmission-line impedance; however, this is not possible except under the most favorable conditions. Therefore, a mismatch loss will nearly always occur. While a mismatch loss is not a real loss because there is no dissipation of energy, it does reduce the carrier-frequency voltage and thus becomes a loss, the same as a real loss.

The band-pass filter is suitable for 200 to 1,000 -ohm line impedance and 0.002- to 0.01-mf capacitance range. Fig.3.14 shows the performance at various values of line impedance. The curves for the lower values of line impedance illustrate the performance degradation caused by the impedance mismatch between the line impedance and the characteristic impedance of the filter.

3.9.6.3 Analysis of Coupling Performance:

Fig.3.15 shows the variations in maximum and minimum loss at three values of line impedance for the band-pass filter as the coupling capacitance changes. The losses into a 500-ohm load at 0.003 mf and above are small enough to be of little concern; however, below 0.0025 mf the losses increase rapidly. The losses at the 100-ohm and 200-ohm impedance level are appreciable over the entire range of capacitance.

From the data shown in Fig.3.15 it can be seen that the coupling loss of band-pass filter becomes quite large at the lower values of line impedance. Therefore, a value consistent with acceptable performance was necessary.

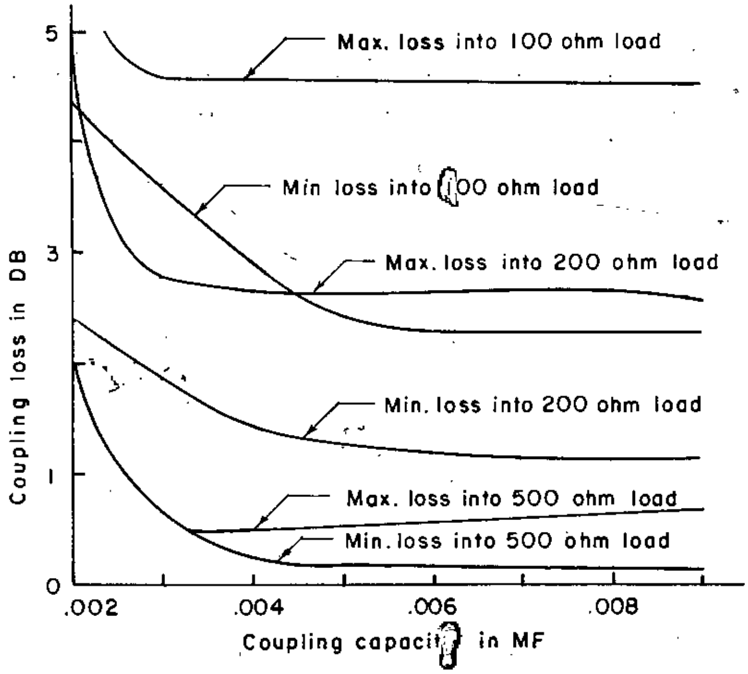


Fig. 3.15: Max. and minimum coupling losses of band-pass filter kHz for 50 to 200 kc band.

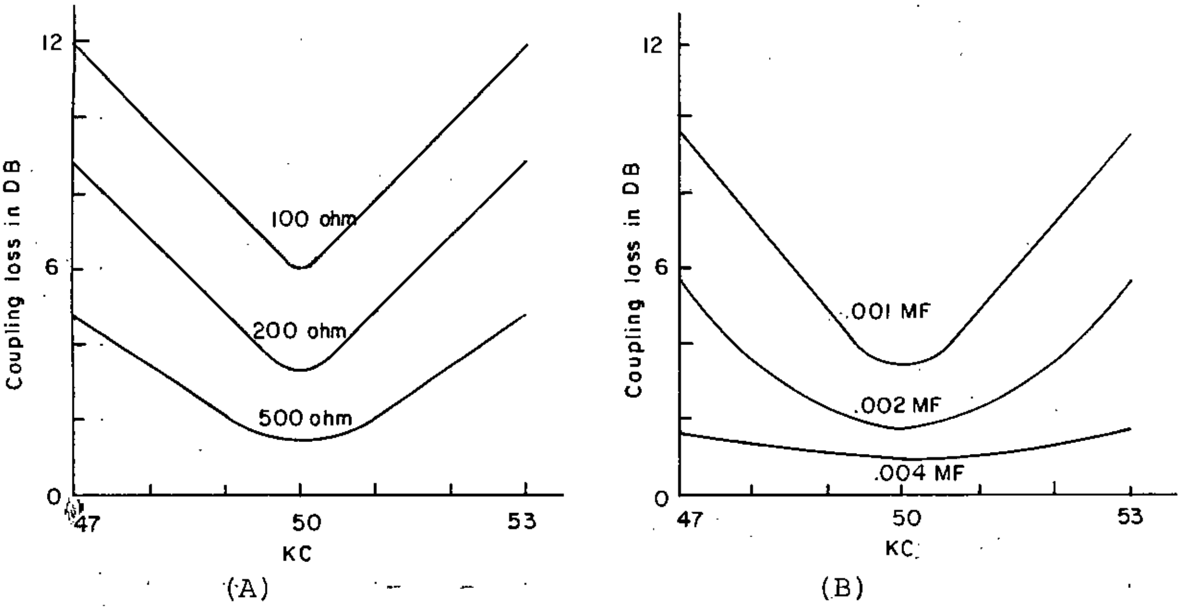


Fig.3.16a: Two-frequency resonant-tuned coupling circuit performance with 0.001 mf.

3.16b: Performance of circuit of Fig. 3.16a at 200-ohm line impedance and various values of coupling capacitance.

Typical characteristic curves of a resonant-tuned coupling circuit are shown in Figs. 3.14(A) and (B). These curves show the variation in performance with capacitance and with line impedance. They also show the variation in performance over a 3-kc band of frequencies on either side of the resonant frequency. It obviously was not logical to use the center frequency performance of resonant-tuned coupling. Instead, the loss at ±3 kc from the center frequency was used. The ±3-kc points were chosen because a carrier telephone channel has 3-kc side bands. The fact that frequency-shift carrier channels are applied over a band of ±6 per cent of the center frequency, which is 3 kc at 50 kc but more at higher frequencies, has been noted but not used in the comparison.

Fig.3.17 shows how the performance of resonant-tuned coupling varies with frequency and also with capacitance. Note that curves are shown for coupling loss at 3 kc from the center frequency. The curves are plotted for a 200 ohm load impedance.

The top curve of Fig.3.17 exhibits losses that appear to be marginal for satisfactory application at the lower frequencies of the carrier band. This, of course, is a well-recognized fact, and carrier telephone has been limited to frequencies above 50 kc because of the narrow band or high losses at the side-band frequencies of the coupling circuit. Since the curves do not show any definite breaking point, it is difficult to generalize as to what is considered acceptable. However, a large portion of the existing carrier applications uses capacitors of the 0.002-mf size; therefore, it

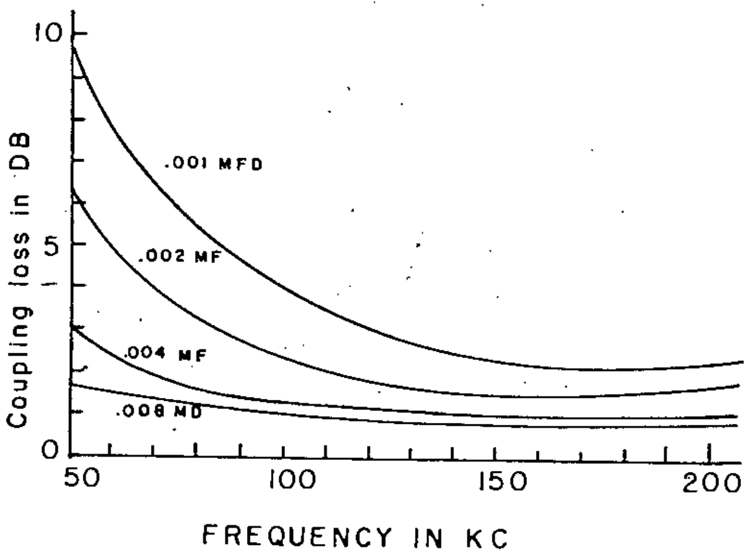


Fig. 3.17 Performance of resonant-tuned coupling at ± 3 kc from center frequency with 200 ohm line impedance.

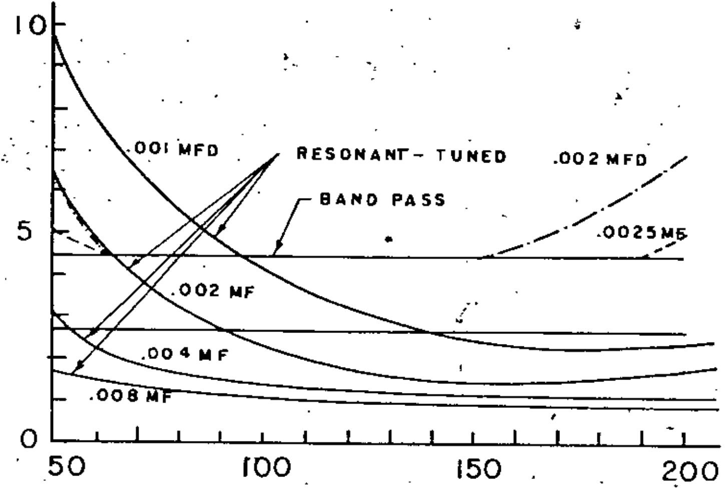


Fig. 3.18 Comparison between performance of band-pass coupling and resonant-tuned coupling for 200 ohm line impedance.

seems reasonable that the performance with this value of coupling capacitance should be satisfactory.

In Fig.3.18 the performances of resonanttuned coupling and of band-pass coupling with separation circuits are plotted to the same co-ordinates. For equal values of capacitance, resonant-tubed coupling is better over the major part of the 50 to 200-kc band. However, below 65 kc, the performance of band-pass coupling is equal to or better than that of resonanttuned coupling with a 0.002-mf capacitor.

3.10 Line Trap:

A line trap is a device for isolating the carrier channel from certain detrimental conditions found in the power system and to isolate carrier channels from one another to prevent interf~~r~~erence. To accomplish this isolation, the trap must have a high impedance at carrier frequencies. Line traps are installed in series with the power-line conductors and therefore must carry the power-frequency current that is present.

The main-coil conductor in modern traps may be copper or aluminum and may be large stranded cable or composed of multiple flat layers. The conductor is helically wound, usually in a single layer, to form and air-core inductance coil which is rigidly supported by several columns made of suitable high-strength material. Tensile strength is provided by a steel strain rod through the center of the trap attached to rigid assemblies at each end. American traps are enclosed on the ends by insulating covers. Openings near each end, where the coil winding terminates on external connecting studs, terminates on external connecting studs, are covered by suitable barriers to prevent small birds from nesting inside the trap.

Line traps may be mounted in substation structures by vertical suspension or placed either vertically or horizontally on insulated pedestals. In isolated locations such as a transmission-line tap point, traps may be suspended horizontally in series with a short span of transmission-line conductor.

3.10.1 Line-trap Ratings:

A line trap has three power-frequency current ratings: continuous-current rating, thermal short-circuit rating, and mechanical short-circuit rating.

Table3.10: Line Trap Thermal and Mechanical Current Rating*

Continuous-current rating rms symmetrical, amp	2-sec thermal current rating, rms symmetrical, amp	Mechanical current rating, rms symmetrical, amp
400	15,000	15,000
800	20,000	20,000
1200	36,000	36,000
1600	44,000	44,000
2000	63,000	63,000

* Taken from National Electrical Manufactures Association Standards Publication.

The continuous-current rating is the current which a line trap is capable of carrying continuously without exceeding a specified temperature. The short-time thermal current rating is the current which a line trap is capable of carrying for 2 sec without exceeding a specified temperature. This 2-sec fault current duration is standard in America, although other test durations ranging from 1 to 4 sec are sometimes used in Europe. By American standards, the mechanical current rating is the current which a line trap is capable of withstanding when the initial peak is completely offset. This rating is given as an rms figure, but because of the offset characteristic of transmission-line fault currents for which this rating is made, tests must be made with a peak current 2.83 times the rms value. European mechanical ratings are given as peak values.

It is desirable that the impedance of line traps be negligible at the power frequency. The nominal inductance of most traps currently being manufactured in the United States is 0.265mh which corresponds to a 60-cycle reactance of approximately 1/10 ohm. European traps are manufactured with inductances ranging from 0.180 mh to more than 1 mh. The higher inductance traps have lower short-circuit current capability.

3.10.2 Protection:

Line traps and their tuning elements are protected from lightning surges by one or more suitable arresters. Arrester characteristics are coordinated with the trap inductance and with its short-circuit ratings so that line faults within rated limits will not flash the arrester. In older model traps, arresters were enclosed within tuning pack housings. Newer styles have a separate arrester connected in parallel with the main coil, sometimes with auxiliary protection in the tuning packs.

3.10.3 Tuning

A line trap may be tuned as single-frequency, double-

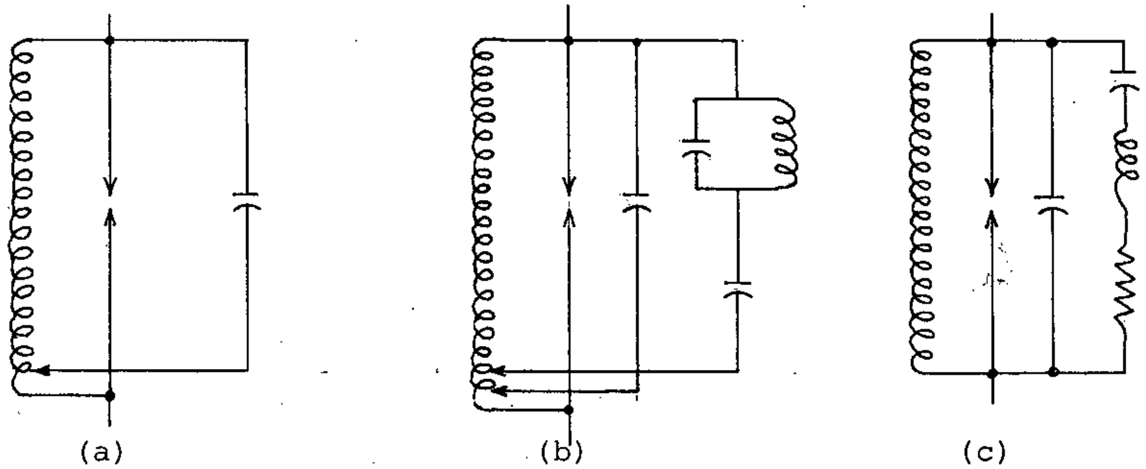


Fig. 3.19 (a): Single frequency line trap (b) Double frequency (c) Broadband

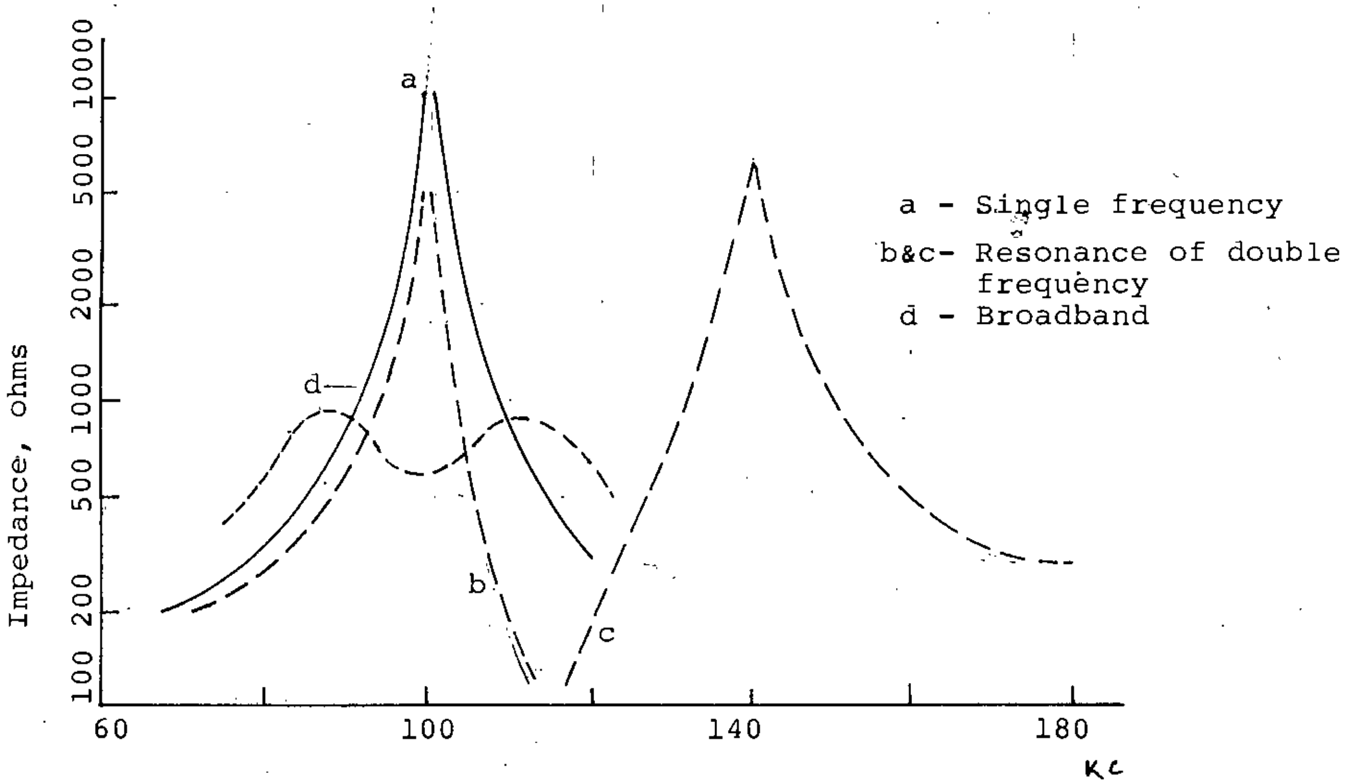


Fig. 3.20: Impedance characteristics of .265 mh line traps.

frequency, or broadband. Typical schematics of each are shown in Fig. 3.19.

For traps made in the United States, single-frequency tuning requires one pack which will provide tuning ranges of either 30 to 90, 50 to 150, or 70 to 200 kc, depending on the capacitance values within the pack. Each pack contains two capacitors which may be connected individually, in series, or in parallel to select one of four values of capacitance which divide the frequency range into narrow bands. Fine adjustment within a band is accomplished by locating a tap on the main coil.

Line traps currently available require three packs for double-frequency tuning. The higher of the two frequencies is tuned in the same manner as a single-frequency trap. The pack containing the inductance is also tuned independently to the higher frequency. The third pack completes tuning requirements for providing maximum impedance of the entire circuit at the lower frequency, with fine adjustments made by a second tap on the main coil. The frequency ranges for second-frequency tuning packs are the same as for single-frequency traps. Both frequencies of the double-frequency trap, however, need not fall within the same range. With appropriate pack combinations, widely spaced frequencies, e.g., 40 and 180 kc, can be tuned.

The tuning components of a broadband trap are arranged as a filter circuit with the main-coil inductance of the trap serving as one element. The network includes a terminating resistance. Most broadband line traps are fixed-turned, either to the appropriate geometric-mean frequency to obtain maximum bandwidth in the upper in the upper portion of the carrier-frequency spectrum or to another geometric-mean frequency specified on order. These traps provide minimum impedances of 400 to 600 ohms over their bandwidths, depending on the inductance of the main coil and the associated design parameters. One 0.265 mh trap provides an impedance of 400 ohms or more within the band from 90 to 200 kc. A 1-mh trap provides 600 ohms or more over a bandwidth from approximately 51 to 200 kc. Adjustable auxiliary broadband tuning packs fro use with standard single-frequency.265 mh traps are available with minimum impedances as high as 1,000 ohms over usable bandwidths, e.g., approximately 147 to 200 kc.

3.10.4 Impedance Characteristics:

Impedance characteristics of typical line traps are shown in Fig. 3.20. In general, both the impedance magnitude and bandwidth of single-frequency and double-frequency line traps are higher with higher resonant frequencies. The magnitude of each impedance peak associated with a double-frequency trap is approximately one-half that which is obtainable by tuning each frequency individually with separate single-frequency traps. The impedance magnitude of the broadband trap is a function of design parameters and is independent of the geometric- mean frequency to which the trap is tuned. The bandwidth, however, is directly proportional to the square of the geometric-mean frequency. Although the impedance magnitude obtainable with a broadband trap is much less than the peak impedance of a single-frequency trap, its bandwidth is greater and the impedance has a more predominant resistive component.

3.10.5 Line-trap Application:

The purpose of line traps is to minimize carrier losses by confining carrier energy to the desired path as nearly as po possible. In addition, traps are effective in reducing noise levels at carrier receivers and in minimizing interference to and from other carrier circuits.

3.11 Channel Bandwidth:[1]

For voice communication over the average power-line carrier channel, the important consideration is intelligibility rather than high quality of reproduction. Intelligibility is defined here as the percentage of a group of nonrelated words which can be recognized and understood over a channel. With a signal-to-noise ratio of 30 dbm an intelligibility of greater than 95 percent can be obtained[25] when an audio bandwidth of 250 to 2,150 cycles is reproduced. It is important that both the carrier apparatus and transmission channel combined provide this bandwidth. In many cases in the past, acceptable communication has been obtained with less bandwidth, but since intelligibility is also reduced with decreased signal-to-noise ratio, it is believed that systems should be based on a bandwidth of 250 to 2,150 cycles or more to allow some safety factor to take care of reduction in intelligibility during periods of high noise.

For other services, such as protective relaying, telemetering, load control and supervisory control, a channel of considerably reduced bandwidth is permissible. For example, successful relaying has been carried out with carrier systems capable of transmitting an audio spectrum up to about 300 cycles. The amount of bandwidth varies with the speed of response of the function being transmitted. Generally speaking, however there has been little difficulty in obtaining channels suitable for single control functions.

3.11.1 Amplitude-Modulated Signals:

An AM signal can be represented by a constant-level carrier and two sets of side-band components, one extending above and one below the carrier frequency. There are two side-band components corresponding to each audio frequency modulating the transmitter. For the conditions of intelligibility discussed above, it is required that a channel be provided wide enough to transmit a 2,150-cycle signal. This means that the total bandwidth needed will be 2X2,150 or 4,300 cycles. If we assume that the carrier equipment has a response which does not fall off more than 3 dbm for a total bandwidth of approximately 6 kc, then the carrier equipment response will be down approximately 1.5 dbm over a bandwidth of 4,300 cycles. Using the usual convention of defining bandwidth as that portion of the response curve included between the 3 dbm points, we then see that our transmission channel response should not be down more than 1.5 decibels over the bandwidth of 4,300 cycles.

3.11.2 Single-Side-Band Modulated Signals:

A SSB signal cane be represented by a very low level carrier and one set of side-band components extending either above or below the carrier frequency. Again, for the conditions of intelligibility discussed previously, it is required that a channel be provided wide enough to transmit a 2,150-cycle signal with not over 1.5-dbm bandwidth of 2,150 cycles will be needed, and that the channel response should not be down more than 1.5 dbm over a bandwidth of 2,150 cycles.

3.11.3 Frequency-Modulated Signals:

An FM signal can be represented by a carrier and one or more sets of sidebands extending above and below the carrier frequency. There are usually several side-band components corresponding to each audio frequency modulating the transmitter. It has been shown that to keep the audio distortion in a typical FM carrier system to within the desired limits, the channel should have a phase characteristic which is linear over a bandwidth of at least 6 kc. From an examination of the universal resonance curve for series inductance-capacitance circuits, it appears that phase characteristics begin to depart from linearity at the point where the response is down 1 dbm. If we use this as a basis for considering a circuit with a deviation of 2.5 kc, the channel response should not be down more than 1 dbm over a bandwidth of 5,000 cycles.

3.12 Selection of Frequency:[1]

In this discussion of frequency selection, it is assumed that the use of frequencies for power-line carrier current is restricted to the range between 30 and 200 kc. The lower frequency limit is imposed by the difficulty of coupling a sufficiently wide band to the power line through the available values of coupling a sufficiently wide band to the power line through the available values of coupling capacitance, and the upper limit is imposed by the extensive use of frequencies between 200 and 415 kc for space-radio facilities (principally for enroute navigation and terminal traffic control of aircraft). The upper limit of 200 kc also is imposed by the increasing attenuation of the channel with higher frequencies.

As previously mentioned, it is not reasonable, because of the increasing noise as frequency is decreased, to make a general assumption that any part of the 30-to-200-kc range will yield the best signal-to-noise ratio for all transmission lines. The optimum signal-to-noise ratio is very definitely a function of the type of channel and its total attenuation. In general terms, short lines with low attenuation will give the best performance at the higher end of the frequency range while the optimum frequency is lower for long lines and high attenuations. Where appreciable lengths of power cable are involved, the attenuation rises rapidly with frequency and the use of lower frequencies becomes imperative.

Using these generalizations as a basis, it appears advisable to reserve the highest frequencies for pilot relaying, as this function generally implies a relatively short channel. Telephone channels, on the other hand, very frequently are applied to long and complex line configurations, but this does not necessarily imply that low frequencies should be used for best results. Other factors enter the picture. Telephone channels require adequate bandwidth, and it will be found that the channel characteristics will have greater changes within frequency increments equal to the audio passband at the lower frequencies. It is for this reason and because of the difficulty of obtaining and adequate bandpass within the terminal equipment itself that powerline carrier-current telephone equipment is produced only above 40 kc. Thus, it seems most reasonable to reserve the center portion of the frequency range for telephone operation.

Narrow-band frequency-shift equipment for telemetering, control, and many other functions is capable of the greatest range of operation. It is frequently required to operate through great range and, in such cases, can be applied to the greatest advantage at the lower frequencies.

3.13 Standard Noise Values:[1]

Since the measured data on transmission-line noise varies so widely it appears that no standard value of noise can be set. It is essential, however, that noise be taken into account in carrier application and, in the absence of measured data on the system being considered, some assumed value must be used. A study of the noise data vailable has been made, and geometric means of the curves taken on a large number of lines indicate that 18.7 millivolts (quasipeak), as measured over a 400-cycle bandwidth, will not be exceeded more than about 10 percent of the time. This value has been used successfully in many applications. On a particular system, it is recommended that actual data be taken under varying weather conditions to arrive at a standard value for carrier application.

Any standard value adopted can be translated to correspond to the bandwidth of the receiver in question by use of the following relations:

Quasipeak(voice)-noise voltage $\propto$ (bandwidth)$^{\frac{3}{4}}$ (approximately). Average ((relay)-noise voltage$\propto$(bandwidth)$^{\frac{1}{4}}$ (approximately).

The circuits of the Stoddart noise meter are so designed that when compared with an AM or SSB receiver, a given r-f signal-to-noise ratio produces the same audio signal-to-noise ratio. The noise value in each case should be corrected for bandwidth. The AM signal level is that of the peak value of the unmodulated carrier, the audio output being that due to 100-percent modulation (peak of audio wave). To make this clearer for an AM case, consider a received signal level of 300 millivolts rms unmodulated. Take the standard quasipeak noise figure of 18.7 millivolts, and convert to the equivalent for the 6 k-c AM bandwidth. This gives 142 millivolts.

3.14 Allowable Signal-to-Noise Ratios:[1]

Minimum tolerable signal-to-noise ratios for various carrier applications are given in Table3.11. The proper characteristic of the noise (for example peak amplitude, average amplitude, etc.) must be considered in establishing these ratios for each application. The receiver bandwidth also must be considered in most applications, because noise response is usually a function of bandwidth.

Table 3.11: Minimum Tolerable Signal-to-Noise Ratios

Keyed-Telemetering	Carrier Relaying or Supervisory Control	Tone Telemetering	Voice Communication
15 dbm	20 dbm	15 dbm for a single received tone (15+20 log N) dbm for multiple tones (where N is the number of tones)	25 to 30 dbm (Psophomatric)

CHAPTER - 4

TECHNIQUES AND METHODS FOR MEASURING

4.0 Preliminaries:

In this chapter methods for measuring noise and grounding resistance of protective device will be discussed briefly. Also a discussion will be made about measuring units of noise and signal.

4.1 Noise and Signal Measurement:[28]

4.1.1 Noise

It is difficult to measure the amplitude of noise due to the non-deterministic nature of noise waveforms and amplitude dependence on bangdwidth. If an a-c voltmeter is connected to a noise source, then since noise is random, meter reading will be fluctuated randomly and it is so meaningless to measure noise in this way. Thus, it is usually necessary to average the noise amplitude over some interval so that a more or less constant meter reading is obtained. A meter that integrates the reading over a time period which is long compared to the reciprocal of the bandwidth removes most of the fluctuations. So rms noise voltage can be measured by an a-c voltmeter by averaging over finite time interval and dividing the rms^2 noise voltage by resistor, noise power can be determined. Measurement of absolute magnitude of noise power is not important. Rather it is important to measure how much it annoys a telephone user. Thus measurement of subjective effects of noise is important. So, the meter is designed to measure the following effects:

(1) the readings should take into considerations the fact that the interfering effect of noise will be a function of frequency spectrum as well as of magnitude.

(2) When different noises are present simultaneously, the meter should combine them to properly measure the overall interfering effect.

(3) When different types of noise cause equal interference as determined in subjective tests, the meter should give equal readings.

Besides, the transient response of the meter should be similar to that of the human ear.

Interference is made up of two components viz (i) annoyance and (ii) the effect of noise an intelligibility. Both are function of frequency. Hence proper frequency weighting is required in the meter which is stated by point '1' above: For example, a 200 Hz tone of given power is 25 dB less disturbing then a 1000 Hz tone of same power. Hence, the weighting network incorporated in the noisemeter will have 25 dB more loss at 200 Hz than at 1000 Hz. It is assumed (by several tests) that the effect of noise power is maximum at 1000 Hz. This frequency is used as the reference frequency in Bell system. But CCITT and CCIR[28] recommended reference frequency is 800 cps. To determine weighting at different frequencies (i.e. frequency weighting curve) annoyance is measured in the absence of speech by adjusting the level of a given tone until it is as annoying as a reference 1000 Hz tone. This is done for many tones and for many observers and the results are averaged and plotted. A similar experiment is done in the presence of speech at the average received volume to determine the effect of noise an articulation. The results of the two experiments are combined and smoothed resulting in the C-message weighting curve. Similar experiments give other types of weighting curve. For psophometeric weighting (CCIR and CCITT recommended) the reference frequency is taken as 8000 Hz. These are shown in the Appendix-2. Weighting like 144, F_1A etc. are not used now[32].

Another important factor is that noise add on power basis. Thus meter must also read in this way.

The last important factor is the transient response of the human ear. It has been found that, for sounds shorter than 200 Msec. the human ear does not fully appreciate the true power in the sound. For this reason the noise measuring meter is designed to give a full indication on bursts of noise longer than 200 msec. For shorter bursts, the meter indication decrease.

Thus, frequency weighting, power addition and transient response of a noise measuring meter describe the way in which a meassage circuit noise is to be measured. Besides, a noise reference and scale of measurement must also be provided. The chosen reference is 10 watts or -90 dBm. The scale marking is in decibel and measurements are expressed in dB above reference noise (dBrn). For psophometric reading, this reference is at 800 Hz and for Bell system it is 1000 Hz[28].

In particular, let w(f) represent the weighting of the noise shaping network in dB relative to 1kHz reference frequency. Thus,

$$|H(f)|^2 = 10^{w(f)/10} \qquad \ldots \qquad 4.1$$

Where H(f) is the transfer function of the weighting network. The total weighted noise power for noise density of $P_i(f)$ watts/Hz is given by

$$P_T = \int_0^{\infty} |H(f)|^2 \; P_i(f)\,df \text{ watts} \qquad \ldots. \qquad 4.2$$

The effect of weighting over the frequency range f_1 to f_2 is given by

$$\lambda = 10 \log \frac{\int_{f_1}^{f_2} P_i(f)\,df}{\int_{f_1}^{f_2} |H(f)|^2 \; P_i(f)\,df} \text{ dB} \qquad 4.3$$

Thus, weighting network attenuates the noise power by dB. For $f_1 \simeq 0$, $f_2 \simeq 3$ kHz, (telephone channel) $\lambda = 2$dB for flat $P_i(f)$ and C-message weighting. For psophometric weighting and flat $P_i(f)$, λ becomes 2.5 db.

Till now, measurement of noise is considered for telephone channel with analog signal. For analog TV signal, separate type of weighting is required according to the effect of noise to eye. Digital signals such as Data and PCM are not affected by noise in the same way as analog voice signals. For example, the annoying hiss due to thermal noise has no effect on digital signals unless its amplitude approaches the amplitude of the signals. On the other hand, impulses which cause tolerable clicks or pops on voice circuit result in almost certain errors because of their high amplitude. Thus separate type of noise measuring technique is used for digital signal. Details can be found from reference.[34]

4.1.2 Signals:

Message or speech signal is also nonperiodic (otherwise no information) and so difficult to measure. The nature of speech or program signal is such that the average, r.m.s. and peak values are irregular functions of time so that one number cannot specify any of them. But regardless of the difficulty of the problem, the magnitude of the telephone signal must be measured and characterized in some fashion so that proper design of transmission media can be made. Signal magnitudes must be adjusted to avoid overload and distortion and gain and loss must be measured. For this purpose a characterized unit called volume unit (vu) is used. It is an emperical kind of measurement which rarely are as large as 0.1 watt and which may be lower than 1 pW (pico watt), the use of watt as a unit of measurement is awkward. A convenient unit is the milliwatt i.e. 10^{-3} watt. Many operations can further be simplified by expressing power in relative dB. Normally power is compared with one milliwatt and then expressed in dB. This is called dBm. Thus a power of 1 mW is odBm and a power of 1 pW is $10 \log(10^{-12}/10^{-3})$ dBm or -90 dBm.

4.2.2 Noise

It was shown in the previous section that for both psophometric and C-message measurement reference power of 1 pW is taken. Reference frequency for weighting is 800 cps for psophometric weighting and 1000 cps for C-message weighting. Psophometric noise power is the average noise power delivered to 600 Ohm resistance and expressed as picowatt psophometric (pWp). Thus

$$\text{pWp} = \frac{(\text{psophometric mV})^2}{600} \times 10 \quad \text{picowatts} \qquad .. \; 4.6$$

or in dB, $\text{dBp} = 10 \log \text{pWp}$ 4.7

Thus I pW at 800 Hz is OdBp and 1 pW at 1000 Hz is OdB rnc. So, a OdBm power having a bandwidth of 0-3 kHz is equal to 88.0 dB rnc (c means C-message weighting). or 87.5 dBp. This is so as weighting of 0-3 kHz is 2 dB for C-message and 2.5 dB for psophometric. Thus,

$$\text{dBp} = \text{dBrnc} - 0.5 \qquad .. \qquad 4.8$$

evolved to meet practical need and is not definable by precise mathematical formula. The vu meter used for this purpose gives the reading in vu. The principal functions of the vu meter are

(1) Measuring signal amplitude in a manner which will enable the user to avoid overload and distortion.

(2) Checking transmission gain and loss for the complex signal.

(3) Indicating the relative loudness with which the signal will be heard when convented to sound.

For convenience, the meter scale is made logarithmic but unit is vu not dB. It can be related with dB by the following relation,

$$\text{Average power} = \text{vu} - 1.4 \text{ dBm} \quad \ldots \quad \ldots \quad 4.4$$

Such relation hold for a continuous taken For noncontinuous talker the relation is

$$\text{Average power} = \text{vu} - 1.4 + \log \log \tau_L \text{ dBm} \quad .. \quad 4.5$$

Where τ_L is the load activity factor. It should be noted that vu meter has a flat frequency response over the audible range and is not frequency weighted in any fashion.

4.2 Units for Measuring Noise and Signal:

4.2. Signal

Since telephone circuits operate with signal powers for input flat noise from 0 to 3 kHz

Using above relations following table may be made.

Table 4.1: Shows the relation between different units for Noise Power.

Noise Unit	Total power of OdBm		White noise of -4.B dBm per kHz.
	1 kHz	0 to 3 kHz	
dBrnc	90.0 dBrnc	88.0 dBrnc	88.4 dBrnc
pWp	$1.26X10^9$ pWp	$5.62X10^8$ pWp	$6.03X10^8$ pWp
dBp	91.0dBp	87.5 dBp	87.B dBp

4.3 Procedure for measurement of signal level by level meter(MLA24A)

In accordance with the impedance under measurement, the pushbutton is depressed of the input impedance. Setting the meter to norm, the signal under measurement is applied to the input terminal applicable to the above-mentioned impedance. The input level is adjusted (dBm) dial so that the meter lower-scale indication is given in 0± 1 dB range. The sum of the readings of the input level (dBm) dial and the meter indication gives the level of the signal under measurement. When detailed data within ±1 dB is required, the meter is to set to exp, and obtain the value by reading the upper scale.

4.4 Procedure for measurement of noise by psophometer

This procedure provides a noise measurement method at the terminal on the telephone circuit. At the transmit side, terminate the 4WS line under measurement is terminated with the terminator of the nominal impedance 600 ohm. At the receive side, setting the imput impedance to the psophometer tel (600 ohm. nominal) the noise components is measured.

4.5 Method of measurement grounding resistance by auto earth tester

Driving into the ground the auxiliary earth bar (C) which is supplied with the earthing resistor, at a distance of 10 to 20 meters from the earthing object be measured, (E), and the other auxilary bar (P) about midway on a straight line between the auxiliary earth bar (C) and the earthing object to be measured (E) and connect these with the earthing resistor terminals E.P.C. with connecting cords.

4.5.1 Battery check

Setting the change-overswitch to Batt. check, the push-button switch is pushed (push on) and make sure that the meter indicating needle is within the green zone. At this time the connecting terminals are to be in measuring condition. If the needle does not swing to the green zone, replace the battery with a new one.

4.5.2 Earth voltage

Setting the switch-over switch to Ac. volt, existance of the earth voltage can be ascertained. However, do not press the push-button switch. When the earth voltage is over 10 volts, measure with the earth voltage in the smallest possible state by either removing the earthing object from the electric installation or switching off the circuit.

4.5.3 Earth resistance

A proper resistance range is selected by the change-over switch according to the kind of earthing work, and while pressing the push-button switch, the dial is turned to balance the galvanometer.

Value obtained by multiplying the dial reading by the magnification of the range is the measured value.

CHAPTER - 5

MEASUREMENTS AND RESULTS

5.0 Preliminaries:

Methodology, parameters of the study, measurements for receiver output for noise,signal to noise ratio and grounding resistance of protective device for different P-L-C link of BPDB are given in this Chapter. Other related information are collected from different metering stations which are also tabulated and discussion based on informations and measurements are also given in this Chapter.

5.1 Methodology:

To identify the various causes of signal to noise ratio reduction of power line carrier (P-L-C) system of BPDB, it was proposed to collection of informations for different metering station at different location of the country. Also at some metering stations noise, signal strength, signal to noise ratio at the out put of the receiver and grounding resistance was measured. A questionnaire was prepared for this which contain items like (shown in the Appendix- $\overset{6}{1}$′):

1) Individual metering station: line configuration, operating line voltage, coupling capacitor rating,method of coupling, tuning arrangement, wave trap rating, mode of propagation of carrier signal, Transmetting and receiving carrier frequency, Band-width of the line matching unit, wave trap characteristics and adjustment of filter and amplifier.

2) Sources of signal attenuation: Missmatching, mode of propagation, coupling loss, tapping loss, reflaction, radiation, receiption of radiated signal in various phase diff, higher range of carrier frequency, different weather condition.

3) Sources of noise: Loose connection wiring (arcing effect) Radio interference (corona), Bandwidth performance, coupling arrangement, grounding resistance, switching, line fault, ripple of the power supply, weather variation etc.

5.2 Parameters of the study:

Collection of informations and measurement of the receiver output noise, signal, signal to noise ratio, grounding resistance of protection device and P-L-C system of different metering points are involved for the following parameters.

1) Attenuation: In carrier transmission it is convenient to consider the transmission characteristic of a system in terms of attenuation or the decrease of power along the transmission power.

The total attenuation of a power line carrier circuit consists of resistance, and rediation losses in the transmission line itself; losses due to the power straying from the desired path and losses due to coupling equipment and by pass. Reflection (due to mismatch) is also included in losses.

2) Noise and interference: The noise level at the input to a carrier receiver determines the minimum received signal level necessary for adequate performance. Increasing receiver sensitivity beyond nominal requirements is of no benefit because performance depends on the ratio of signal to noise.

Power line noise consists of discrete impulses, occuring either erratically or periodically superimposed on a back ground noise at a lower level.

Noise levels depend upon voltage dimensions, degree of contamination and other conditions of a power line. They may vary over a wide range with variable weather condition.

3) Signal to noise ratio: It is not ordinarily possible to reduce appreciably the noise level present at a given receiving point in a carrier system. The only practical way to improve signal-to-noise ratio is to raise the signal level at the receiving point. It is not usually feasible to raise signal levels by increasing the transmitting power because appreciable gain interms of db requires in ordinately large increases in power. A much more practical solution is to reduce the channel attenuation by judicious application of line traps to eleminate short taps of spur lines and alternates paths. The use of repeater stations may be required in some cases.

5.3 Measurements and Results for Noises:

Measurements for noises in links connecting two metering points via exchanges, were made by using psophometer. The connection diagrams are shown in Fig. 5.1. Results are given in table 5.1. Clearly, results contain all sorts of noises in cable and switching network. It may be assumed that results closely approximates to the true value. Of course this again vary with days, weeks, months, and years. However, the variations are normally very small.

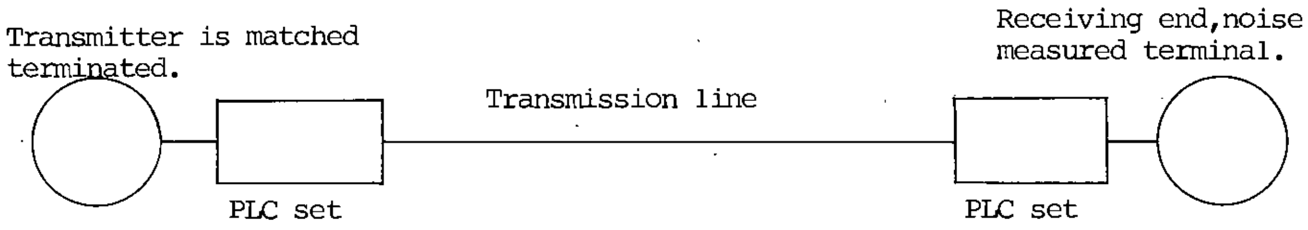


Fig. 5.1: Experimental set up for noise measurement by psophometer.

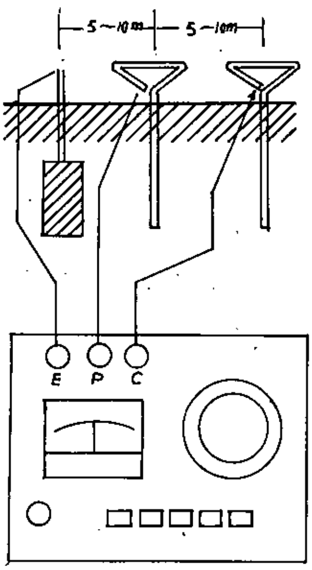


Fig. 5.2: Measurement of grounding resistance by Auto earth tester.

Table 5.1 : Experimental Data for Noise for different links.

Measuring metering station	Terminating metering station	Noise level(absolute) 'psophomatric'dBm
Siddhirgonj	Dohazari	-40
"	Madanhat	-42
"	Ishwardhi(1)	-45
"	" (2)	-40
"	Polasbari	-48
"	Faridpur	-41
"	Barisal	-55
"	Jhenaidhah	-64
"	Nowapara	-62
"	Goalpara	-65
"	Bheramara	-61
"	Bogura	-41

(Readings were taken in the period between 11.00 A.M. and 3.00 P.M. and noise values shown are weighted).

5.4 Measurement and Result of SNR:

Some of the P-L-C links have been selected to take measurement of receiver output SNR. Measurements were taken at Siddhirgonj (load dispatch centre). Siddhirgonj metering station is common for every link on which measurement take place.

Initially other end of the each link was matched terminated and noise at receiving end side at Siddhirganj was measured. Clearly, since all other links are working, the measured noise contain total noise (thermal, shot, impulse, other interferance etc.). Besides, signal at receive side of the link Siddhirganj metering station was measured by transmitting test tone in other end of the link. This result divided by the measured noise gives SNR. Results are shown in Tables 5.2. Measurements were taken in the month of November, 1984

Table 5.2 : SNR for different links for P-L-C system of BPDB.

Receiving Station	Transmitting Station	Transmitted signal,dBm	Received signal measured by level meter,dBm	Noise level,dBm (psophometric)	Signal to noise ratio(SNR),dBm
Siddhirganj	Tongi	0 (1000Hz)	-10	-40	30
"	Ghorashal	"	-14	-30	16
"	Shahji Bazar	"	-18	-33	15
"	Comilla	"	-31	-45	14
"	Ullon	"	-45	-55	10

(Reading were taken between 11.00 A.M. and 4.00 P.M. and noise shown are weighted).

5.5 Frequency Response of the receiver at the metering station of Ullon

The measurement was taken on Siddhirgonj-Ullon link. The 0dBm signal at different frequency is applied to the input terminal of the transmitting station (Siddhirgonj). Output level of the receiver at Ullon was measured by level meter,(MLA24A) which is shown in Table 5.3.

Table 5.3.: Receiver output signal level at different frequency

Frequency in KHz	0.3	0.6	0.8	1.0	1.4	1.6	2.0	2.4	3.4
Level in dBm	-53	-52	-51	-47	-45	-45	-45	-52	-53

5.6: Measurement and results of grounding resistance of protective device:

In every metering station, the grounding resistance of the protective device is of great importance.Some of the metering station, the grounding resistances were measured which are shown in Table 5.4. Measurements were also taken in addition of the connection of protective device with the grounding rod.

Table 5.4: Grounding resistance of protective device for different metering station

Metering Station	Resistance in ohm.
Siddhirganj	.50
Ishwardi	.45
Ullon	3.00 (including connection
Mirpur	3.50
Kamalapur	.75
Rajshahi	.40
Bheramara	.55
Jhenidha	1.00
Bottail	1.30

(Readings were taken in the month of February, 1985)

5.7. Meassage Channel Objectives

The telephone speech signal is usually delivered to the telephone organisation in the form of audible sounds impinging on the telephone transmitter. It is the telephone company's responsibility to deliver a replica of this sound to the ear of the called subscriber. To perform this in a batter way certain objectives are necessary. A concept known as grade of service is commonly used to determine acceptable message channel objectives. It combines the distribution of customer opinion with the distribution of plant performance to obtain the expected percentage of customer opinion in a given category. One of the objectives for message channel are given below:

5.7.1 Message Circuit Noise Objective

Message circuit noise is defined as the short term average noise level as measured with a psophometer or meter using C-message weighting. The relationship between the meter reading and customer opinion of the impairment was determined by subjective tests. The quality of the circuit with noise was judged as excellent, good, fair, poor or unsatisfactory. This results is shown in Table 5.5. Received volume used is - 28 vu which is known to be suitable.

Table 5.5. Different judgement qualities and corresponding noise levels*.

Quality	Noise in dBrnc	Noise in dBmp
Excellent	15	- 75.5
Good	25	- 65.5
Fair	33	- 57.5
Poor	42	- 48.5

---

*(Supported by hundred percent people with whom subjective tests were performed).

5.8 Reports on survey of different metering station of BPDB:

Metering station are located all over Bangladesh. Therefore P-L-C system exists throughout the country (Shown in Appendix -4). About fifty metering station are locatdd in different areas of the country, High voltage transmission lines are devided into two parts i.e. eastern gride and western grid, they are also interconnected.

Therefore the whole P-L-C network is shown in Appendix-5 and also metering stations lay out are given in Appendix-3 individually. Following informations are obtained regarding P-L-C system of BPDB with a view to assessment of various causes of signal-to-noise ratio reduction from field survey.

132 KV high voltage transmission lines are commonly used for P-LC communication, 66 and 33 KV transmissions are rarely used for this purpose. Most of the transmission line conductors are vertically arranged. Double circuit transmission lines are rarely found. Centre conductor are seldom used for power line carrier signal transmission. Transmission line configuration and line voltage of different links of BPDB are shown in Table 5.6

More than 35% metering station consist of more than two transmission line and about 40% metering station consist of Two transmission line. (Shown in Appendixes -3)

Singal side-band amplitude modulated supressed carrier signal is transmitted and demodulation is performed by syncronous detection. The range ofthe carrier frequency is about 100 KC to 500 KC near about 75% carrier frequency is above 200 KC.

Table 5.6 : Line configuration and Line voltage of different links of BPDB.

Metering station	Direction	Type of circuit	Conductor arrangement	Conductor used for P-L-C	Line voltage,KV
Siddhirganj	Ghorashal	Double	Vertical	Upper,lower	132
"	Comilla	Double	"	"	132
"	Ullon	Single	Horizontal	Centre	132
"	Kamalapur	"	Vertical	Lower	33
"	Hasnabad	"	"	Centre	132
Hasnabad	Mirpur	"	"	"	132
"	Siddhirganj	"	"	"	132
Mirpur	Hasnabad	"	"	"	132
"	Tongi	"	"	"	132
Tongi	Ullon	"	Two Hori. Two Vert.	Lower	132
"	Ghorashal	Double	Vertical	Centre,Centreq	132
"	Ishwardi	"	"	"	132
"	Mirpur	Single	"	Centre	132
Ullon	Tongi	"	"	"	132
"	Siddhirganj	"	Horizontal	"	132
Ghorasal	"	Double	Vertical	Upper,Lower	132
"	Ashuganj	"	"	"	132
"	Tongi	"	"	Centre,Centre	132
Ashuganj	Ghorashal	"	"	Upper,Lower	132
"	Kishoregonj	Single	"	Upper	132
"	Shahjibazar	Double	"	Upper,Lower	132
Kishorganj	Mymensingh	Single	"	Upper	132
"	Ashuganj	"	"	"	132

Mymensingh	Ashuganj	Single	Vertical	Upper	132
"	Jamalpur	"	"	"	132
Jamalpur	Mymensingh	"	"	"	132
Shahjibazar	Ashuganj	Double	"	Upper,Lower	132
"	Srimongal	Single	"	"	132
Srimongal	Shahjibazar	"	"	"	132
"	Fenchuganj	"	"	"	132
Fenchuganj	Srimongal	"	"	Upper	132
"	Sylhet	"	"	"	132
Sylhet	Chhatak	"	"	Centre	132
"	Fenchuganj	Single	"	Upper	132
Chhatak	Sylhet	"	"	Centre	132
Comilla	Siddhirganj	Double	"	Upper,Lower	132
"	Feni	"	"	"	132
"	Chandpur	Single	"	Centre	132
Feni	Madhanhat	Double	"	Upper,Lower	132
"	Comilla	"	"	"	132
Madonhat	Fani	"	"	"	132
"	Kulshi	Single	Horizontal	Centre	132
"	Kaptai	Double	Vertical	Upper,Lower	132
"	Sikalbaha	"	"	Centre	132
Chandraghona	Madhonhat	"	"	Lower	132
"	Kaptai	"	"	"	132
Kaptai	Madhanhat	"	"	Upper,Lower	132
Kulshi	Halishahar	Single	Horizontal	Outer	132
"	Baroaulia	"	Vertical	Lower	132
"	Madhanhat	"	Horizontal	Outer	132

Baraulia	Kulshi	Single	Vertical	Lower	132
Halishahar	"	"	Horizontal	Outer	132
"	Shikolbaha	"	"	"	132
Sikalbaha	Madhonhat	Double	Vertical	Center	132
"	Dohazari	Single	"	"	132
"	Halishahar	"	Horizontal	Outer	132
Dohazari	Shikolbaha	"	Vertical	Centre	132
Ishurdi	Goalpara	Double	"	Centre,Centre	132
"	Bogra	Single	"	Centre	132
"	Rajshahi	"	"	Upper	66
"	Pabna	"	"	"	66
"	Tongi	Double	"	Centre,Centre	132
Ullapara	Pabna	Single	"	Centre	66
"	Bogra	"	"	"	132
Bogra	Polashbari	"	"	"	132
"	Ishwardi	"	"	"	132
Rangpur	Polashbari	Single	"	"	132
Saidpur	Rangpur	"	"	"	132
Purba Sayedpur	Thakurgaon	"	"	"	132
Bheramara	Bottail	Double	Vertical	Centre,Centre	132
Jessore	Nowapara	Single	"	Centre	132
Nowapara	Bheramara	"	"	"	132
Goalpara	Bagerhat	"	Two Vert. Two Horiz.	Lower	132
Bagerhat	Goalpara	"	Horizontal	Centre	132
Barishal	Mongla	"	"	"	132
"	Bagerhat	"	"	"	132
Mangala	Bagerhat	"	"	"	132
Serajgonj	Ullapara	"	Vertical	Centre	66
Pabna	Isherdi	"	"	"	66

At some metering stations, coupling capacitor is connected to the line matching unit then protective device. Earthing switch or drainage coil was not found at some metering station. Most of the critical connections are very poor such as the connection of protective device, coupling capacitor, line matching unit, weave trap, co-axial cable etc.

During installation period, the amplifier and filter section were adjusted by the foreign consultant. Still they were not adjusted.

Power supply provides the energy to the electronics from common battery. It is charged by power line through the rectifier and filter arrangement. Ripple portion of filter output is prominant.

In some metering stations, noise problem is reduced by the replacement of the power supply. Also under and over charging problem is there. Battery was found in dirty in most of the metering station.

Phase to ground coupling is used for single circuit. Due to lack of balanceing transformer, phase to ground coupling is used for double circuit. During the installation period, in western section, design specification of line matching unit, coupling capacitor etc. is not maintained at all. Both end of the same link, ratings of the coupling capacitor and line matching unit are not same respectively. In Table 5.7, ratings of the line matching unit at different metering station are given. Theoritical coupling capacitor can be calculated which is shown in Appendix-1.

Table 5.7: Ratings of the line matching unit and coupling capacity of different metering station.

Metering Points	Direction	C.C. in p f	Line matching unit		
			Bandwidth in kc	Characteristics impedance in ohm	Capacitor in p.f.
Siddhirgonj	Ghorasal	-	108-486	240-250	6000
"	Ashuganj	-	108-486	240-250	6000
"	Hasnabad	13500	100-492	320- 75	5000
Hasnabad	Mirpur	13500	64-577	320- 75	13400
"	Siddhirgonj	13500	64-577	320- 75	13400
Mirpur q	Hasnabad	13500	64-577	320- 75	13400
"	Tongi	13500	104-414	240-250	6000
Tongi	Ullon	5000	132-500	-	16500
"	Ghorashal	16500	80-480	240- 75	16500
"	Siddhirgonj	19000	84-589	240-125	19000
"	Mirpur	16500	64-577	320- 75	13400
Ullong	Tongi	13500	132-500	-	5575
"	Siddhirgonj	5575	132-500	-	5575
Ghorasal	"	6000	104-414	240-250	6000
"	Ashuganj	6000	104-414	240-250	6000
"	Tongi	-	80-480	240- 75	16500
Kishorgonj	Mymensingh	8300	132-500	-	5575
"	Ashuganj	8300	132-500	-	5575
Ashuganj	Mymensingh	8300	132-500	-	8300
"	Jamalpur	8300	140-440	-	5575
Jamalpur	Mymensingh	8300	84-434	320-125	6000
Comilla	Siddhirgonj	5000	80-240	-	5575
Modonhat	Shikolbaha	8300	88-567	320-125	-

Kulshi	Modonhat	5600	64-500	-	5600
"	Halishahar	5600	64-500	-	5600
"	Baroaulia	5600	64-500	-	5600
Dohazari	Shikolbaha	-	88-567	320-125	5575
Ishwardi	Goalpara	3700	84-589	-	6000
"	Bharamera	8300	60-270	240-125	13000
"	Bogora	19000	104-414	240-250	6000
"	Tongi	19000	84-589	240-125	19000
Polashbari	Rangpurq	8300	132-500	-	8300
"	Bogora	8300	132-500	-	8300
Bogora	Polashbari	8300	132-500	-	5575
"	Ishwardi	8300	76-582	320-125	8300
Rangpur	Polashbari	8300	76-582	320-125	8300
Purbo Syedpur	Syedpur	7500	45-220	125-400	6000
"	Thakurgaon	-	84-434	320-125	6000
Thakurgaon	Purbosayedpur	7500	45-220	125-400	6000
Bheramara	Goalpara	8300	104-414	240-250	6000
"	Ishwardi (1)	5750	76-582	320-125	8300
"	" (2)	5000	76-582	320-125	8300
Botail	Jhenaidha	6000	60-270	-	6000
"	Bheramera	6000	60-270	-	6000
Jhenaidha	Jessore	6000	76-582	320- 75	8300
"	Botail	6000	60-270	-	6000
Jessore	Nowapara	6000	60-270	-	6000
"	Jhenaidha	6000	76-582	320-125	8300
Nowapara	Goalpara	-	64-576	320-125	10000
"	Jessore	6000	64-576	320-125	10000

Goalpara	Bagherhat	3000	200-450	600- 75	3000
"	Nowapara	6000	76-582	320-125	6000
Bagherhat	Goalpara	3000	200-450	600- 75	6000
"	Barishal	3000	200-450	600- 75	3000
"	Monghla	3000	200-450	600- 75	3000
Mongla	Bhagerhat	3000	200-450	600- 75	3000
Pubna	Ullapara	8800	132-500	-	8800
"	Ishwardi	8800	132-500	-	8800
Ullapara	Serajgonj	8800	132-500	-	8800
"	Pubna	8800	132-500	-	8800
Serajgonj	Ullapara	8800	132-500	-	8800

Some of the line matching units are broad band, others are narrow band type. When line matching units are replaced, design specification is not maintained. Some of the links are express type, and some of the links are back to back connection.

Most of the wave traps are not in its proper characteristics.When fault is occured then the station earth switch is closed, the P-L-C signal is by-passed through the station earth switch. Tolerance of the short circuit currents depends on the inductance. The ratings of the wave traps are shown in the Table 5.8. The current rating of the wave trap is not properly matched with the transmission line current. Therefore the transmission line current capacity is shown in Table 5.9.

Table 5.8: Wave trap ratings of different metering station of BPDB

Metering Station	Direction	Current in amp	Inductance in mh.
Siddhirgong	Ghorashal	500	0.18
"	Comilla	250	0.18
"	Ullon	630	0.20
"	Kamalapur	500	0.18
"	Hasnabad	630	0.20
Ghorashal	Siddhirgonj	630	0.20
"	Ashuganj	630	0.20
"	Tongi	1200	0.35
Ashuganj	Ghorashal	500	0.18
"	Shahjeebazar	630	0.18
"	Keshorgonj	630	0.20
Shahjeebazar	Ashugonj	500	0.18
"	Srimongol	500	0.18
Srimongol	Shahjeebazar	500	0.18
"	Fenchuganj	500	0.18
Fenchuganj	Srimongol	500	0.18
"	Sylhet	500	0.18
Mymensingh	Jamalpur	630	0.20
"	Kishorgonj	630	0.20
Kishorgonj	Mymensingh	630	0.20
"	Ashuganj	630	0.20
Jamalpur	Mymensingh	500	0.18
Tongi	Ullon	1200	0.35

Ullon	Tongi	630	0.20
"	Siddhirgonj	630	0.20
Kamalapur	Siddhirgonj	630	0.20
Chandpur	Comilla	800	0.20
Comilla	Siddhirgonj	250	0.18
	Fani	250	0.18
	Chandpur	500	0.18
Feni	Comilla	630	0.20
	Madanhat	630	0.20
Madanhat	Halishahar	630	0.20
"	Feni	200	0.18
"	Chandraghona	200	0.18
Halishahar	Modanhat	630	0.20
Chandraghona	Kaptai	630	0.20
	Modanhat	630	0.20
Kaptai	Feni	250	0.18
"	Madanhat	250	0.18
Hasnabad	Mirpur	630	0.20
"	Shiddhirgonj	630	0.20
Mirpur	Hasnabad	630	0.20
"	Siddhirgonj	630	0.20
Kulshi	Halishahar	1250	0.20
"	Baraulia	1250	0.20
"	Madanhat	1250	0.20
Sylhet	Fenchugonj	500	0.18

Ishurdi	Tongi	1200	-
"	Bogura	1200	-
Saidpur	Rangpur	630	0.18
"	Purba Saidpur	400	0.18
Purbasaidpur	Saidpur	400	0.18
"	Thakurgaon	400	0.18
Thakurgaon	Purba Saidpur	400	0.18
Bharamera	Goalpara	500	0.18
"	Bottail	500	0.18
"	Ishurdi	500	0.18
Bottail	Jhenida	500	0.18
"	Bheramara	500	0.18
TJhenidha	Jessore	500	0.18
"	Bottail	500	0.18
Jessore	Noapara	500	0.18
"	Jhenida	500	0.18
Noapara	Goalpara	630	0.20
"	Jessore	630	0.20
Goalpara	Bagerhat	630	0.20
Bagerhat	Goalpara	630	0.20
"	Borishal	630	0.20
"	Mangla	630	0.20
Barisal	Bagerhat	630	0.20

Table 5.9: Transmission Line current of different section of Power line of BPDB.

Transmission line section		Rated Capacity		Present Capability
		MVA	Current in Amp.	
Siddhirgonj	-Comilla(2)	162	700	400A
"	-Madanhat(1)	162	700	400A
Kaptai	-Chandraghona(2)	162	700	400A
"	-Madanhat(1)	162	700	400A
Madanhat	-Halishahar			
Ashuganj	-Ghorasal(1&2)	162	700	600A
Ghorasal	-Siddhirganj(1&2)	162	700	600A
"	-Tongi(1&2)	315	800	800A
Ashuganj	-Kishorganj	136	600	400A
Shahjibazar	-Srimangal	162	700	400A
Shahjibazar	-Ashuganj	162	700	400A
Tongi	-Mirpur	162	700	400A
Siddhirganj	-Ullon	162	700	400A
"	-Hasnabad	162	700	
Tongi	-Ishurdi(1&2)	315	800	800A
Ishurdi	-Bogra (1&2)	136	600	600A
Ishurdi	-Pabna(66KV)	535	420	420A
"	-Rajshahi(66 KV)	53.5	420	420A
Bheramara	-Ishurdi(1)	136	600	600A
"	-Bottail	136	600	600A
Goalpara	-Bheramara	136	600	600A
Bheramara	-Faridpur	136	600	600A
Goalpara-	-Bagerhat	136	600	600A

In most of the metering station there is not arrangement for controlling the temperature and humidity.

It was reported that the performance of the power line carrier communication of BPDB in Winter season is preferably better, In Rainy season it is too much worse. In wet season, noises increased due to thunder storms and lightining. In wet season, the corona noise is too much higher. There is no record regarding P-L-C system in any office of BPDB. Different connections and realy contacts is not good. The P-L-C equipment is very old. Therefore the performance of these equipments is not satisfactory.

5.9 Average annual thunder storm days of the transmission line

Siddhirganj - Sylhet line passes through the places having average annual thunder storm days: Dhaka-71, Brahmanbaria - 49, Srimongal - 41 and Sylhet - 109. And Siddhirganj - Kaptai line passes through the places having average annual thunder storm days : Dhaka - 71, Comilla - 21, Chittagong - 56 and Rangamati - 81. The average annual thunder storm days of the two transmission lines are tabulated in Table 7.

Table 5.10: Average annual thunder storm days of transmission Line.

Name of the line	Length of the line	Average annual thunder storm days
Siddhirganj-Kaptai	170	57
Siddhirganj-Sylhet	155	68

5.10 Frequency of lightning flashes N are calculated by the Formula(38).

$$N = 1.8\ h_a \frac{D}{20} \times \frac{l}{100}$$

h_a = 100 ft. = 30.6 meter

l = 272 Km

D = 57

$$N = 1.8 \times 30.6 \times \frac{57}{20} \times \frac{272}{100} = 440$$

Similarly the number of lightning flashes N of Siddhirganj - Sylhet line is 370. The results shown in the table 11.

Table 11: Lightning flashes N of transmission lines.

Name of the line	Number of thunder storm days	Length of line in Km	Height of line in meters	Frequency of lightning flashes, N 6
Siddhirganj - Kaptai	57	272	30.5	440
Siddhirganj - Sylhet	68	249.5	30.5	370

5.11 Discussions:

The signal-to-noise ratio of an electrical communication system is mainly function of system noise and attenuation. The output noise, signal level and signal to noise ratio of some of the P-L-C links of BPDB have been tabulated in tables 5.1, 5.2. When the result are compared to the table 5.5, the noise level of some links is within the reasonable limit, but SNR performance is very poor. Therefore the attenuation problem is there.
In some other links the noise level is also prominant, resulting in poor SNR.

Random noise is caused by the thermal agitation in the power line conductor and pickup of static signals. Thermal noise in tubes or resistors in the receiver produces random noise with results. Similar to that produced on power line. Small impulsive discharges at many different points, although scattered, together add up to random noise. As these discharges get bigger, they may more and more be considered as impulse noise. Impulse noise, in addition, is caused by lightning strokes, switching and line faults, which produces impulse at random rate.

Bad weather increases the line noise level. Thander storms produce discharges which are picked up by the line. Light rain after a period of dry weather increases the noise level. The first moisture deposited on a dirty insulator will increases the conductivity and the leakage considerably. After the rain has washed off the dust, the noise falls but not as low as a value during the fine weather. Thermal noise normaly depends on the room temperature of the P-L-C equipment. In most of the metering station of BPDB,there is no arrangement of controlling the temperature and humidity.

It was reported that the performance of the P-L-C system of BPDB which was under investigation is better in winter season than in rainy season. The average thunder storm days which are shown in table 5.10 are very high for the P-L-C links under a study. The number of lightning flashes N which is whown in table 5.11 is very high as the isokeraunic level is very high.

Frequency of the line fault is very high. Connection of the grounding of protective device forms contact resistance. (Shown in table 5.5). It is of great importance for bypassing of surge voltage.

The current rating of the transmission line is not matched with the current rating of the wave trap. In some metering points such as Comilla, Feni etc., the wave traps are under rated. For this reason the heat is developed. The connection point of the wave trap was found to be loose. Loose connection also generates noise. At Modanhat metering station, when the wave trap was replaced, the noise of the particular link reduced considerably.

The SNR performance for phase to phase coupling arrangement is better than the phase to ground coupling.

But the coupling method of P-L-C system of BPDB is phase to ground coupling. Power supply is one of the sources of noise in P-L-C system. Over charging, under charging and electrolytic level maintenance problem is there..

In vertically arranged power line conductors, Radio interference is more than the horizontal. In most of the power line of BPDB, the conductor are arranged vertically.

Corona discharge also contributes considerable noise. Corona modulation is a some what different phenomenon and is specifically associated with the presence of carrier. The effect of the discharge, in addition to creating a small disturbance by itself is to alter the impedance of the power line so that signal will be absorbed at a varying rate. This produces amplitude and phase modulation, and is directly proportional to the signal strength. Increased transmitter power or reduced attenuation will therefore not improve the signal-to-noise ratio.

It was reported that during wet season when percentage of humidity is high (Percentage of humidity is shown in Appendix - 7). Corona noise in P-L-C links of BPDB is very much prominant.

The reduction of the output signal level of P-L-C system is due to attenuation. The signal is attenuated due to leakage, reflection, radiation etc.

Wave trap is used for preventing carrier current-flow in different section other than the disired ones. Vertually it offers high impedence to the carrier frequency current and low impedance for power frequency current. Theoritically it acts as an open circuit for carrier frequency signal.

Most of the wave traps which are in use in P-L-C system of BPDB are very old. The performance of the wave traps are not satisfactory. At Ashuganj, During falt period, when the station earth switch is closed , the output signal level is too low. It is assured that the carrier signal is by passed through the station earth switch. This happens due to the improper impedance characteristics of the wave trap.

The attenuation is higher for phase to ground coupling than phase to phase coupling. Phase to ground coupling is used in P-L-C system in BPDB. Generally the coupling loss is increased when the rating of the coupling capacitor is below 0.004 mf. In some of the metering stations of BPDB , the coupling capacitor value is less than 0.004 mf. If the coupling capacitor value is not of design specification, it will contribute mismatching in making series rasonance with line matching unit. In P-L-C link, the characteristic impedance of the line matching unit should equal to the surge impedance of the line for avoiding the reflection due to mismatching. The characteristics impedances of some of the links are found to be/of small value in comparism with the characteristics impedance of line matching unit which are shown in table 5.7. Most of the characteristic impedance of the line matching units which are used in P-L-C links of BPDB are with in the range from 240 to 320 ohm.

Therefore it is of great importance for adjustment of different section of the P-L-C link with the line matching unit. Imped Impedance matching transformer is used for matching the link. But still the adjustment is not performed on the link of BPDB at all.

In phase to ground coupling, if the outer conductor is used for P-L-C signal transmission, the attenuation is higher than the centre conductor.

In P-L-C link of BPDB, the centre phase conductor is seldom used. The centre phase conductor is used for Siddhirgonj to Tongi link. The output SNR is 30 dbm which ;is optimum.

From the SNR point of view, the frequency range should be in between 30 to 200 KHZ. The optimum signal to noise ratio is very definitly a function of the type of channel and its total attenuation. In general terms, short lines with low attenuation will give the best performance at the higher end of the frequency range while the optimum frequency is lower for long lines and higher attenuation. Where appreciable lengths of power cable are involved. The attenuation rises rapidly with frequency and the use of lower frequency becomes imperative.

The 100-500 kHz range is used in P-L-C system of BPDB. The carrier frequency of above 75% links are more than 200 kHz. T The lower and uper range have been selected randomly for the respectively links. In some link, specialy at Ashuganj, without conductive continuity for carrier current sometime receiver received the signal upto threshhold level.

Most of the P-L-C equipments are very old. The performanc of the equipment is not at all satisfactory. There is no drawing and testing manuals for links and cabinets. Routine maintenance seemed to be also very poorly managed.

CHAPTER - 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions & recommendations:

All modern power system, Now-a-days have central load dispatch centre (L-D-C) where all informations are transmitted from different metering points located in power stations and sub stations by using the power line carrier system. With the proposed installation of tele-metering system in BPDB in the near future, it can be assumed that the existing or modified P-L-C system will be used for all data transmission to the load dispatch centre at Shiddhirgonj. Because of the addition of more information to be transmitted, which will reduce the available power for each signal, and the great importance of the P-L-C link for BPDB. It is imperative that all possible improvement be made on the P-L-C system for the successful operation of the proposed telemetering system.

It is not ordinarily possible to reduce appreciably the noise level present at a given receiving point in a carrier system. The only practical way to improve signal to noise ratio is to raise the signal level at the receiving end point. It is not usually feasible to raise the levels by increasing the transmitting power because appreciable gain in terms of db requires in ordinetely large increases in power. A much more practical solution is to reduce the channel attenuation by all means, such as judicious application of wave traps and also reduc~~e~~ing the reflection and radiation lo~~o~~seby matching of the respective link impedance as well as proper carrier frequency selection. The use of repeater arrangement may also be required in some cases.

The following factors are surely the cause of reduced signal level and thus poor signal to noise ratio:

1. Line-matching units are connected to coupling capacitors whose values are in some cases different from the designed values, resulting in higher coupling loss.
2. Poor wiring arrangement which could affect the coupling (stray capacitance).
3. Coupling arrangements are different at the two ends of the same link.
4. Coupling with the centre conductor is seldom used, mostly the outer conductors have been used.
5. The performance of most of the wave traps is not satisfactory.
6. The large range of frequency as well as arbitrary selection for each link.
7. Noise produced by corona is significant.
8. Poor grounding connection in some of the stations.

A great improvement of the existing P-L-C network of BPDB in particular could be achieved by the implementation of the following recommendations:

1. A complete survey of the installations: Study of phase coupling arrangements, frequency selection, verification of components and other connected carrier equipments etc.
2. Checking and installation of new coupling equipment as well as wave traps wherever necessary.

3. Re-commissioning of every link after taking related measurements to optimize the coupling mode.
4. Wirings and connections should be made properly.
5. Higher end of the frequency range should be used for short links, lower range of frequency is for long links.
6. Control of corona effect during rainy season.
7. Improvement of the environment for the communication equipment (radio and telephone), this also applies to the power supplies.
8. Accurate drawing of every installation, including upto date file of every link and cabinets should be made so that good practice of the system maintenance could be established.

References

1. AIEE Committee, Guide to Application and treatment of channels of power-line carrier. Trans. AIEE vol. 73 Pt. IIIA PP; 417-436 - 1954.

2. Alsleben, E, Guiding value for the Planning of Power Line Carrier Communication Systems and Information on the determination of the line characteristic, CIGRE, Report-319, 1962

3. W.L. Everitt. Communication Engineering (book), McGraw-Hill Book Company, Inc., New York, N.Y., 2nd ed., 1937.

4. N.W. Melachian. Complex variable and oerational calculus (book), The Macmilian Company, New York, N.Y., 1942.

5. Adams, G.E.; Wave Propagation along unbalanced High Voltage Transmission Lines, Trans. AIEE, Vol. 78, Pt. III. pp.634 - 646, 1959.

6 Connor, F.R. "Noise" Edward Arnold (Publishers) Ltd. 1st Edition, 1973.

7. I.S. and E.S. Sokolnikoff. Higher Mathematics for Engineers and Physicists (book), McGraw-Hill Book Company. New York, N.Y., 1941.

8.	R.C. Cheek, J.D. Moynihan,	A study of carrier frequency. Noise on Power-lines Part. I. Trans. AIEE, Vol. 70 Pt. II, 1951.
9.	Jones, P.B. and Rowbolham, T.R.	Communication system analysis Butterworth and company Ltd., 1972
10.	Frank B. Gunter.	The application of power-line carrier coupling equipment to typical field installations-Part I, Trans. AIEE, Vol. 71. Pt. III, 1952, pp. 866-70.
11.	Fink & Carroll.	Standard Hand book for Electrical Engg. 10th edition, McGraw-Hill.
12.	Donland, H, Hamsher.	Communication system Engg. Hand book McGraw Hill, pp. 14.3 - 14.30.
13.	Brown, J. and Glazier, E.V.D.	"Telecommunications" English language book society and Chapman and Hall 2nd edition 1974, pp. 135-153.
14.	G.D. Lippert, W.E. Pa Pakala S.C. Bartlett, C.D. Fahrnkopf.	Radio Influence tests in field and laboratory 500 kv test project of the American Gas and Electric Company, Trans. AIEE Vol. 70, pp. 251 - 69. 1951.
15.	J.D. Moynihan B.J. Sparlin	A study of carrier - frequency noise on power-lines. Part II Trans. AIEE, Vol. 70 pt. II - 1951 pp. 1127-34.
16.	G.E. Adams.	The calculation of the radio interference level of Transmission lines caused by corona discharges. Trans. AIEE, Prt - III, Vol. 75, 1956. pp. 411-419

17. Study Committee No. 9.	Measurement & Radio disturbances due to corona effect on Extra High-voltage line CIGRE Report - 416, 1956.
18. W.D. Good man.	British Developments and Applications of Carrier current principles for operating Requirements of power utilities Trans. AIEE Vol. 70 Pt. II 1951, PP. 1319-24.
19. J.D. Moynihan,	Application of line traps to power line carrier systems Trans. AIEE Vol. 7 pt. III, 1952, PP. 1058-62.
20. Jones D.E., and P.W. Waddington	Coupling Method for P-L-C system Trans. AIEE., Vol.-7a, Pt. III. 1957 PP. 1284 - 1287.
21. John and Beeker.	New Method of Calculation Carrier Current Attenuation. Trans. AIEE, Vol. 73, Pt. III-A, 1954, PP. 417-36.
22. F.C. Krungs J.L. Woodworth	Analysis of losses in Power line carrier coupling circuits, Trans. AIEE-III B. Vol-73, 1954 PP. 1213-18.
23. John A. Doremus Robert P. Crow, William H. Freeman	A broad-band coupling unit for power-line carrier with Associated potential device. AIEE Transactions, Vol. 71, pt. III, Oct. 1952, pp.870-87.

24. A. Chevallier	Carrier current on power line Beama journal, London, England, Vol. 60.
25. Robert L. Fillmore	Input filler design for frequency modulated P-L-C receivers. Trans. AIEE., Vol. 71. Pt. III, 1952 PP. 450-54.
26. A. Mikkelsen	Attenuation by carrier transmission on power line specially during formation of Ice and Rime on the conductor. CIGRE Report - 323, 1950.
27. J.D. Myniham.	Application of line trap to P-L-C systems, Trans AIEE., Vol. 71 pt. III 1952 pp. 1058-62.
28. Member of the Technical Staff	"Transmission System for Communications", Bell Telephone Lalboratories, Inc., Revised Fourth Edition, 1971, p. 30-33, 38-39, 49-68,170-176.
29. Anritsu [illegible].(comp.)	Operational manual for level meter MG442A, PP. 68-69.
30. Connor, F.R.	"Noise" Edward Arnold (Publishers)Ltd. 1st Edition, 1973.
31. Hewlett Packard (Comp.)	.Operational and service manual for psophometer. 3556A.

32. Tant, M.J. "White Noise Book" White Crescant Press Ltd., Luton, England, 1974.

33. Carrier divisions of BPDB. Functions & Maintenance description, Sept. 1983. pp. 1-15.

34. Panter, Philip F. Modulation, Noise and spectral analysis, McGraw Hill book company, Inc. 1965 pp. 172-178, 429-430.

35. E.V. Aggers, Dudley E. Foster C.S. Young. Instruments and Methods of Measuring Radio noise Trans. AIEE. Vol. 59, 1940.

36. AIEE Committee. Report on Method of Measurements at carrier-current frequencies. Trans. AIEE Vol. 67, pt. II-1948 pp. 1429-32.

37. Md. Emdadur Rahman Khan. A study on the noise and interference in telecommunication system with special reference to Bangladesh, BUET. M.Sc. Thesis, 1980.

38. Md. Shariful Islam. "Study of insulation level of the transmission system in Bangladesh & Possible causes of insulation failure", BUET, M.Sc. Thesis, 1975.

APPENDIX - 1

Questionnaires for field survey of metering stations of BPDB

1. Name of the metering station: ....

   Name of the Possible links:

2. Line voltage: ....

3. Number of tapping transmission line: ....

4. Type of modulation and demodulation: ....

5. Mode of Propagation: ....

6. Coupling arrangement

   (a) Coupling capacitor (C.C) rating: ....

   (b) Mathod of coupling: ....

   (c) Condition of coupling arrangement: ....

   ....

7. Tunning element (L.M.U)

   (a) Type ....(b) Condition: ....

   ....

   (c) Maintenance ....

8. Carrier frequency

   (a) Transmitting frequency...........(b) Receiving frequency:.......

   (c) Bandwidth of the L.M.U. ....

9. Type of link: ....

10. Condition of protective system: ....

    ....

11. Condition of grounding: ....

    ....

12. Condition of wireing for critical conections: ....

....

....

13. Environment of communication equipment:.........................

....

14. Arrangement of power supply for different section of P-L-C
system: ....

....

15. Condition of adjustment of filter & amplifier:.................

....

16. Location of power, electric motor, radio station etc. in the
vicenity:...

....

17. Effects of corrona: ....

....

18. Frequency ;of the fault occurance:
(a) Transmission line:...............(b) Feeder line:...............

19. Condition of relay contact:...................................

20. Survice age of the equipment:................................

21. Line length of the respective link:..........................

22. Probability of reception of other radiated carrier signal:
....

23. Existing problem regarding noise, signal level at the receiving end.:
....

24. Impact on noise due to variation of weather condition:
....

APPENDIX - 2

The equation for the capacitance of the coupling capacitor element of the constant band-pass filter is

$$C = \frac{2(f_2-f_1)}{4\pi f_1 f_2 R}$$

where

f_2 and f_1 = cutoff frequencies

R=load resistance seen by the filter.

For R equal to 400 ohms and for cutoff frequencies of 200 and 50 kc

$$C = \frac{2(200-50)10^3}{4\pi(50)(200)(10^6)(400)}$$

$$C = 0.006 \text{ mf}$$

For a constant high-pass filter the capacitance of the coupling capacitor element is given by the equation

$$C = \frac{2}{4\pi f_c R}$$

where

f_c = lower cutoff frequency

R = load resistance seen by filter

Again, for 400 ohms and for lower cutoff frequency of 50 kc

$$C = \frac{2}{4\pi(50)(10^3)(400)} = 0.008 \text{ mf.}$$

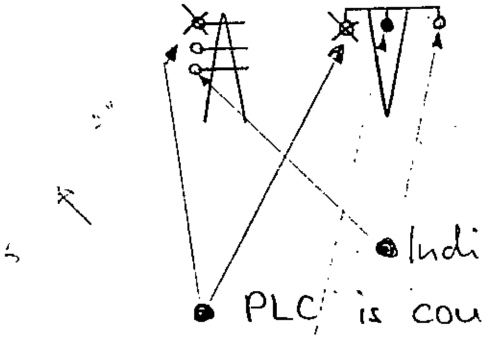
If the load impedance or line surge impedance is reduced to 200 ohms, the capacitances must be doubled; thus C for the band-pass filter would need to be 0.012 mf and C for the high-pass filter should be 0.016 mf.

APPENDIX - 3

Table: Relative Humidity in % between 1931-1960

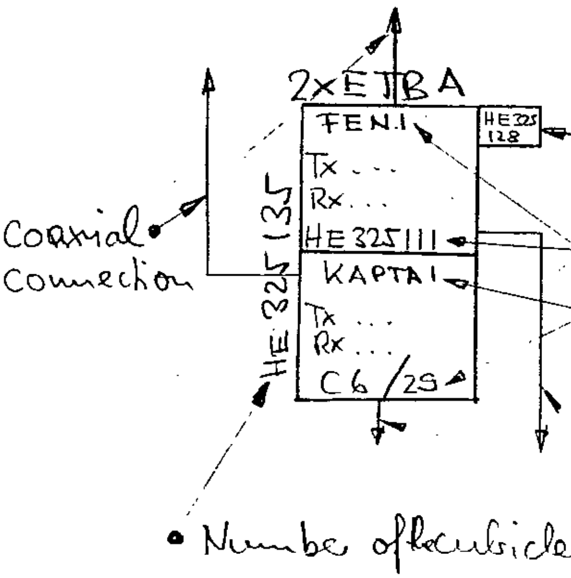
Name of the place	Maximum Humidity		Minimum Humidity	
	% Humidity	Months	% Humidity	Months
Chittagong	85	July	63	February
Rangamati	99	Nov. & Jan.	50	February
Cox's Bazar	89	August	68	Jan. & Feb.
Noakhali	95	October	60	February
Comilla	96	October	54	February
Brahmanbaria	94	December	53	March
Srimangal	97	December	57	March
Sylhet	97	July	51	March
Mymensingh	94	July to Sept.	73	March
Dhaka	95	June to Dec.	44	March
Narayanganj	92	October	45	March
Pabna	95	Jan. - Dec.	44	March
Serajganj	95	Oct. - Dec.	50	March-April
Faridpur	96	July	49	March
Jessore	96	July-Sept.	52	March
Satkhira	96	July	53	March
Barisal	94	July-Oct.	56	Feb. - March
Khulna	95	July-Sept.	53	March
Bogra	87	August	37	March
Dinajpur	93	July-Aug.	36	March
Rangpur	95	Jan. - Sept.	42	March

Appedex – 4



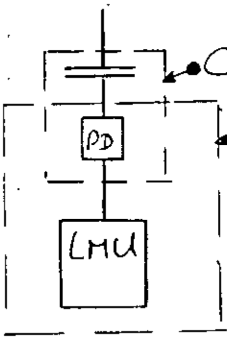
Arrangement of the conductors at the first tower looking from the substation towards the line

- Indicates a conductor
- PLC is coupled onto that conductor
- WT & CC fixed but no connection to PLC



2 ETBA-sets are fixed in one cubicle

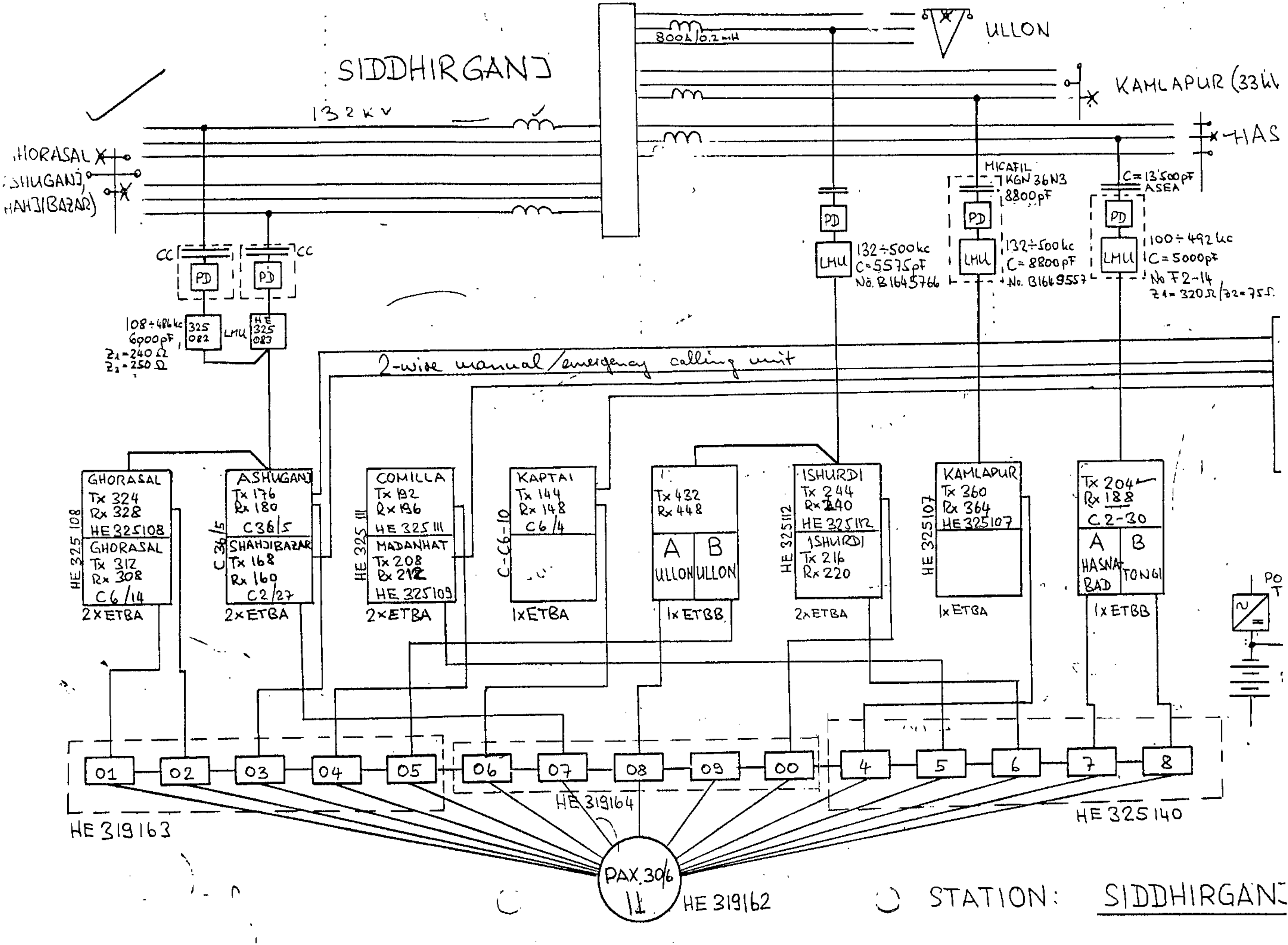
- Number of Tx-Output filter. Only mentioned if it differs from the ETBA-Number.
- Number of ETB-set
- Name of station where the PLC with matching frequencies is fixed.
- 4 wire connections



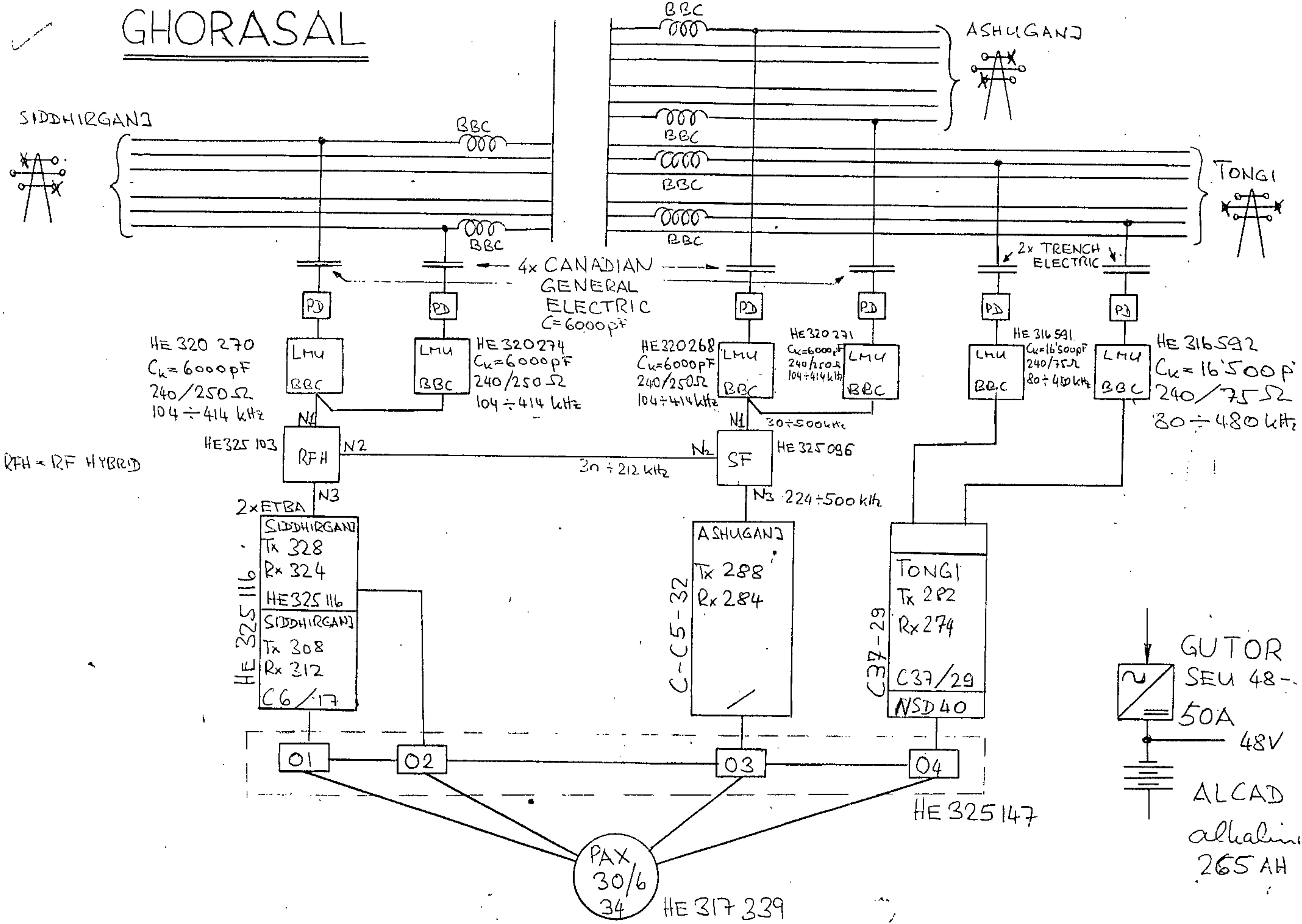
- CC + PD are fixed as one unit
- PD + LMU are fixed as one unit

Emergency-telephone set. Usually connected to the PLC (4 wire-jack-extension)

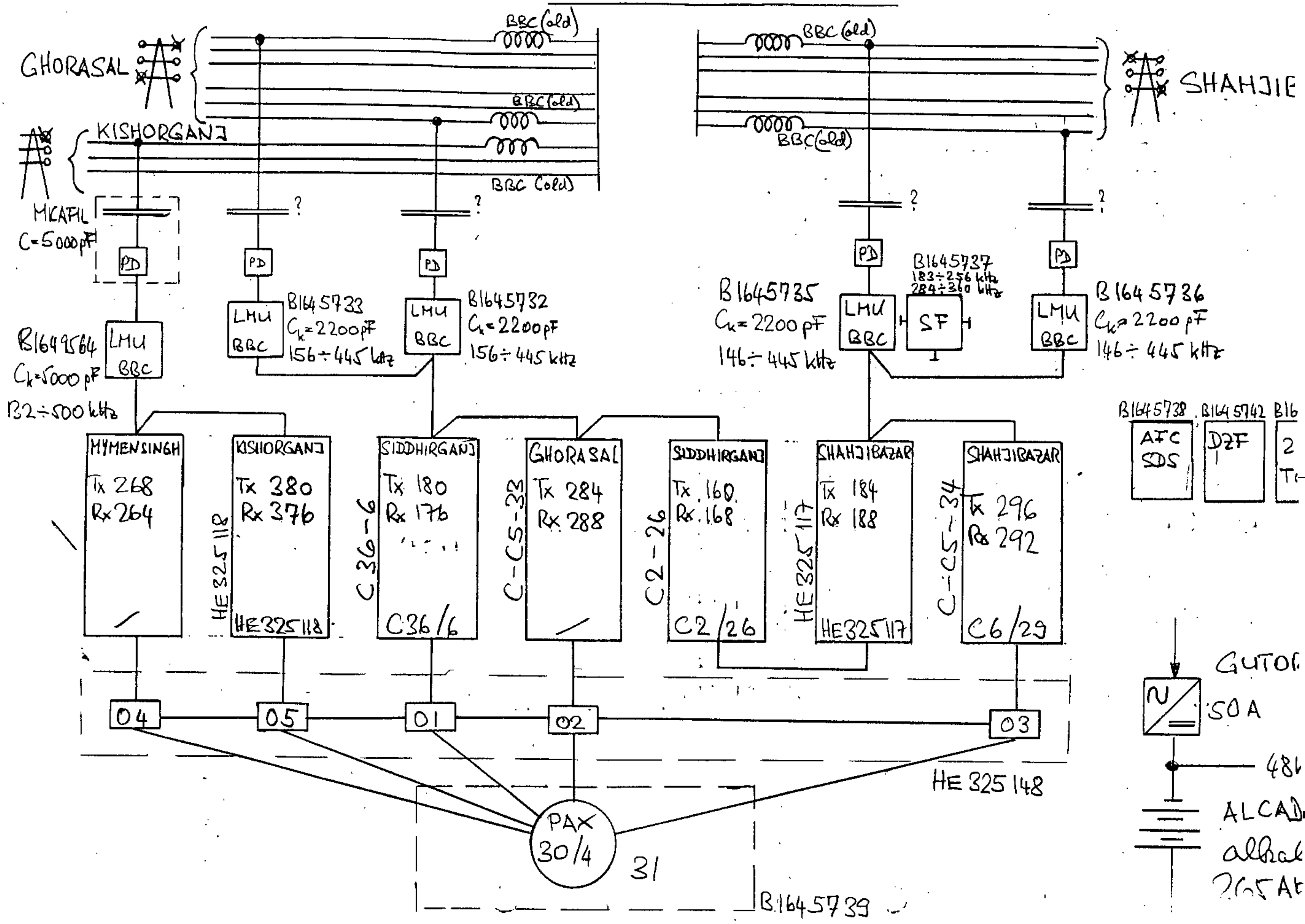
Data in brackets (mainly for line coupling devices) was taken out of a survey of WP [illegible] in 1975. It might have changed since

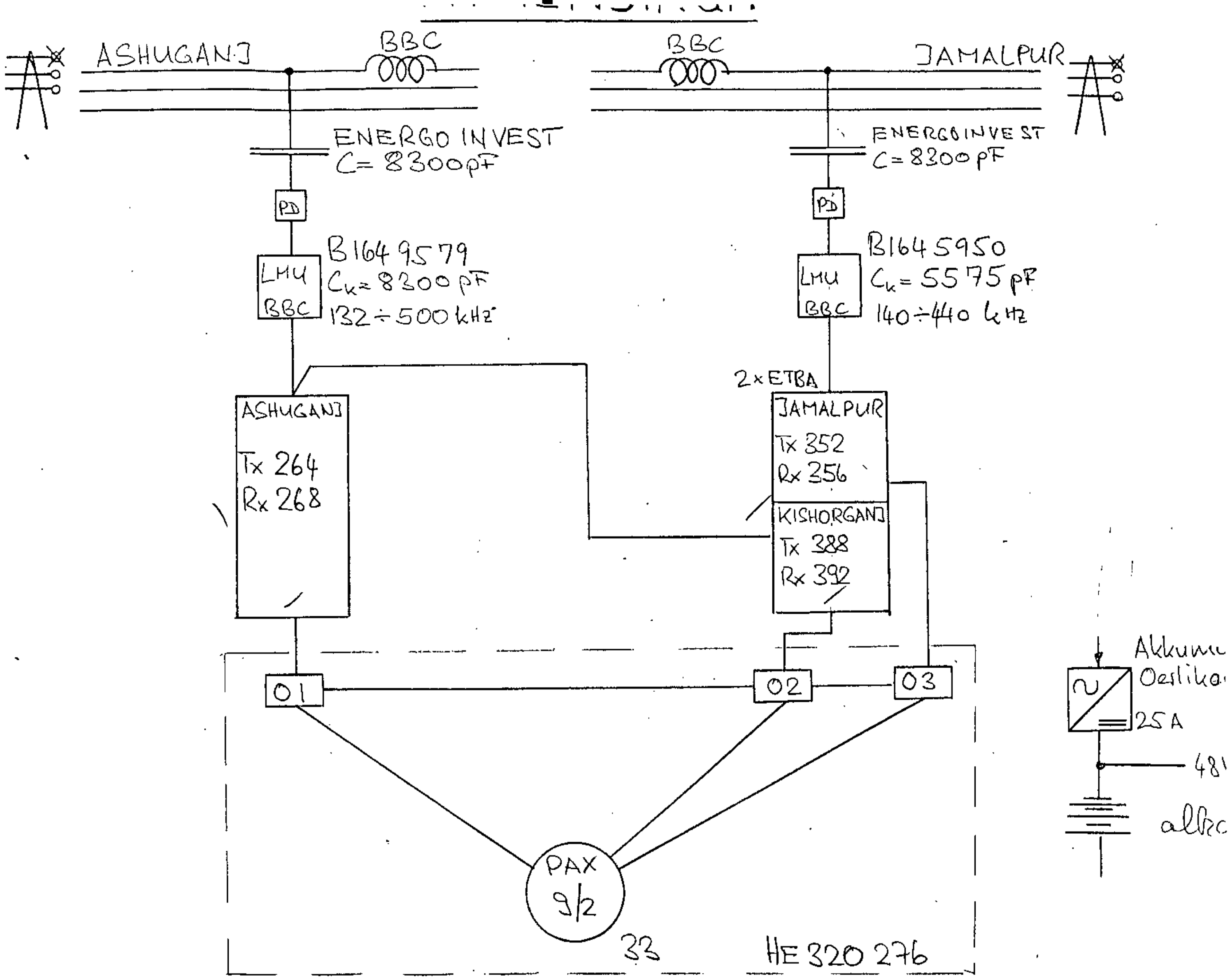
SIDDHIRGANJ
132 KV
800A/0.2mH
ULLON
KAMLAPUR (33kV
HAS
HORASAL
SHUGANJ,
HAHJIBAZAR)
CC
PD
CC
PD
108÷486kc
6900pF
Z1=240 Ω
Z2=250 Ω
325
082
LMU
HE
325
083
PD
LHU
132÷500kc
C=5575pF
No. B1645766
MICAFIL
KGN 36N3
8800pF
PD
LHU
132÷500kc
C=8800pF
No. B1649557
C=13'500pF
ASEA
PD
LHU
100÷492kc
C=5000pF
No F2-14
Z1=320Ω/Z2=75Ω
2-wire manual/emergency calling unit
GHORASAL
Tx 324
Rx 328
HE 325108
GHORASAL
Tx 312
Rx 308
C6/14
HE 325 108
2×ETBA
ASHUGANJ
Tx 176
Rx 180
C36/5
SHAHJIBAZAR
Tx 168
Rx 160
C2/27
C 36/5
2×ETBA
COMILLA
Tx 192
Rx 196
HE 325 111
MADANHAT
Tx 208
Rx 212
HE 325109
HE 325 111
2×ETBA
KAPTAI
Tx 144
Rx 148
C6/4
C-C6-10
1×ETBA
Tx 432
Rx 448
A
ULLON
B
ULLON
1×ETBB
ISHURDI
Tx 244
Rx 240
HE 325112
ISHURDI
Tx 216
Rx 220
HE 325112
2×ETBA
KAMLAPUR
Tx 360
Rx 364
HE 325107
HE 325107
1×ETBA
Tx 204
Rx 188
C2-30
A
HASNABAD
B
TONGI
1×ETBB
PO
T
01
02
03
04
05
06
07
08
09
00
4
5
6
7
8
HE 319163
HE 319164
HE 325140
PAX.30/6
11
HE 319162
STATION: SIDDHIRGANJ

GHORASAL

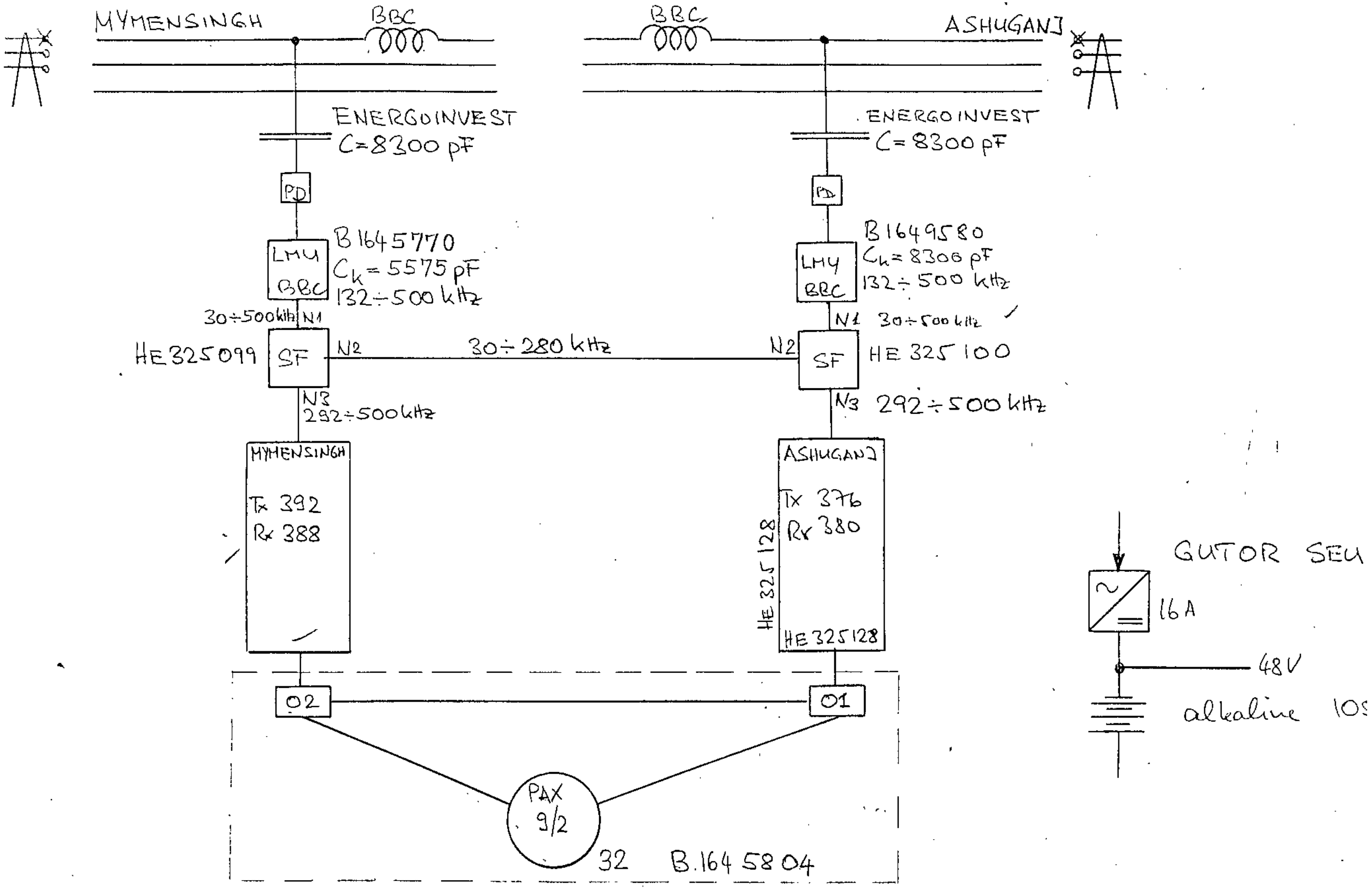

SIDDHIRGANJ
BBC
BBC
BBC
BBC
BBC
BBC
ASHUGANJ
TONGI
4x CANADIAN GENERAL ELECTRIC
C=6000pF
2x TRENCH ELECTRIC
PD
PD
PD
PD
PD
PD
HE 320 270
Ck=6000pF
240/250Ω
104÷414 kHz
LMU BBC
LMU BBC
HE 320274
Ck=6000pF
240/250Ω
104÷414 kHz
HE320268
Ck=6000pF
240/250Ω
104÷414kHz
LMU BBC
HE320271
Ck=6000pF
240/250Ω
104÷414kHz
LMU BBC
LMU BBC
HE 316591
Ck=16'500pF
240/75Ω
80÷480kHz
LMU BBC
HE 316592
Ck=16'500pF
240/75Ω
80÷480kHz
N1
N1
HE325 103
RFH
N2
30÷212 kHz
N2
SF
HE 325 096
30÷500kHz
RFH = RF HYBRID
N3
N3 224÷500 kHz
2xETBA
SIDDHIRGANJ
Tx 328
Rx 324
HE325 116
SIDDHIRGANJ
Tx 308
Rx 312
C6/17
HE 325 116
ASHUGANJ
Tx 288
Rx 284
C-C5-32
TONGI
Tx 282
Rx 274
C37/29
NSD40
C37-29
01
02
03
04
HE 325 147
PAX 30/6 34
HE 317 339
GUTOR
SEU 48-
50A
48V
ALCAD
alkalin
265 AH

ASHUGANJ

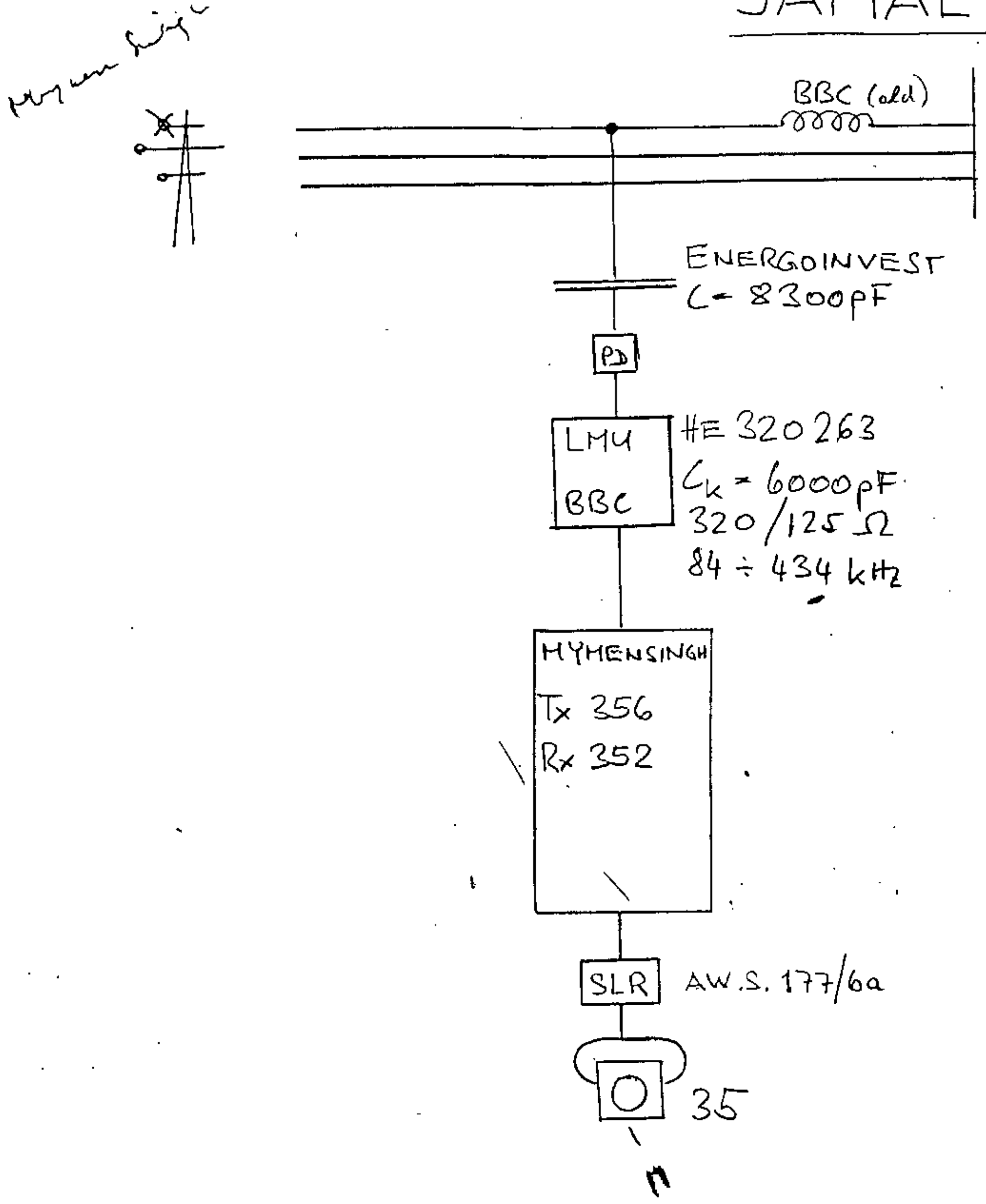

GHORASAL
KISHORGANJ
SHAHJIE
BBC (old)
BBC (old)
BBC (old)
BBC (old)
BBC (old)
MICAFIL
C=5000pF
PD
PD
PD
PD
PD
?
?
?
?
LMU BBC
B1649564
Ck=5000 pF
32÷500 kHz
LMU BBC
B1645733
Ck=2200pF
156÷445 kHz
LMU BBC
B1645732
Ck=2200pF
156÷445 kHz
B1645735
Ck=2200 pF
146÷445 kHz
LMU BBC
B1645737
183÷256 kHz
284÷360 kHz
SF
LMU BBC
B1645736
Ck=2200 pF
146÷445 kHz
B1645738
AFC SDS
B1645742
DZF
B16
2
Tc
MYMENSINGH
Tx 268
Rx 264
KISHORGANJ
Tx 380
Rx 376
HE325118
HE325118
SIDDHIRGANJ
Tx 180
Rx 176
C36-6
C36/6
GHORASAL
Tx 284
Rx 288
C-C5-33
SIDDHIRGANJ
Tx 160
Rx 168
C2-26
C2/26
SHAHJIBAZAR
Tx 184
Rx 188
HE325117
HE325117
SHAHJIBAZAR
Tx 296
Rx 292
C-C5-34
C6/29
04
05
01
02
03
HE 325148
PAX 30/4
31
B1645739
GUTOR
50 A
48
ALCAD
alkal
265 Ah

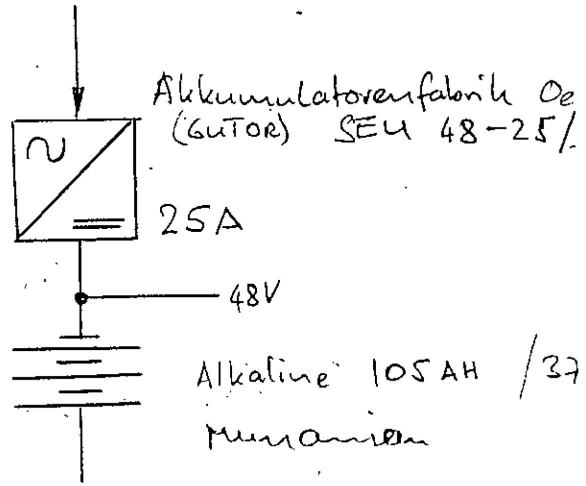

ASHUGANJ
BBC
BBC
JAMALPUR
ENERGO INVEST
C= 8300pF
ENERGOINVEST
C=8300pF
PD
PD
LMU
BBC
B164 9579
Ck= 8300 pF
132÷500 kHz
LMU
BBC
B164 5950
Ck= 5575 pF
140÷440 kHz
2×ETBA
ASHUGANJ
Tx 264
Rx 268
JAMALPUR
Tx 352
Rx 356
KISHORGANJ
Tx 388
Rx 392
01
02
03
PAX
9/2
33
HE 320 276
Akkumu
Oeslika
25 A
48
allkc

KISHORGANJ


MYMENSINGH
BBC
BBC
ASHUGANJ
ENERGOINVEST
C=8300 pF
ENERGOINVEST
C=8300 pF
PD
PD
LMU
BBC
B 1645770
C_k=5575 pF
132÷500 kHz
LMU
BBC
B1649580
C_k=8300 pF
132÷500 kHz
30÷500kHz
N1
N1
30÷500 kHz
HE325099
SF
N2
30÷280 kHz
N2
SF
HE 325 100
N3
292÷500kHz
N3
292÷500 kHz
MYMENSINGH
Tx 392
Rx 388
ASHUGANJ
Tx 376
Rx 380
HE 325 128
HE 325128
O2
O1
PAX
9/2
32
B.164 58 04
GUTOR SEU
16A
48V
alkaline 10

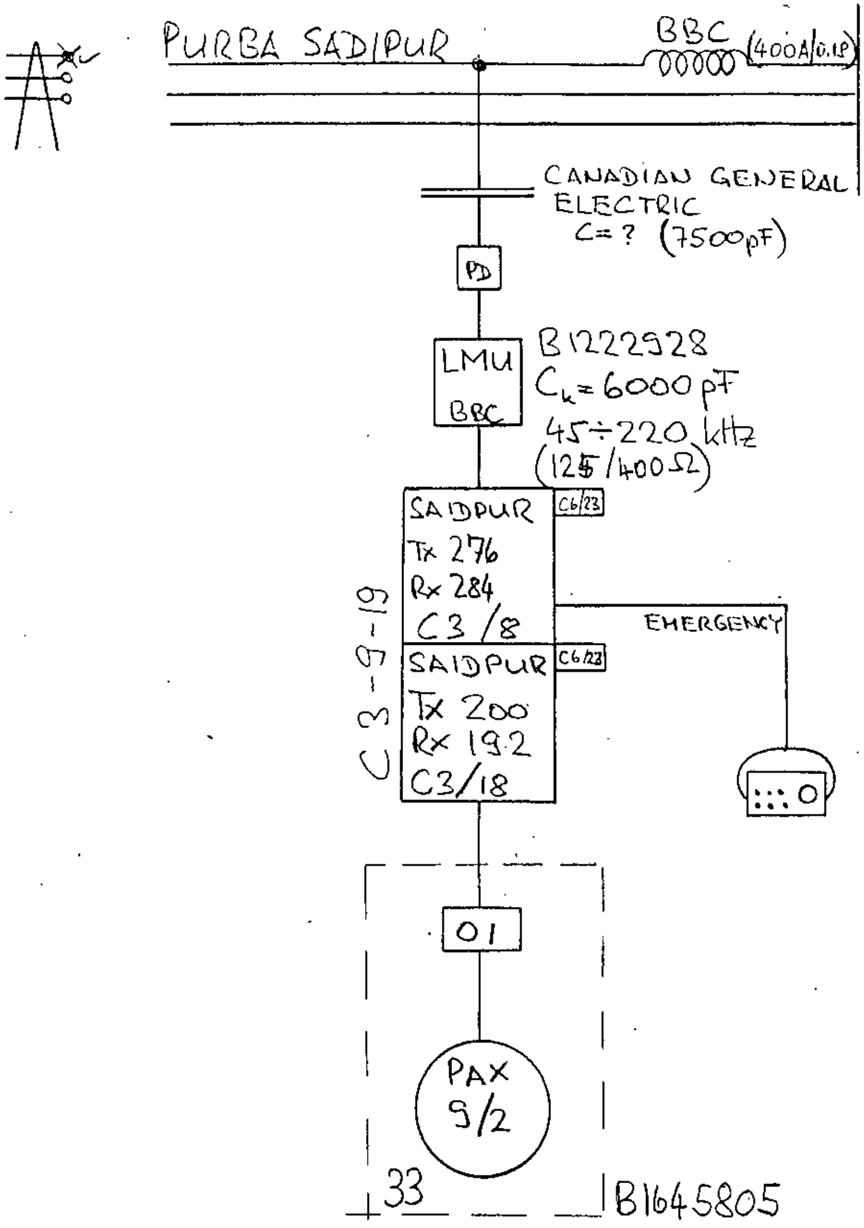
JAMALPUR

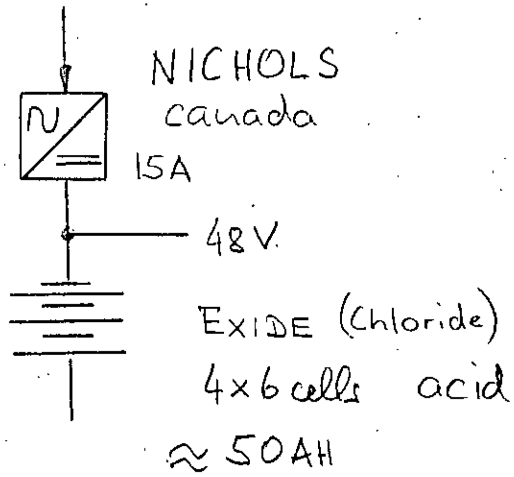

Mymensingh
BBC (old)
ENERGOINVEST
C = 8300pF
PD
LMU
BBC
#E 320263
C_k = 6000pF
320/125 Ω
84 ÷ 434 kHz
MYMENSINGH
Tx 356
Rx 352
SLR
AW.S. 177/6a
35


Akkumulatorenfabrik Oe
(GUTOR) SEU 48-25/
25A
48V
Alkaline 105AH /37

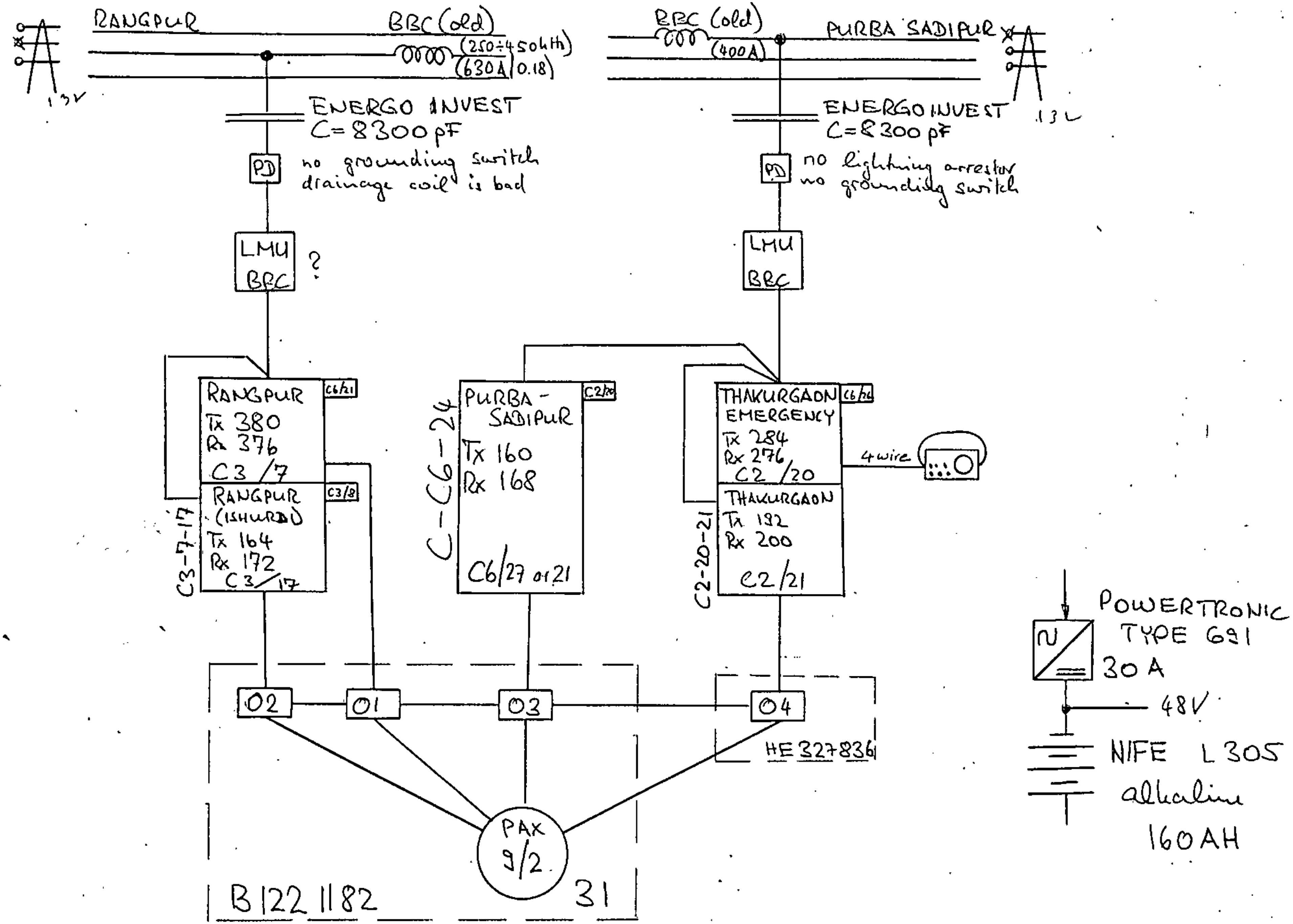
THAKURGAON

132





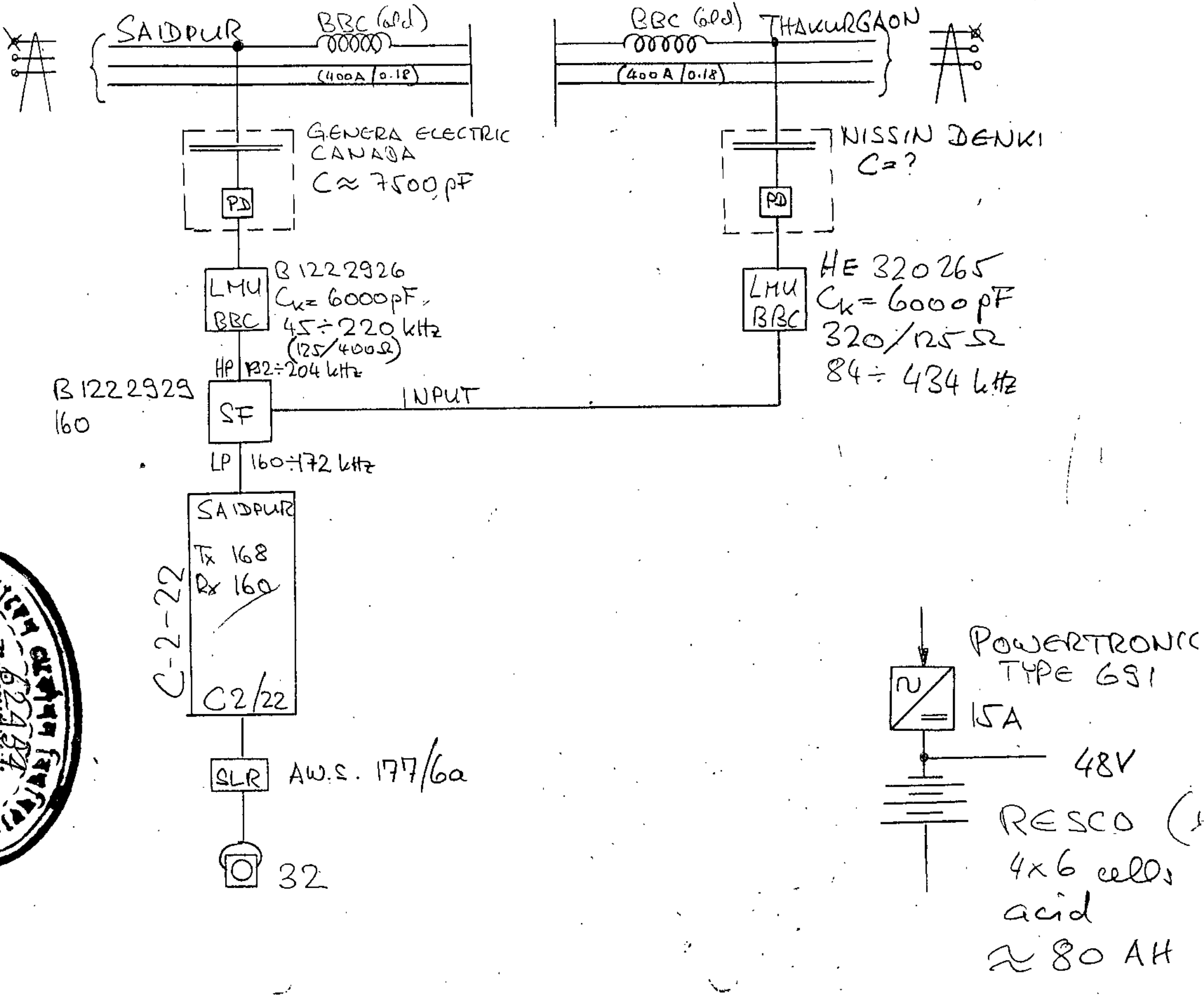
SAIDPUR



RANGPUR
BBC (old)
(250÷450 μH)
(630 A) 0.18)
132 V
ENERGO INVEST
C=8300 pF
PD
no grounding switch
drainage coil is bad
LMU
BBC
?
RANGPUR
Tx 380
Rx 376
C3 /7
C6/21
RANGPUR
(ISHURDI)
Tx 164
Rx 172
C3/17
C3/8
C3-7-17
PURBA - SADIPUR
Tx 160
Rx 168
C6/27 or 21
C2/20
C-C6-24
BBC (old)
(400 A)
PURBA SADIPUR
132 V
ENERGO INVEST
C=8300 pF
PD
no lighting arrestor
no grounding switch
LMU
BBC
THAKURGAON EMERGENCY
Tx 284
Rx 276
C2 /20
C6/26
4 wire
THAKURGAON
Tx 192
Rx 200
C2/21
C2-20-21
02
01
03
04
HE 327836
PAX
9/2
B122 1182
31
POWERTRONIC
TYPE 691
30 A
48 V
NIFE L305
alkaline
160 AH

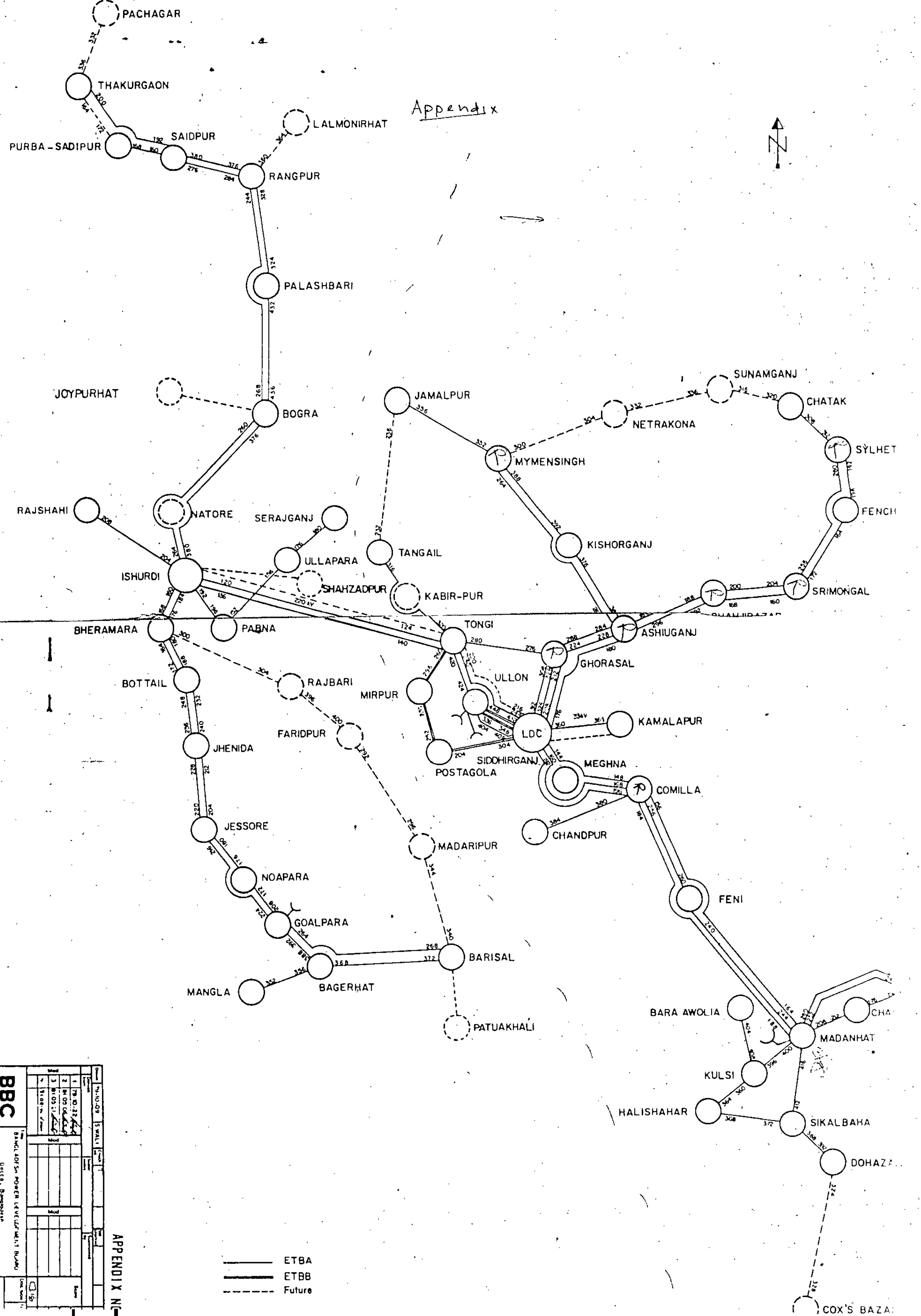
PURBA SADIPUR

132



F 105 755

Appendix



APPENDIX N

BBC
BROWN BOVERI

BANGLADESH POWER DEVELOPMENT BOARD
Dacca, Bangladesh
P.L.C GENERAL LAYOUT AND FREQUENCY PLAN

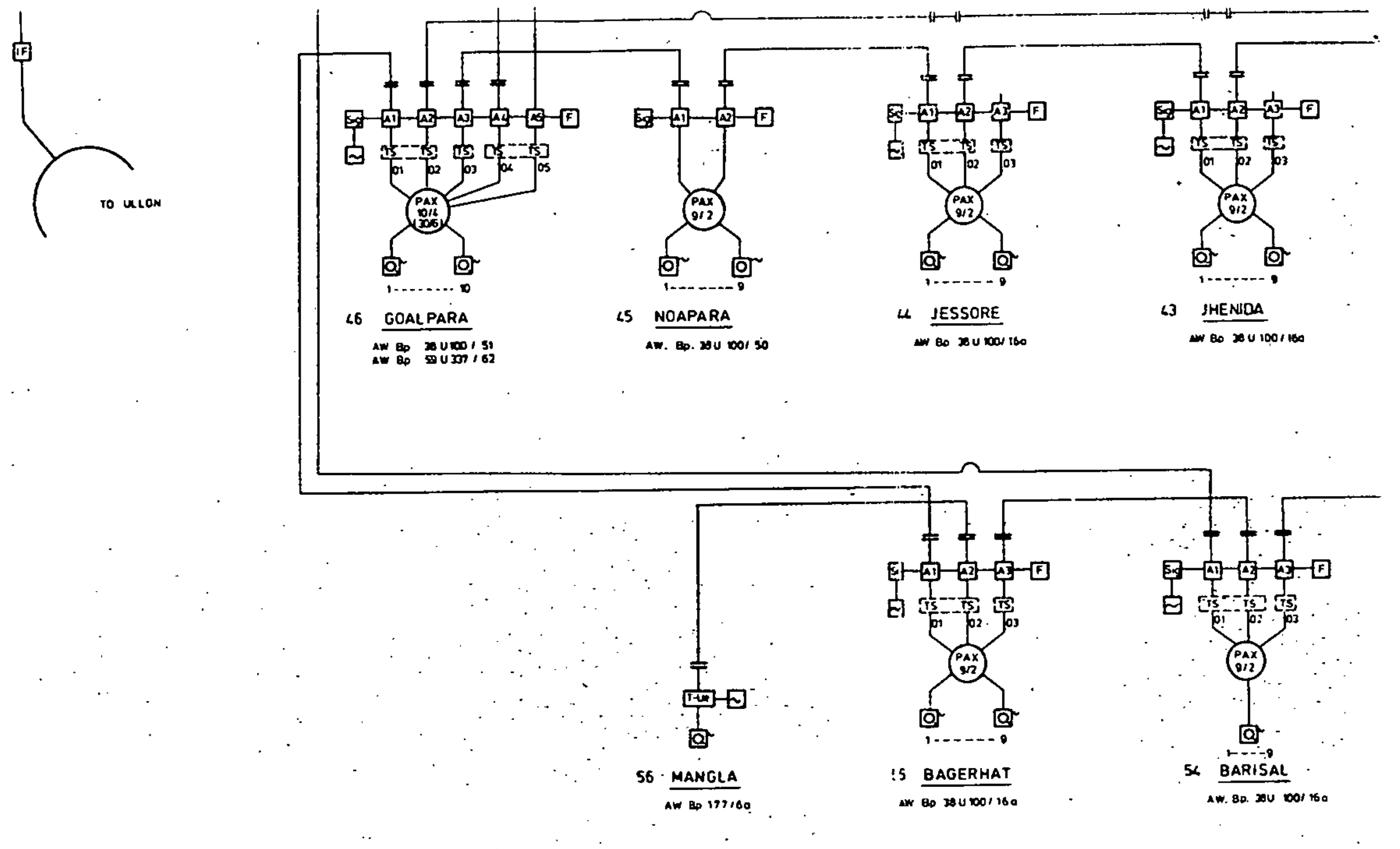
79-10-09 S WALI

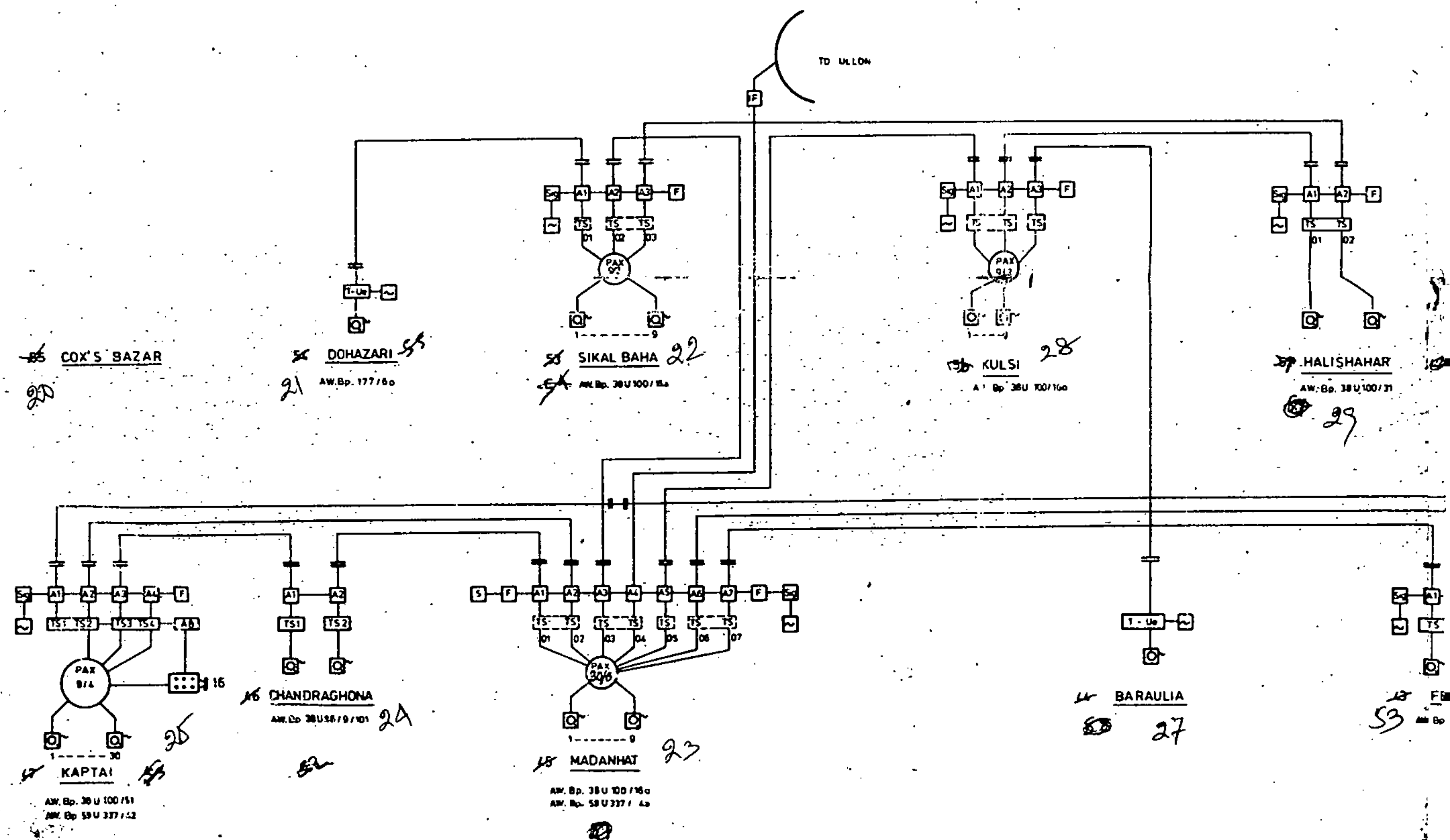
Mod	
1	79-10-22
2	80-09-06
3	81-05-11
4	81-09-

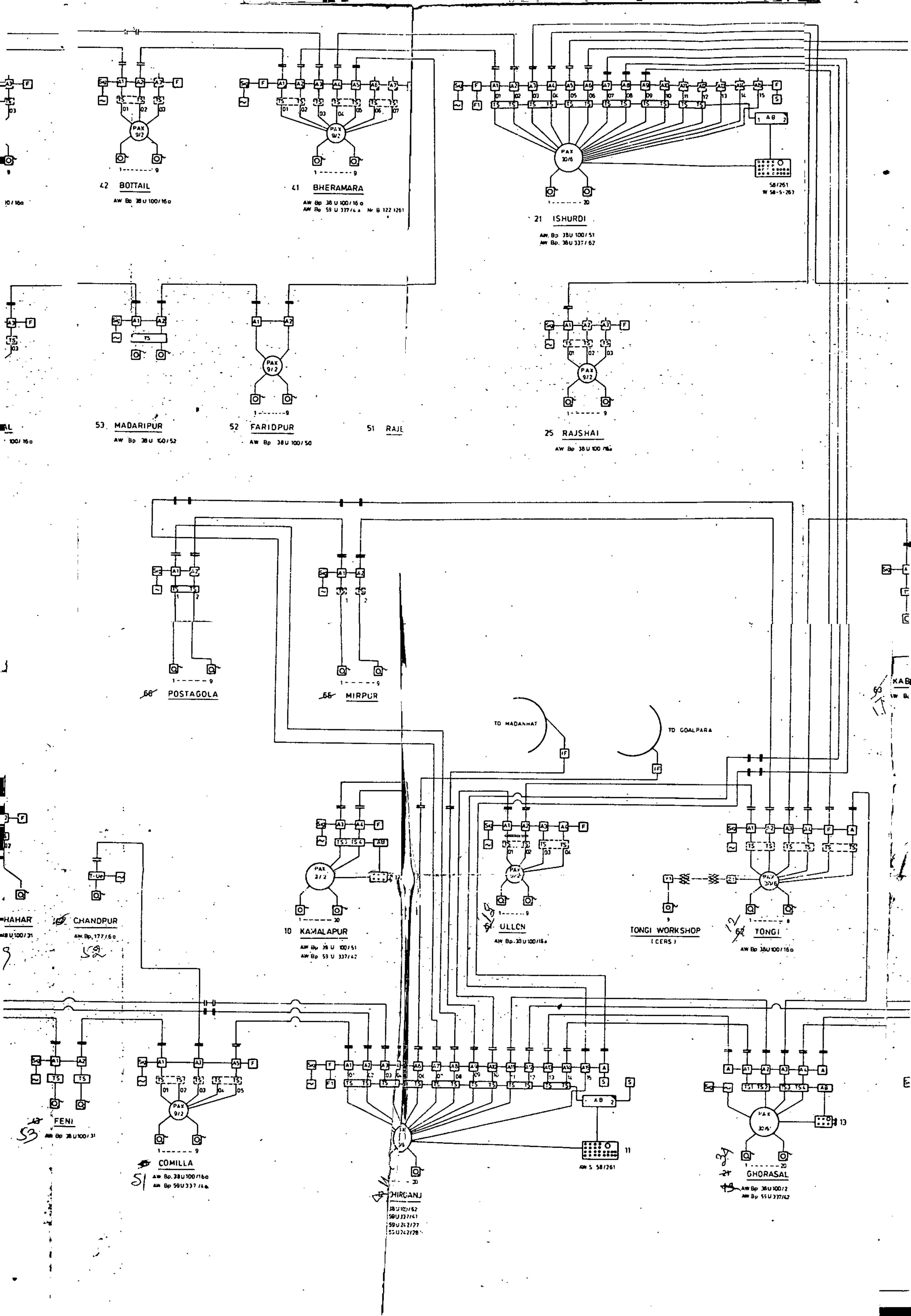
HENS

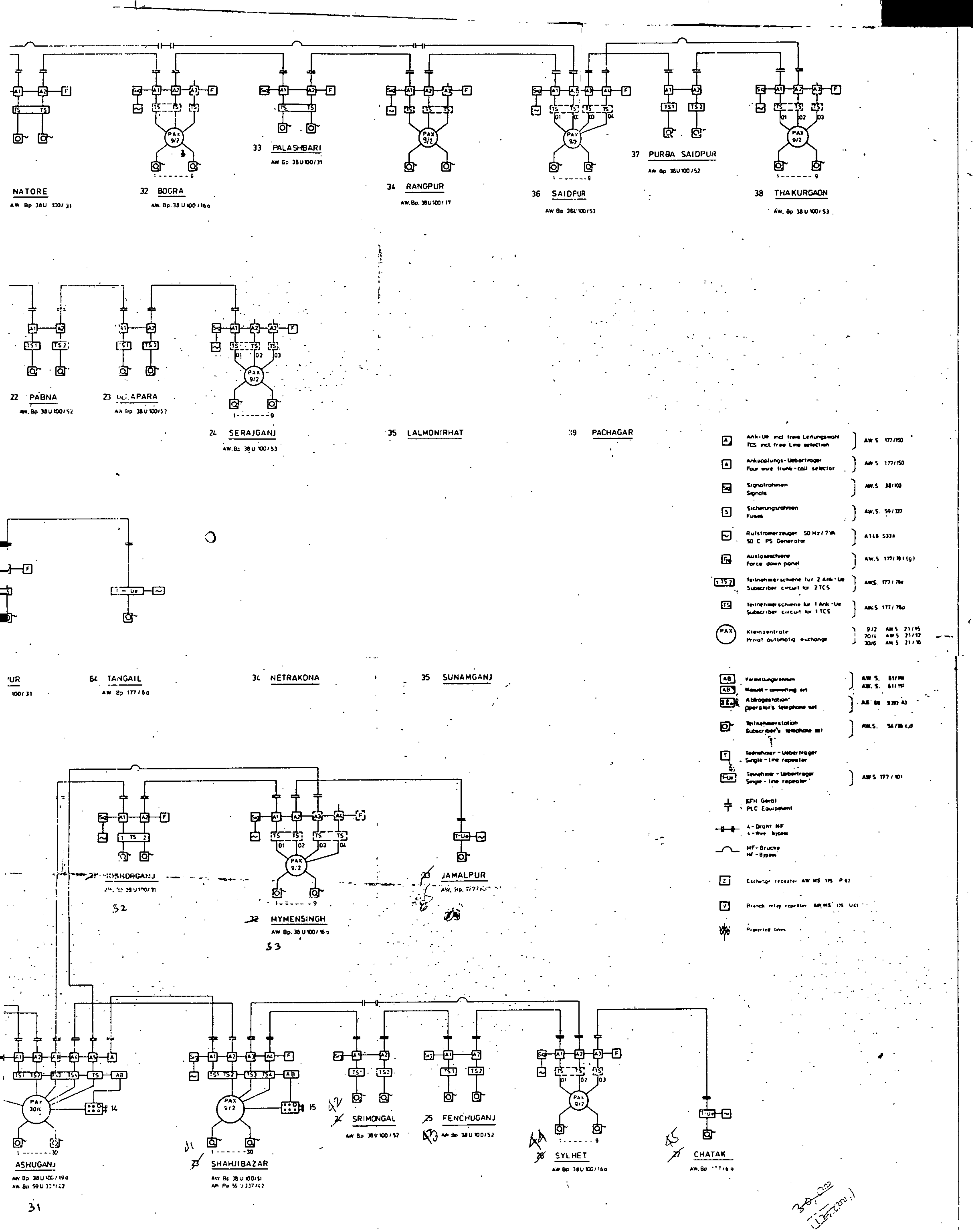
Appendix

Appendix






42 BOTTAIL
AW Bp 38 U 100/16 a
41 BHERAMARA
AW Bp 38 U 100/16 a
AW Bp 59 U 337/4 a Nr B 122 1261
21 ISHURDI
AW. Bp. 38U 100/51
AW Bp. 38U 337/62
58/261
W 58-5-263
AB
PAX 9/2
PAX 30/6
PAX 3/2
53 MADARIPUR
AW Bp 38 U 100/52
52 FARIDPUR
AW Bp 38 U 100/50
51 RAJE
25 RAJSHAI
AW Bp 38 U 100/16a
66 POSTAGOLA
65 MIRPUR
TO MADANHAT
TO GOALPARA
KAB
63
HAHAR
U 100/31
10 CHANDPUR
AW. Bp. 177/6 a
52
9
T-Ue
10 KAMALAPUR
AW Bp 38 U 100/51
AW Bp 59 U 337/42
14 ULLCN
61
AW Bp. 38 U 100/16 a
TONGI WORKSHOP
(CERS)
12 62 TONGI
AW Bp 38U 100/16 a
43 FENI
53
AW Bp 38 U 100/31
COMILLA
51
AW Bp. 38 U 100/16 a
AW Bp 59 U 337/4 a
11
DHIRGANJ
38 U 100/62
59 U 337/61
59 U 242/77
59 U 242/78
AW S 58/261
11
13
3
21 GHORASAL
43
AW Bp 38 U 100/2
AW Bp 55 U 337/42



30-00
(125.250.)

HF TELEPHONIE ANLAGE
WAPDA BANGLADESH

PLC TELEPHONIE SYSTEM
WAPDA BANGLADESH

SIEMENS-ALBIS

AW Uep 7095