POWER LINE CARRIER COMMUNICATION

by

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I. INTRODUCTION

In the last few years the power system industry has focused on means of controlling a number of substations remotely. The main objective has been to find ways of transmitting an order from one main station through some kind of a network and then receive the order at the desired substation where the order should be carried out. This paper will focus on ripple control as a communication link consisting of transmitter and receiver equipment. Power line carrier communication as another communication link will be covered in more detail. Tests on ripple control started over fifty years ago in Europe (9). By 1972, networks in Europe, Asia, Australia and Africa have been equipped with audio frequency generator equipment having a total substation capacity of 120 GVA and controlling about 5 million receivers averaging 2.5 common channels per receiver. The technological changes over the last twenty years is the most significant factor in the growth of ripple systems. The rest of this paper is devoted to the schemes by which ripple control signals could be carried over some distance. The motivation here is to find some kinds of communication links having the best performance with reasonable cost and simplicity. Some requirements are imposed on the remote-control channels (1), of which the following are pertinent to this study:

1. The use of Power Distribution Network (PDN) as an economical and reliable means of communication.
2. A flexible communication scheme.
3. Improvement and simplification of channel equipment.

Ripple control and Distribution-Line-Carrier (DLC) will be discussed in this paper including their comparisons with other communication links. The problems involved with DLC networks, mostly signal attenuation, noise and interference will also be considered. Some approaches for solutions to such problems have been outlined.

II. MAJOR COMMUNICATION LINKS

The main problem in automating the distribution system is to find a suitable communication network. The major communication links being considered are the telephone, radio, pilot wire, coaxial cable, distribution-line-carrier and ripple control.

Each of the above schemes will be lightly touched on, except the distribution-line-carrier and ripple control, which will later be covered in more detail because of their advantages over the other schemes. A viable way of improving the system reliability and the overall system operation is to automate the distribution systems (2). Automatic meter reading AMR, for example, will reduce the operating cost of difficult to read meters and manual reading error.

Controlling the load by switching the individual loads, when in use, will be a more efficient way of peak-load control. This is done mainly by voltage reductions. The Research Laboratories, the Headquarters Distribution Systems Department of the Westinghouse Meter Division (3) have all been working on developing a communication system to be used in automated distribution.

Residential and feeder automation are the major automated distribution services, each one being used in different areas. Residential automation includes meter reading, selective load control, remote service connect/disconnect, and other functions performed at the home.

Feeder automation includes remote monitoring and circuit breaker control, as well as control of switches, fuses, reclosers, line sectionalizers, and shunt capacitors, along with other such functions which are performed on the high-voltage part of a distribution circuit.

1. Telephone System: This system is a feasible means of automatic meter reading. It has, however, the limitation on mass addressing as a multifunctional system that makes it not so useful. The lack of administrative cooperation between the electric utility and the telephone company is also a drawback.
2. Radio System: This system could be used in a one-way communication system; but from an economic point of view, it has not been used as a two-way communication. It is, however, technically feasible and is presently being used in some applications for selective load control.
3. Pilot Wire: This is an auxiliary conductor used with remote measuring devices or for operating apparatus at a distance. Pilot wire is technically but not economically feasible and is not attractive in large scale applications. The coaxial cable is also too expensive and not a good candidate for automation distribution functions.

The foregoing facts and observations of their limitations in different areas shows that there should be better ways of achieving this goal. The Distribution-Line-Carrier and ripple control will now be covered as two major approaches to this goal.

DLC has the following advantages:

1. Can provide all functions of automated distribution.
2. Easily expanded for additional automation distribution function.
3. Technically and economically feasible.
4. Could be used for two-way communication and mass addressing.

Ripple control as another approach has the following capabilities:

1. Mass controls (street lighting, washing machines, tariff change-overs)
2. Individual controls (special lighting, selective load controls)
3. Special applications (alarms, switch gear control in power system, etc.).

The rest of this paper will focus on these schemes in more detail.

2.1 Ripple Control

2.1.1 What is Ripple Control? (10)

Ripple control is so called because it provides centralized facilities for remote load switching via signals superimposed on 50 Hz power systems. (The 50 Hz is the frequency used in Europe and will be assummed through this discussion unless otherwise is stated.)

The effect of a 450 Hz wave (the frequency being used) superimposed on the fundamental voltage is shown in Figure 2.1.

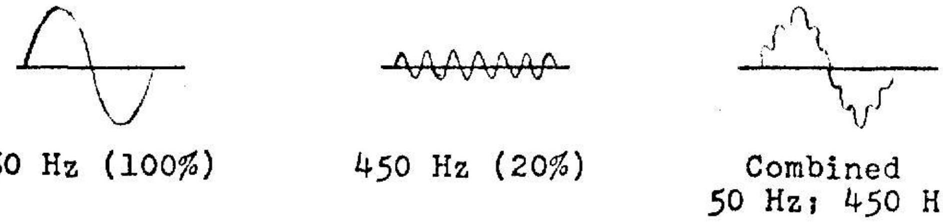

FIG. 2.1 A 450 Hz AUDIO FREQUENCY SIGNAL SUPERIMPOSED ON THE FUNDAMENTAL 50 Hz SUPPLY.

In general, at audio ripple frequencies, the ripple voltage magnitude is of the order of 1% of the 50 Hz fundamental consumer supply voltage, i.e., 2.5 volts. For switching the load on or off, the control system signals are superimposed on the 50 Hz fundamental at the central control point and then propagated via power cables over the medium voltage electricity. The received signal is used for controlling the switches after it has been filtered out. There are some requirements which the supplier and user should take into account. Some of these requirements are as follows:

1. The ripple control scheme should not interfere with the normal running of the power network.
2. The scheme should be simple.
3. It should be easy to install, maintain and operate, and it should be commercially viable.
4. It should be capable of expansion and have the capacity for carrying out a variety of control functions.

Ripple control system includes the transmitting and receiving equipment with which the electric utility transmits instructions by injecting a properly coded audio frequency signal into the power network. These signals travel through lines and transformers, and when received at the receiver they will be decoded, and the instruction will be acted upon. The injecting of ripple control orders is done automatically or manually at the central programming unit. Control could be initiated by a remote signal from a telemetering or load control system or automatically by clock so that it affects daily and weekly programs. Such systems can monitor loads on different substations and could order a central programming unit to initiate injectors when a potential overload occurs or has been detected. Communication between the central programming unit and the remote ripple control transmitter is performed by VF* channels.

Ripple signals are composed of the following:

1. A start impulse.
2. A set of discrete impulses (or lack of impulses) following the start impulse.

This set of discrete impulses is transmitted during distinct time stages, usually 50, occurring over a defined duration of transmission, usually 30 seconds. What this means is that there are fifty information elements to form the desired order codes. As will be seen more thoroughly later in this paper, the first ten elements are used to code the address and the remaining elements are grouped in pairs to form on/off double orders (DO).

Ripple control can be used in different areas, such as the following:

1. Control of lighting installation such as street lighting,

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*Video frequency channels having a frequency range of 100 Hz to several MHz.

display window illumination, etc.

2. Interruption of industrial loads when desired.
3. Interruption of direct space heater, direct water heater, heat pumps, air conditioners, etc.
4. Miscellaneous and emergency uses.

2.1.2 Ripple Control Installation

A ripple control installation includes the following:

1. Injections unit.
2. Central programming and coding of the orders to be transmitted.
3. Static converters producing the audio frequency power.
4. Coupling filters to transfer the audio frequency output of the transmitter with minimum loss into the network that is to be controlled.
5. Ripple control receivers anywhere in the distribution network as needed.

The control frequencies lie in the audio frequency range below 750 Hz.

Some of the advantages of a ripple control installation for the power systems operations are as follows:

1. There is no need for pilot wire connections, which means that anywhere in the controlled network, the control signals could be received by simply connecting a receiver.
2. Daily or weekly orders of a fixed time program can be transmitted.

3. Ripple control is not bound to a rigid time program.
4. A single accurate clock could be used for checking and readjusting whenever it is needed.

2.1.3 The Coding of Ripple Control Orders

The time difference between the start impulse and the signal impulses during the 30 second duration of transmission will be a check of whether or not an order is being transmitted. There are two types of coding available to be used: the direct selection code, when a single impulse identifies the order; and the group selection code, where two or more impulses are used to identify the order. Each of the above code selection methods will be discussed as follows.

Direct Selection:

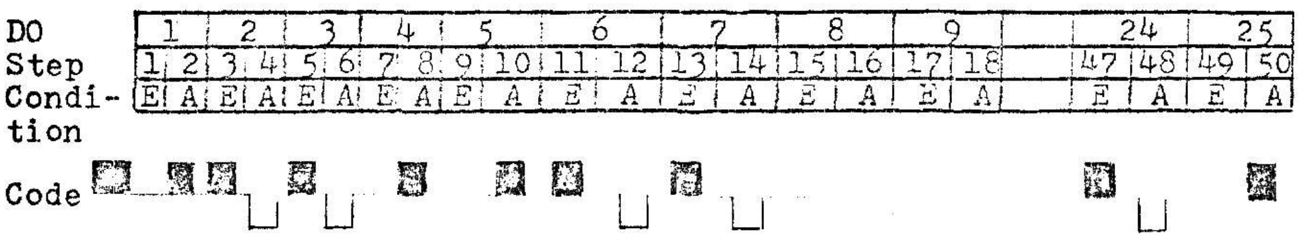

FIG. 2.2 DIRECT SELECTION ORDERS

DO 1 OFF, 2 ON, 3 ON, 4 OFF, 5 OFF, 6 ON, 7 ON, 8 OFF, ... 24 ON, 25 OFF.

▮ Step requiring an impulse.

⊔ Step which must be free from impulse.

— Step indifferent to presence or absence of an impulse.

The 50 impulse steps are grouped in pairs to form 25 ON/OFF double orders (DO). For example, if the order DO 6 ON is required then an impulse must be transmitted into the network at step 11. The following impulse at step 12 would repeal this order, i.e. The output relay would switch back to the OFF position. The start impulse which is larger than a signal impulse is a check code for correct length in the receiver itself. The pulse EA and EA represent the ON and OFF conditions respectively (Fig. 2.2).

<u>Group Selection</u>:

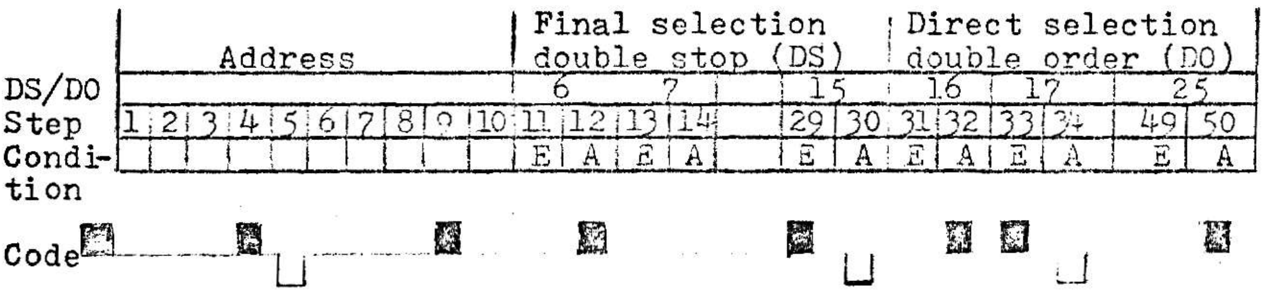

FIG. 2.3 GROUP SELECTION ORDERS DS/5 OFF; DS/15 ON
DIRECT SELECTION ORDERS DO 16 OFF; 17 ON; 25 OFF

The evaluation of the address impulse takes place in the decoder stage of the receiver.

Group selection has the advantage of a much larger order capacity than direct selection. This is because in group selection it is possible to transmit arbitrarily an ON or an OFF impulse in each final selection's double step for the one address during the one telegram (Fig. 2.3).

2.1.4 Methods of Transmission and Reception

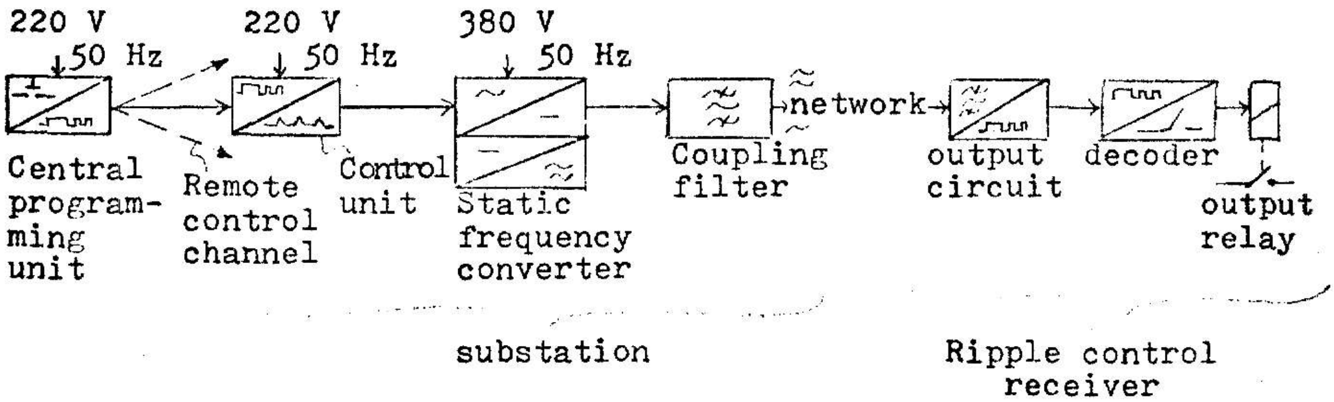

FIG. 2.4 TRANSMITTER/RECEIVER

Central Programming Unit

This unit is the main control device of a ripple control installation (Fig. 2.4). The functions of this unit are as follows:

1. The time programming of the ripple control orders.
2. The initiation of the order either by push buttons or automatically.
3. The control of the transmission cycle.

The functional sections of this programming unit are:

1. The automatic programming section consisting of a master clock, a slave clock, and program controllers.
2. The command rack for direct order or combination selection order.
3. The main control rack for the transmission job from the beginning of the installation to its reception end. In the transmission cycle, after the control unit and the frequency converters are made ready for operation, the

timer and rotary transmission selection start. Then check relays change the position, and after 30 seconds the transmission ends and the installation is switched off.

The impulse telegram is fed via communication links or directly to the substation, which is composed of control unit, static frequency converter, and coupling filter. At this substation the ripple control equipment injects audio-frequency energy into the distributions network in synchronism with the impulse sequences received.

Static Frequency Converter

This unit, which is supplied by the three phase low-voltage system, generates the audio-frequency power needed for ripple control (Fig. 2.5). The coupling filter following the static frequency converter provides a bandpass for the audio-frequency while blocking the power frequency. The static frequency converter and the coupling filter form one functional unit. There are some advantages of a static frequency converter over the rotating converter groups which were used previously. Some of these advantages are as follows:

1. Immediately ready for service.
2. Quiet operations.
3. Electronic impulsing.
4. Free choice of control frequency.
5. Easy synchronization of several transmitters.
6. Reduced space requirement.

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7. Easy installation.

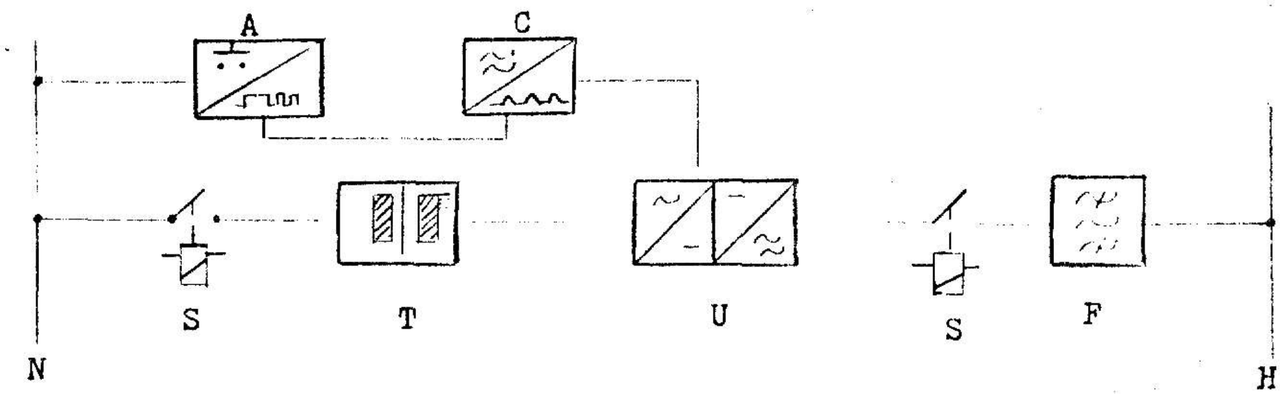

FIG. 2.5 BLOCK DIAGRAM OF A STATIC CONVERTER INSTALLATION

A - Central programming unit

C - Control unit

F - Coupling filter

H - High voltage distributions network

N - Low-voltage supply network

S - Contactors (main and isolating)

T - Regulating transformer

U - Static frequency converter

The static frequency converter is delivered as three single phase units operating independently of each other.

Coupling Filter

The Parallel Coupling. The audio frequency voltage source is connected to the 50 Hz voltage source in parallel coupling (Fig. 2.6). The object of parallel coupling is:

1. To transfer the audio-frequency output of the transmitter with minimum loss into the network that is to be controlled.
2. To prevent reactions from the network on the audio-frequency generator.
3. To isolate the low-voltage network from the high-voltage network.

4. To create an absorption effect in transmission pauses to protect the ripple control receivers from external disturbances.

Design:

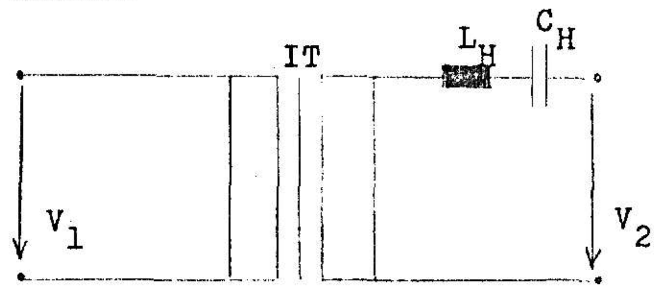

FIG. 2.6. PARALLEL COUPLING, SCHEMATIC DIAGRAM OF BASIC FORM

L_H and C_H is a series-resonant circuit which is tuned to the transmission frequency and possesses the required transfer characteristics. The isolating transformer (IT) is used for insulating purposes. U_2, the output voltage, is at a maximum at f_o, the resonant frequency. An equivalent circuit of Fig. 2.6 above is given in Fig. 2.7 below:

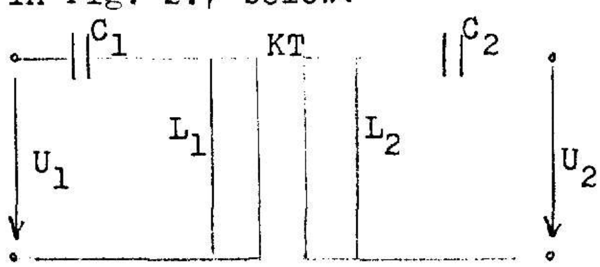

FIG. 2.7 LOOSE PARALLEL COUPLING, SCHEMATIC DIAGRAM

KT, which is the coupling transformer, acts as an isolating transformer simultaneously.

Application:

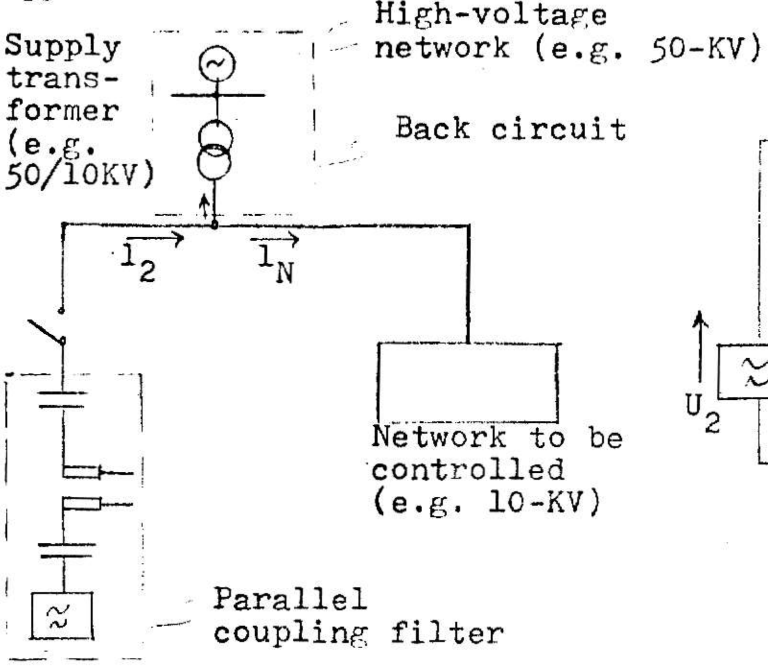

FIG. 2.8 CONNECTION OF THE PARALLEL COUPLING TO THE NETWORK

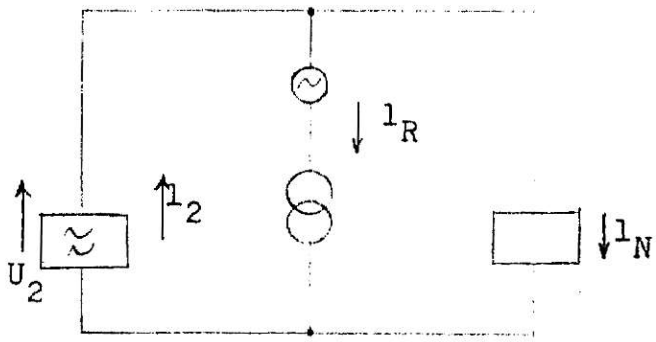

FIG. 2.9 EQUIVALENT DIAGRAM OF A PARALLEL COUPLING

1_2 AF output current

1_N AF current in controlled network

1_R current in back network

Parallel couplings are connected to the bus-bars of the network to be controlled via a circuit-breaker or an on-load isolator which should be able to switch off the capacitive power of the high-voltage capacitor bank (Fig. 2.8). Loose parallel coupling can be utilized over the whole range of ripple control frequencies from 183 Hz to 750 Hz. An equipment diagram of a parallel coupling is shown in Fig. 2.9.

The Series Coupling

The object of the series coupling (Fig. 2.10) is to inject ripple control energy into the network without the functioning of the audio-frequency generator being impaired by current or voltage reactions (Fig. 2.11). With this coupling the audio-frequency voltage source is connected in series with the 50 Hz voltage source. The series coupling also provides insulation reliability.

Design:

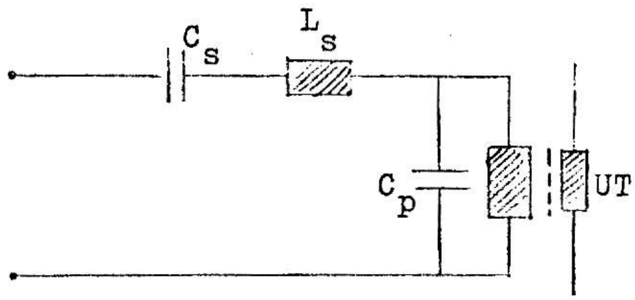

FIG. 2.10 SERIES COUPLING

Transformer UT on the high-voltage side and capacitor bank C_p on the low-voltage side form a parallel resonant circuit which is tuned to the control frequency. A series-resonant circuit C_s/L_s blocks reactions from the network on the audio-frequency generator.

Application:

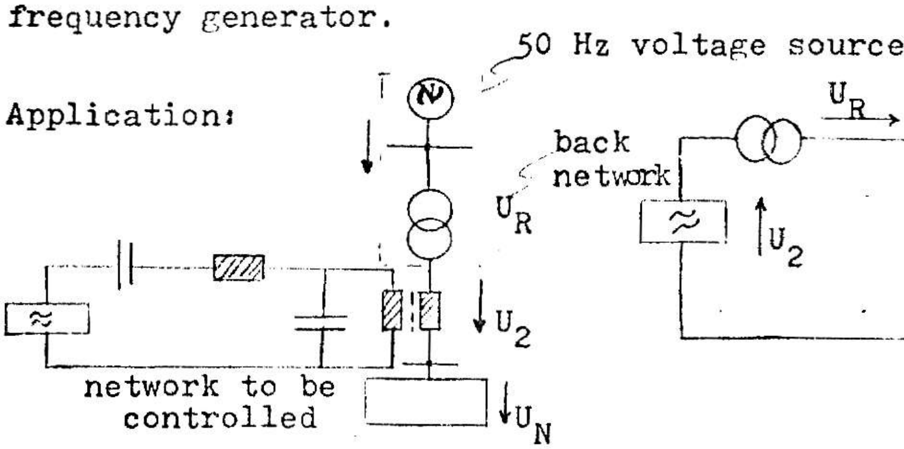

FIG. 2.11 CONNECTION OF A SERIES COUPLING TO THE NETWORK

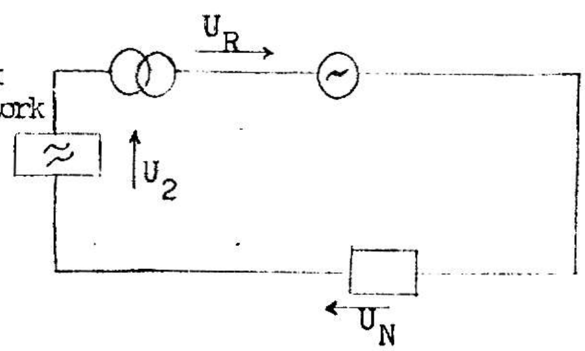

FIG. 2.12 EQUIVALENT DIAGRAM OF A SERIES COUPLING

U_2 AF output voltage

U_N AF voltage across the controlled network

U_R AF voltage across the back

The audio-frequency voltage is not connected to the consumer's network directly in this kind of coupling. The series circuit, consisting of the back network and the network to be controlled, however, is connected to the audio-frequency voltage, as shown in Fig. 2.12. Series coupling is used mainly for the lower control frequencies (up to about 400 Hz).

Ripple Control Receivers

The receiver input circuits are tuned to the audio frequency of the injection equipment and are connected to the low-voltage network. The impulse sequence superimposed on the network voltage is reproduced in the receiver and is compared with the preset code in the decoder. If this comparison shows an agreement, then the corresponding output relay is operated and the desired order is carried out. The ripple control receiver consists of three basic elements:

1. Input circuit.
2. Decoder.
3. Load switch.

The various functions of the receiver are as follows:

1. Input circuit: reception frequency, response sensitivity, and bandwidth.
2. Type of code: as was described earlier, the coding is performed in two basic ways: direct selection or group selection.
3. Housing size and type: up to three load switches per receiver are usually supplied in a standard housing of

molded material.

When designing a project several factors should be taken into account such as the following:

1. Number and chronological distribution of daily ripple control orders.
2. Number of receivers which are to be used.
3. Technology, economy and expected consumer structures in the network.

Proper utilization of ripple control receivers will influence the shape of the daily load curve.

Application of Ripple Control

Ripple control could be used in many areas, with the following advantages:

1. Improvement in economy.
2. Most rapid method of passing orders to any point in the network.
3. Technically centralized operating management.
4. Simplest possible facilities are provided if the matching or extensions of program are required.

Some of the applications of ripple control are as follows:

1. Controlling the network load to result in an improvement in the economy of electricity supply. Ripple control allows the desired consumers' load to be switched on or off at any time during the day. Examples of the consumer's load which can be controlled are as follows:
   a. Household water heaters.

b. Storage power heater.

c. Air conditioning equipment.

d. Industrial heating application.

e. Motor-associated applications.

f. Church heating.

2. Controlling lighting installations: The public lighting of the entire town could be switched off or on at a desired time. Some of these public lighting are as follows:

   a. Street lighting: could be controlled individually or in groups.

   b. Display window illuminations and illuminated advertisements.

   c. Staircase lighting.

   d. Floodlighting of monuments and public buildings.

3. Transmission of alarms: Ripple control signals can penetrate to all parts of the network. An alarm signal thus can be transmitted throughout the area of the network without special control wiring or telephone connections. To receive such alarm signals without using wiring or telephone connections, portable receivers are used which can be plugged into a normal light socket where desired.

The alarm signal can be used in the following ways:

1. Alarms used for police service, ambulances, etc.
2. Overload alarm to warn industrial consumers and enable

them to match their load to the network load conditions.

3. Water alarm in case of flood, or of high tides in coastal regions.
4. Frost warnings for lighting service or agriculture.

Ripple control can also be used in emergency disconnection when serious faults arise or when the network threatens to break down.

2.2 Distribution-Line-Carrier*

Although it has been shown experimentally (4,6) as well as theoretically that DLC is a good communication link, there are problems concerning this link. These problems are the signal attenuation which is caused by the power lines forming the distribution network, signal attenuation caused by distribution equipment and noise, and interference problems which are also present on the distribution system. Some generalizations have been made with respect to power line attenuation. These are as follows:

1. Low attenuation in frequencies between 10 and 30 KHz.
2. Between 50 and 100 KHz, attenuation increases in proportion to frequency.
3. "Dead band" between 100 and 200 KHz, where the attenuation in this band of frequency is high, possibly causing a very high difficult communication.
4. Above 200 KHz, a very high attenuation for long distance communication exists, but for short and medium distances

*Power Line refers to both distribution and transmission lines. Distribution line is used when short length of line with low voltage is considered. Transmission line, however, is used for longer lines and higher voltages.

communication frequencies between 200 and 300 KHz are usable.

The shunt capacitor banks and distribution transformers are the main sources of attenuation by distribution equipment. These two are discussed in different bands of frequencies as follows:

1. Above 10 KHz, the shunt capacitor will short circuit the communication signal; a parallel-tuned LC circuit is used at the capacitor bank to overcome this problem.
2. Between 30 and 100 KHz band, the signal voltage attenuation between primary and secondary of distribution transformers is in the range of 10 to 70 dB.
3. Above 50 KHz, the primary and the secondary input impedance are not sensitive to load changes.
4. Below 20 KHz, load changes can result in a significant change in impedance.

There are also some noise and interference problems caused by local radio stations, transmission-line communication, and low frequency radio navigation systems. Household appliances such as kitchen fans also produce noise signals on distribution systems.

Because of noise, unwanted signals, and signal attenuation, the most suitable bands of frequencies for DLC communications are:

1. 20 to 30 KHz.
2. 50 to 100 KHz.
3. 200 to 300 KHz.

Considering the above problems in communication, several approaches could be taken for solving such problems. One approach is: to design a system which works when most of the noise is absent; another is design to a carrier system that works under high-noise conditions. The former may be used in automatic meter reading because the noise generating appliances are switched off at sometime during the day, but it will not be acceptable for selective load control. The latter could be accomplished by using narrow band filters which filter out the noise present in the carrier frequency band. This approach has been taken by Westinghouse who has been working with several utilities to field-test the distribution-line-carrier system and to obtain sufficient data to perfect the equipment involved in such operations.

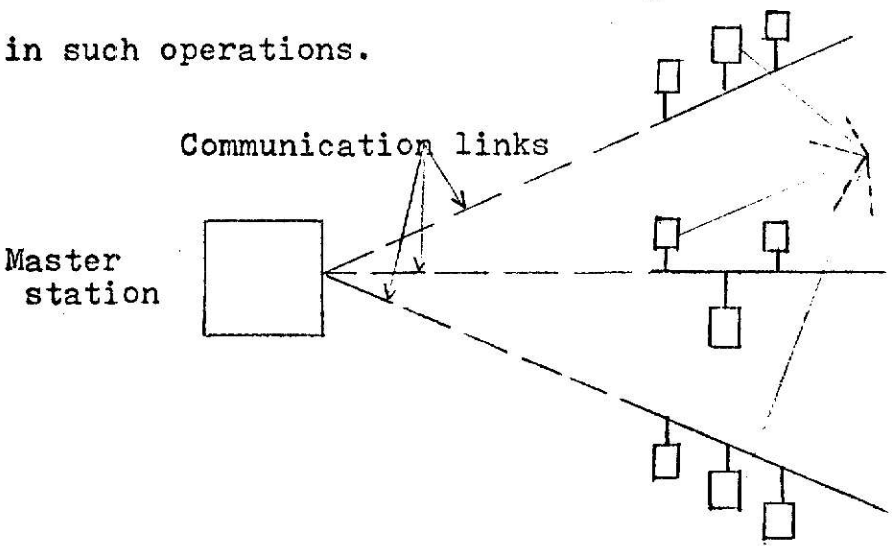

FIG. 2.13 FEEDER AUTOMATION SYSTEM

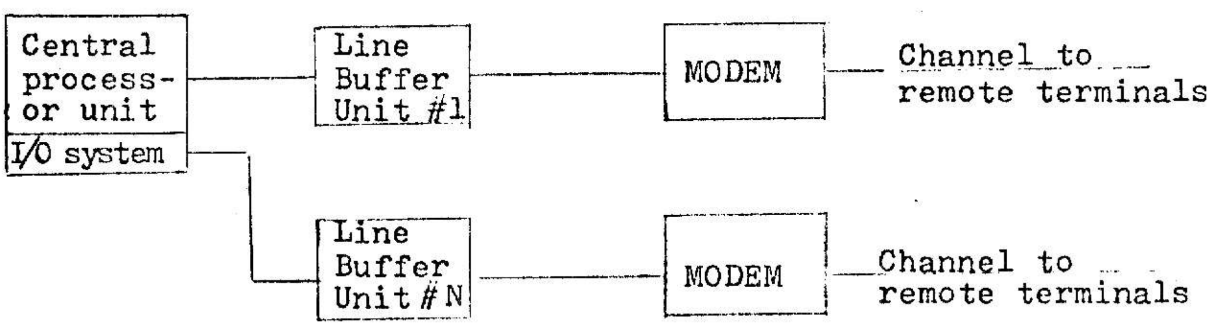

FIG. 2.14 MASTER STATION

Fig. 2.13 shows that the feeder automation system is composed of a central controller, communication links, and remote terminals.

Fig. 2.14 is the heart of the distribution-feeder automation system, where data is received and processed. (MODEM stands for Modulator/Demodulator.)

2.2.1 American Electric Power Approach

765-KV Power-Line-Carrier Communication (4)

Theoretical considerations, experimental determinations and equipment development and design of the 765-KV Power-Line-Carrier Communication (PLC) has been carried out by American Electric Power Services Corp (AEP). Some aspects of these theoretical considerations, experimental determinations of the PLC parameter, and equipment development and design will be given here.

PLC has been used as a communication medium for protection of AEP systems. In fact, there were approximately 1500 miles of 765-KV transmission planned, and about 750 miles were in service by February, 1971.

There are three choices of communication channels for protection: microwave, leased telephone circuits, and power-line-carrier.

1. Microwave is economically unfeasible because it must use several repeaters with long transmission lines. This is one difficulty which makes it unfavorable for use, and there are others which will not be discussed

2. Leased telephone circuits also have some problems, especially their use during national emergencies or strikes when they may be pre-empted and damaged.
3. Power-line-carrier, however, is a reliable medium. Economically, its cost is reasonable. There is, however, as mentioned before, some noise problem causing attenuation losses for the long transmission. These problems as well as some approaches to their solution are discussed here.

The attenuation problem could be removed partially by proper coupling equipment and coupling phase, on horizontal 3 phase lines. There are 3 modes in a single circuit three phase horizontal line. Mode is defined as one of the several types of electromagnetic wave oscillation that may be sustained in a given resonant system. Each type of vibration is designed as a particular mode and has its own particular electric and magnetic field configuration. Each mode is considered in more detail below (Fig. 2.15).

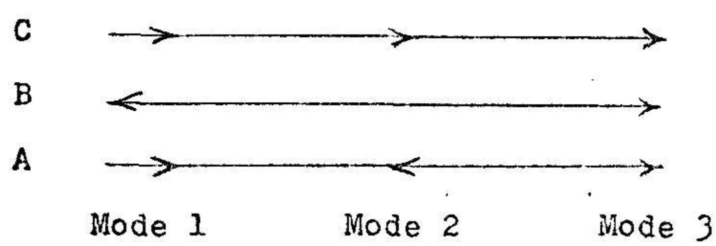

FIG. 2.15 SINGLE CIRCUIT MODES

Mode	phase A	phase B	phase C	approximate attenuation (500-KV line)	characteristic impedence (Ω) (500-KV line)
1	$+I_1$	$-2I_1$	$+I_1$	0.06 dB/mile	215
2	$-I_2$	0	$+I_2$	0.20 dB/mile	255
3	$+I_3$	$+I_3$	$+I_3$	2.00 dB/mile	403

TABLE 1. RELATIVE CURRENTS ON EACH PHASE IN APPROXIMATE MAGNITUDE AND POLARITY

Mode 1 : This mode uses all of the three-phase conductors. The current in the center phase is approximately twice that in the outer phases and there is little current in the ground. This mode has the smallest attenuation compared with mode 2 and mode 3 which could be seen from Table 1. Therefore, if mode 1 coupling could be accomplished, line losses would be effectively decreased. The measurement for this mode, assuming that modes 2 or 3 would not be present and that the receiving end of the line was terminated to be almost reflection free, for a 765-KV power line is shown in Fig. 2.16. For safety, the measurements for all modes were done when the connection to the conductor was made through a 0.1 μF coupling capacitor. Line traps, reactors, and breakers were disconnected during the measurements.

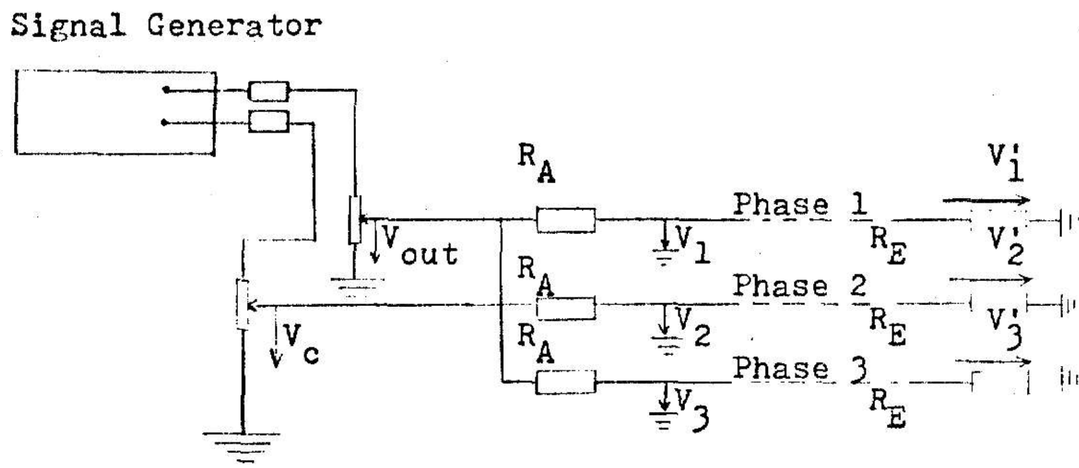

FIG. 2.16 MODE 1 MEASUREMENTS

The characteristic impedance, the ratio of phase components (V and I), attenuation, and velocity for this mode may then be measured (for more detailed information see Ref. 6).

Mode 2 : This mode uses only the outer phases. Thus only outer phase currents are produced, and more current in the ground causes more attenuation than mode 1. For this mode the parameters mentioned above were measured using the circuit shown in Fig. 2.17.

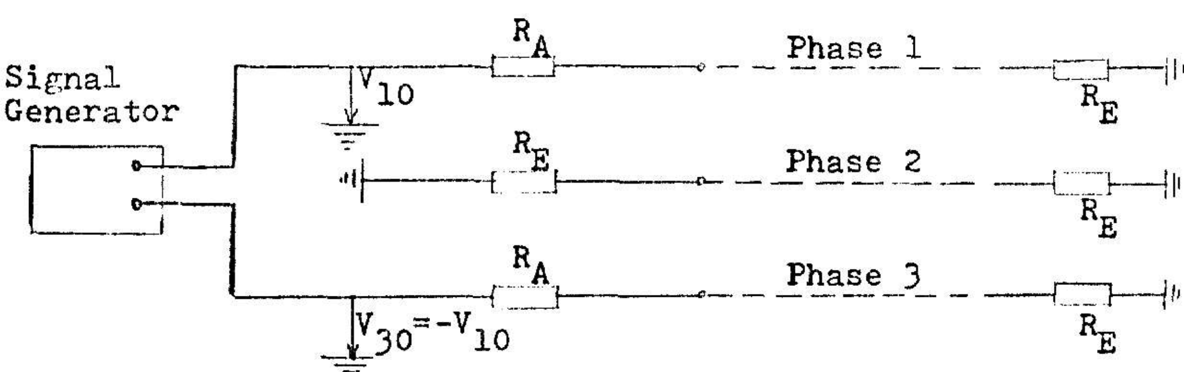

FIG. 2.17 MODE 2 MEASUREMENTS

Mode 3 : This mode uses the ground as the return and all three phases have approximately equal currents flowing in the same direction. As it has the largest attenuation, this mode is ineffective for long path uses. Because of the high attenuation at the line length in use, the measurements for this mode were excluded.

As was mentioned, for long distance transmission only mode 1 appears to be useful for single circuit non-transposed lines. This can be seen from Fig. 2.18 below.

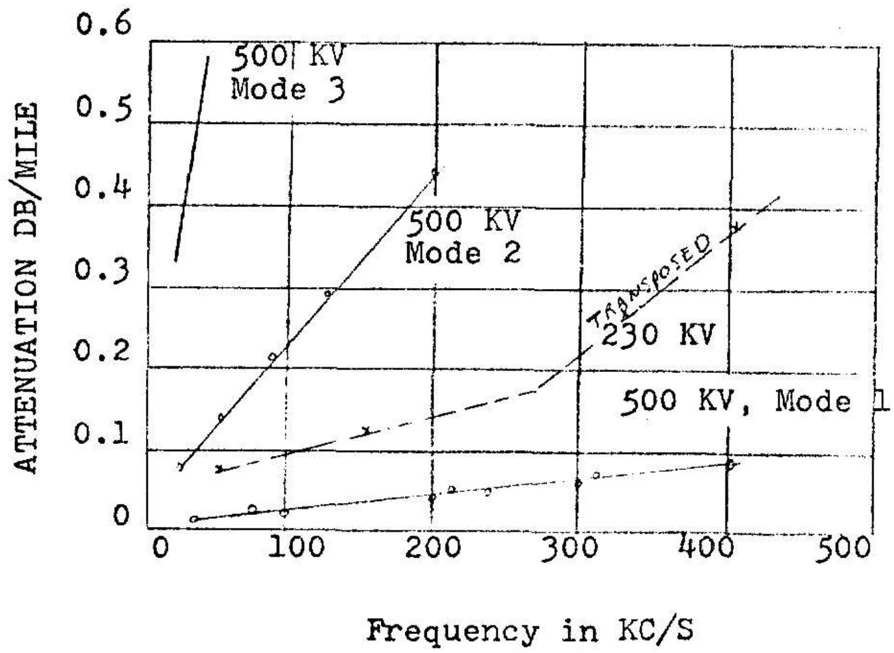

FIG. 2.18 CARRIER ATTENUATION ON 230-KV AND 500-KV LINES

Coupling the equipments properly on the horizontal 3 phase lines in order to remove the attenuation problem is discussed as follows:

At some frequencies there is an interference between modes 1 and 2 which could increase or decrease the attenuation. For frequencies at which the interference between the two modes tends to decrease the attenuation, both modes could be used at the same time. The interaction of these two modes occurs mainly because of the velocity difference between the two. The mode 2 velocity is less than the velocity of mode 1 by about 15%. These two modes could also arrive at the receiver out-of-phase. The cancellation could occur only on the outer phase conductor. Cross-coupling could give the optimum performance in which the different phases are used at each end of the line. The coupling efficiency is the ratio of power in mode 1 to the total transmitted power, $E_c = \frac{P(1)}{P(T)}$ and is tabulated below.

Coupling	E_c			
	Ungrounded		Grounded	
	A	B	A	B
Center - ground..................	.457	.30	.692	.62
Center - outer....................	.710	.67	.776	.83
Outer - outer (+, -)..............	.000	-	.000	-
Outer - outer (+, +)..............	.308	.20	.543	.37
Outer - ground....................	.165	-	.260	-

A. - Calculated values

B. - Measured on 500 KV line

TABLE II. CALCULATED AND MEASURED VALUES ON 500 KV LINE OF COUPLING EFFICIENCY.

It can be seen from table II that coupling center-to-ground or center-to-outer phases have high efficiency and hence provide acceptable transfer of power. On the other hand, the outer-to-outer coupling has zero efficiency and therefore it is of no use.

Voice communication channels used for control functions may use center-phase coupling whose performance is comparable to the best center-to-outer coupling at both ends of a line. Because the momentary loss of signal during a ground fault is acceptable, center-phase coupling could be used. For protection, however, the center-to-outer coupling is preferable. The foregoing could be summarized as follows:

1. Use of mode 1 propagation makes it possible for the carrier links to operate over large distances.
2. Interference between mode 1 and 2 causes large changes in attenuation.
3. Cross-coupling may give optimum performance when the phases for transmitting and receiving are not the same.
4. Center phase-to-ground coupling compares favorably with center-to-outer phase coupling.

The maximum noise level used in all computations was 200 mv into 50 ohms. The minimum signal-to-noise ratio (SNR) for the protection channel is 12 dB for the most adverse conditions in a 200 mile line. Computer calculations for a typical line of 200 miles are given in Appendix B.

Experimental Determination of Power Line Carrier Parameters(6) for 765-KV Power Line Carrier Communications

The measurements were made on the short section, 69 miles from the total of 200 miles, of the voltage-free lines. The results could be extrapolated for application on longer line sections. This section of the line involved a single system of conductors in a horizontal configuration with no transpositions. Each phase consisted of four 954KCmil ACSR cables (485 sp. mm. of aluminum steel) in a square of 18 inches (465 mm). The horizontal distance between conductors was about 45 feet and the minimum height of the conductors above the ground was about 100 feet.

This conductor system was tested for all three of the modes described previously.

Results on the short line have indicated that a possible shortcoming in the measuring technique existed. For the production of a pure mode (either mode in isolation, without the other two) to suffice throughout for a uniform line with reflection free termination, the same voltage ratio at both ends of the line were chosen. Of course in a practical case, where reflection can cause mode conversions at line discontinuities and at line ends, the above criterion is not completely satisfactory.

Characteristic impedances for modes 1 and 2 have been measured, and it can be seen in Figs. 2.19 and 2.20 how they change with frequency.

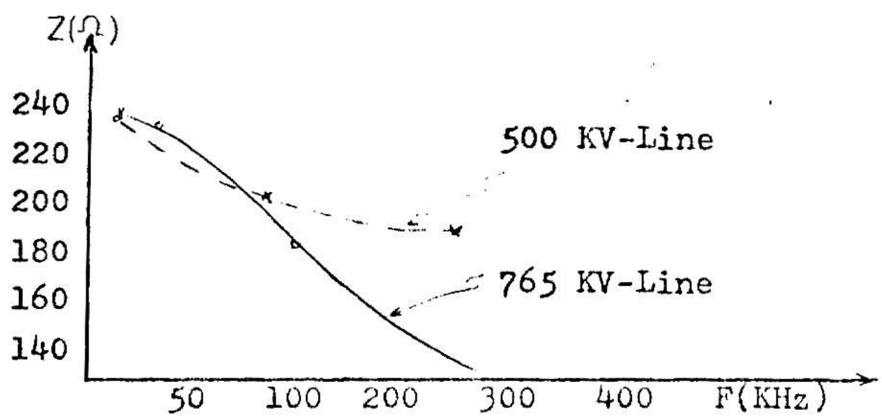

FIG. 2.19 MODE 1 CHARACTERISTIC IMPEDANCE

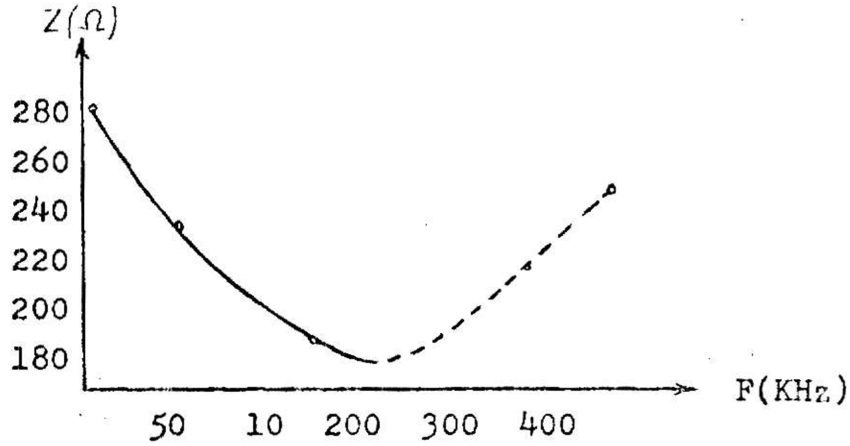

FIG. 2.20 MODE 2 CHARACTERISTIC IMPEDANCE

<u>Mode Attenuation</u>. The attenuation measured for the different phases are each very nearly equal to the value calculated for the propagation of a pure mode under ideal conditions (uniform line correctly terminated) and are identical to the mode attenuation. Within the range of 50-200 KHz the ideal conditions were approached; however, for larger frequencies the attenuation increases. This increase in attenuation at higher frequencies could be explained as caused by the following:

1. The driving signal is a mixture of different modes instead of a pure mode.
2. Mode conversion takes place at the conductor ends or at discontinuities along the line.

It has been shown experimentally on the short line in the case of mode 1 at 500 KHz that if the received signal were a pure mode 1, the voltages of the outer two phases would be the same. Knowing this and noting the two different voltages (480 mv and 280 mv) from the experiment, it must be true that mode 2 is generated somewhere on the line. Mode 2 measurements also show that mode conversion exists at some frequency (at 300 KHz as shown in Fig. 2.21).

Figure 2.21 compares the measured attenuation on the 765-KV line with the values measured on a 500-KV line.

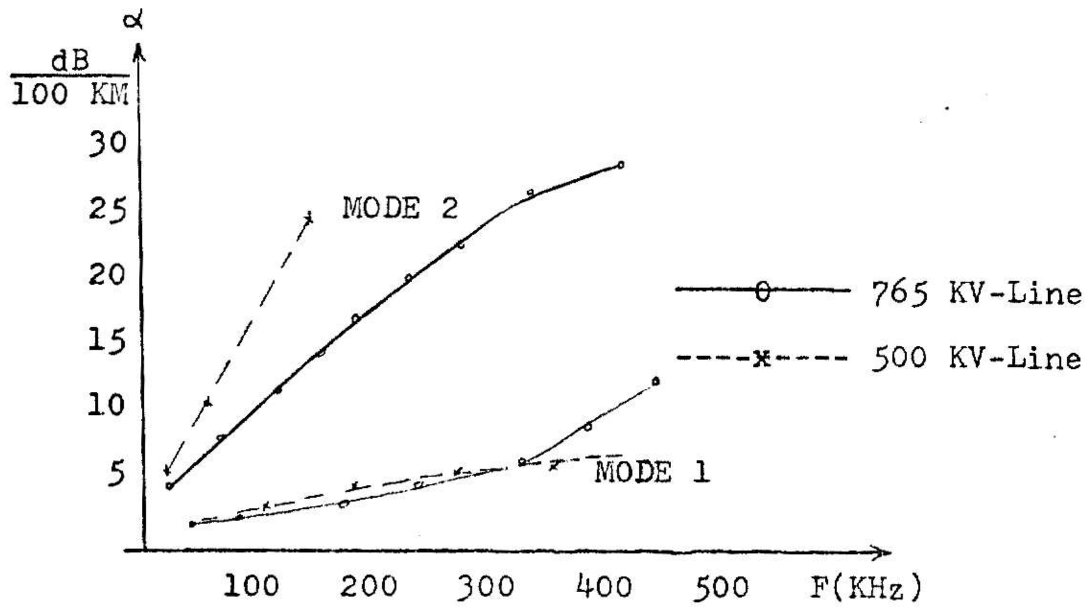

FIG. 2.21 MODE 1 AND 2 ATTENUATIONS

The results of the calculations show that there are several shortcomings in the measuring technique employed. The following modification has been recommended for inclusion:

1. Full termination of the line with a calculated network (6 Resistors), which should be readjusted for each measuring frequency (checked by echo measurement).
2. Consideration should be taken of the frequency dependence of the voltage ratio.

Equipment Development and Design for 765-KV Power-Line-Carrier Communications (7)

What follows will describe the basic approach taken in designing special Single Side Band (SSB) Power-Line-Carrier equipment using baseband injection for the protection of AEP's 765-KV lines. Baseband is the frequency band occupied by the aggregate of the transmitted signals used to modulate a carrier. Choosing Power-Line-Carrier for the communication medium motivates the development of a dual coupling and relaying scheme for maximum security and reliability (7). This requires two separate coupling systems and two separate communication channels. The analysis of a communication channel is discussed here. (For an analysis of coupling equipment refer to Ref. 7).

Design of Communication Channel

The transmission line has a length of about 330 miles and the expected noise level is high, up to 200 mv from a 765-KV substation. The calculation carried out by AEP on the above transmission line has shown that the transmitter must be capable of developing in excess of fifty watts for proper function during fault conditions.

Frequencies were limited to 30-150 KHz to minimize the line loss on the long lines being used. This allows only a 36 KHz bandwidth for the total bi-directional relaying and voice package for a given section of the line. Transmitting at high power and for minimum spectrum, SSB suppressed carrier modulation was used. The phase comparison ground relaying of less than 3 ms and the desired channel speeds for the line protection of less than 14 ms required that the basic relaying transmitters and receivers operate at baseband frequencies (the band of frequency which will pass through a filter with no attenuation). Increased reliability and reduction in the size of the overall system design for baseband frequency operation is thus obtained.

Operation at baseband frequencies allows the use of smaller, less complex, and more effective filters than are available at audio frequencies. Having a simpler equipment design for baseband frequency operation than that of audio frequency operation permits a system with higher reliability and smaller size.

Description of Communication Channel Equipment

Two equipment packages were designed and are shown in the block diagram of Fig. 2.22.

One package was designed to provide the transfer trip channel and phase comparison channel in a 100 watt amplifier scheme which through some logic allows the full amplifier capability to be used by the channel selected. The second equipment package provides a 100 watt SSB channel capable of producing a voice channel or a high level equipment failure tone transmission during fault conditions.

From the basic baseband of 16-32 KHz, baseband frequencies between 28 and 32 KHz were selected in the relaying set. This band of frequencies provides the fastest channel times. A special SSB assembly using 4 KHz wide line filters was developed for use with these baseband signals. Insertion of these signals into a 4 KHz wide channel introduced less than a 0.5 millisecond delay due to the SSB system. 29 KHz was used for line relaying and 31 for phase comparison relaying.

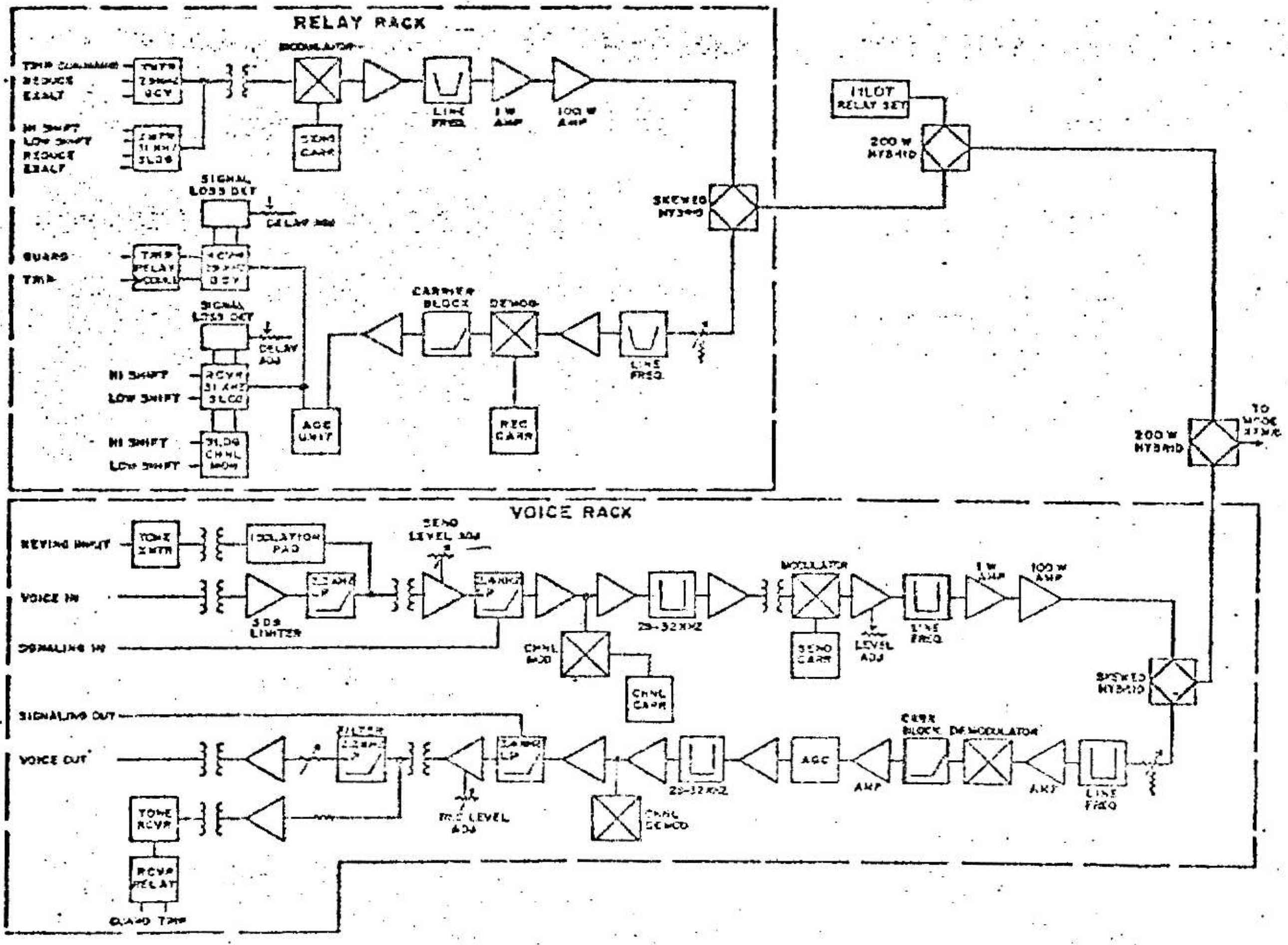

Fig. 2.22 Block diagram of communication equipment for relaying & voice

2.2.2 Main Sources of Attenuation

Determination of Line Losses

Now that the losses in different modes and the problem involved has been considered, certain factors to determine theoretical losses for different frequencies and line lengths can be programmed. It has been shown (4) from experience that line attenuation depends upon the ratio of the mean distance between conductors, d, and the height of the conductor above ground level, h. The plot of line attenuation against d/h and frequency is given in Fig. 2.23.

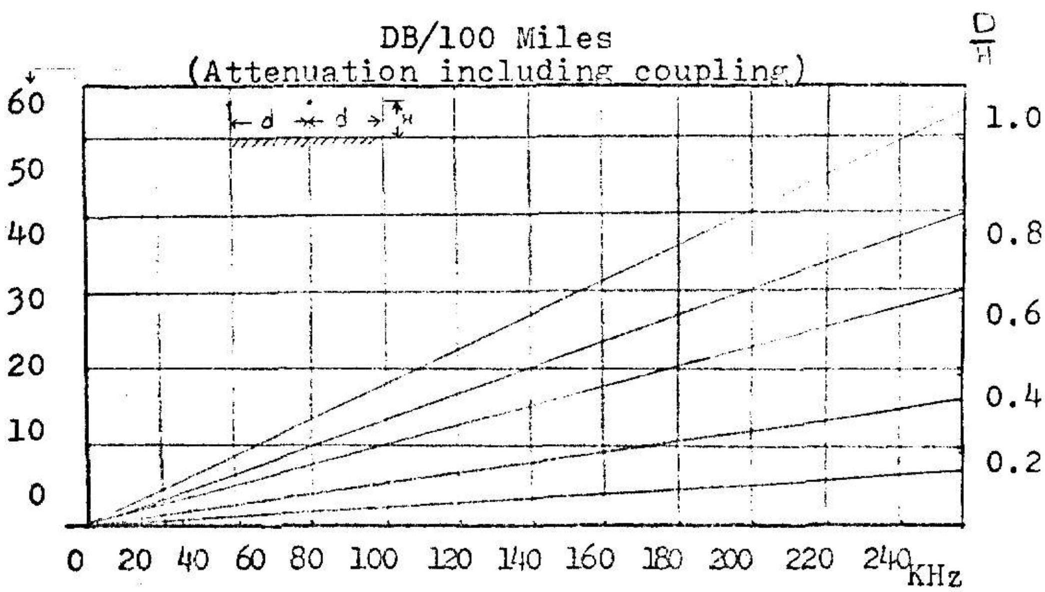

FIG. 2.23 RATIO SPACING BETWEEN CONDUCTORS D TO HEIGHT OF CONDUCTORS ABOVE GROUND H.

$$D = \sqrt{d.d.2d}$$

$$D = 1.26d$$

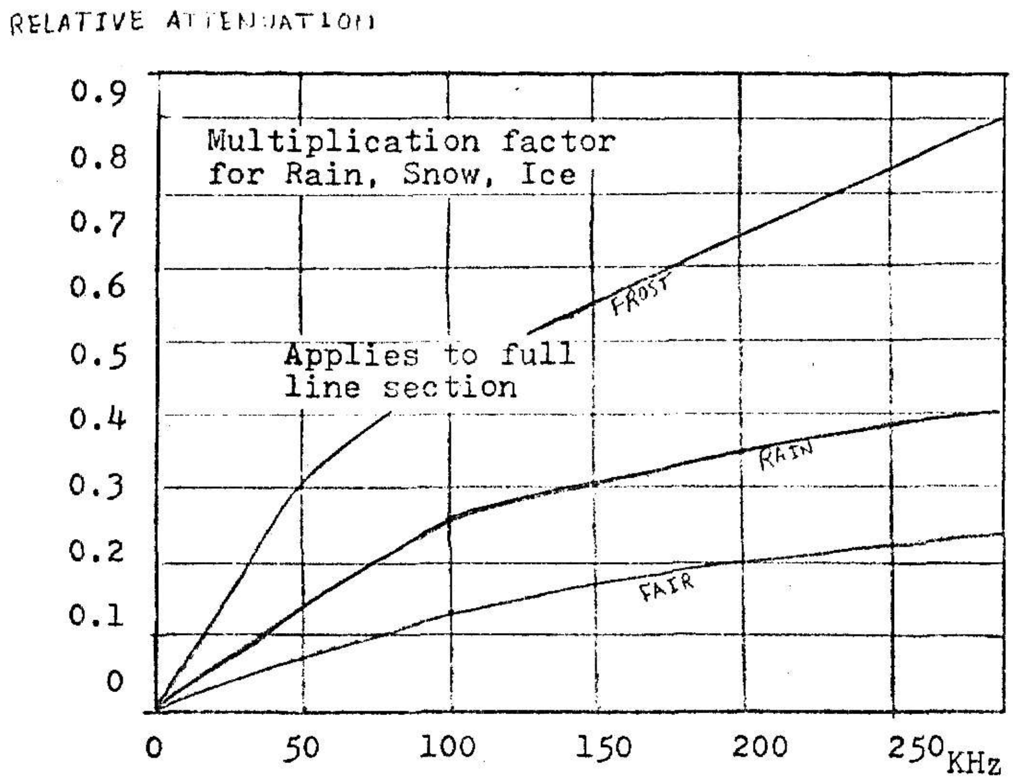

FIG. 2.24 MULTIPLICATION FACTORS FOR RAIN OR ICE

In Fig. 2.23, line attenuation is plotted against the frequency and the ratio d/h. The average d/h for 765-KV lines on the AEP system is 0.8, and the frequencies mostly being used are between 32 KHz and 100 KHz. The reason for using this low range of frequency is the advantage of having lower attenuation at this range than in the high frequency range.

Losses due to frost and ice buildup should also be considered because these factors tend to multiply the attenuation constants. In isolated cases attenuation constants have been known to rise to 15 times the normal value. This is of course not the case for the entire 200-300 mile line considered in the experiment, but for the most extreme cases these losses are also restricted to particularly exposed local areas.

Fig. 2.24 shows the computerized plot of the measurements at lower voltages which have produced the rate of fair frost-ice attenuation.

The above conditions are dependent on the geographical areas and could be reduced by an order of magnitude in many cases. The calculations are done for the worst possible case, and it was assumed the ratio would apply for all lines. It can be seen from Fig. 2.24 that at a frequency equal to 100 KHz, the ratio of rain to fair weather is $\frac{.26}{.13} = 2$, and that the ratio of frost to fair at the same frequency is $\frac{.46}{.13} = 3.5$. It can be seen from this figure that these ratios will increase at higher frequencies, causing more attenuation.

High noise values could be introduced into the carrier circuit from two sources:

1. Power transmission lines, caused by corona discharges across insulators and conductors. (Corona is a luminous discharge of electricity due to ionization of the air, appearing on the surface of a conductor when the potential gradiant exceeds a certain value.) Some such noise is present at all times.
2. Switching and atmospheric discharges.

The signal-to-noise ratio is a deciding factor in the quality of a communication channel. It is desirable to have as high a SNR as can be obtained by controlling the several factors such as line losses.

Fig. 2.25 indicates the relationship between the total line attenuation and the projected noise levels for an output of 1 watt.

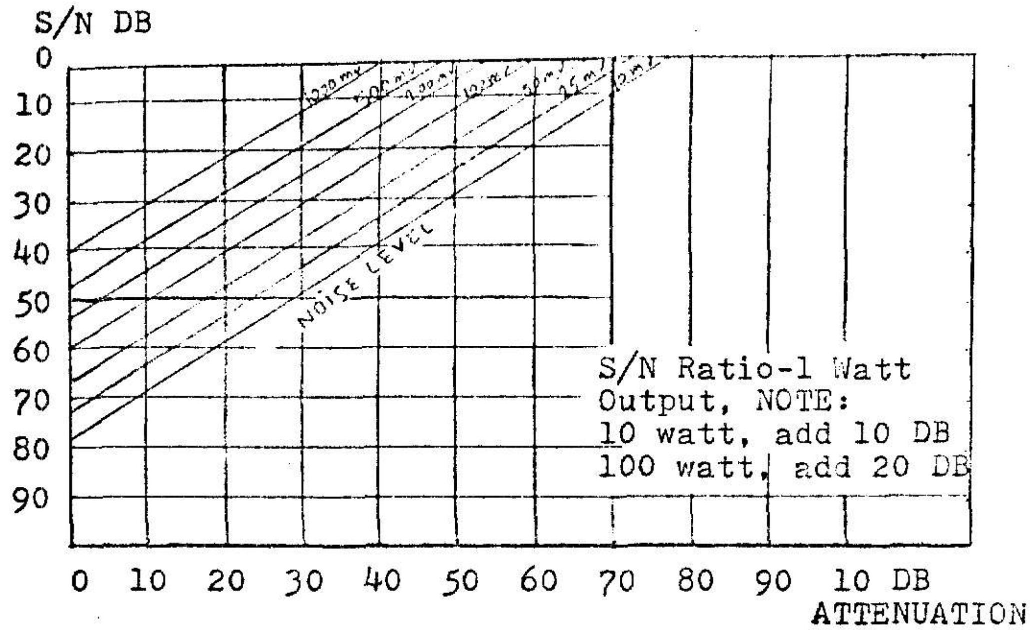

FIG. 2.25 SIGNAL-TO-NOISE RATIO

Crosstalk Generated in Multichannel Systems

Frequency division of channels is the most common principle for multichannel communication. The design principle is given in Appendix A. The content of Appendix A shows that the main problem in the multichannel system is the crosstalk generated in the system. The elimination of the crosstalk generated in multichannel systems has been studied (8) for years. The frequency distribution is considered, which ensures that there will be no coincidence between any form of linear combination of fundamental frequencies and their harmonic components and the frequencies themselves.

It has been shown that it is possible to reduce the cross-talk when transmitting digital data. This is done by making the signal structure more complex, and by using correlation methods of reception.

A significant nonlinearity in the group channel of a multichannel system is exhibited by FM channels and by AM channels in a distributive power network. The choice of method used for surpressing crosstalk depends on the type of modulation which has been used, the method used to form and to separate the signals, and the requirements on the channel itself. Eliminating crosstalk results in more complexity in the apparatus being used. The simplest and most effective method is that of distributing the operational frequencies over the bandwidth so that their linear combinations do not fall within the passband of the receiving filters. What is given in the following will only consider the elimination of crosstalk due to three frequencies ($F_I = F_i + F_j - F_k$). The elimination of interference due to all forms of combination will not be considered here, for the sake of simplicity.

In what follows the problem will be presented and a solution will be pursued (8).

The problem is that the level of crosstalk depends on the degree and nature of the nonlinearity. Simple combination of basic frequencies in the form of sums could be approximated by a polynomial of the second degree. Under this assumption the problem of the division of the subchannels along the frequency axis can be mathematically formulated as follows: N numbers (carrier frequencies) $F_1, F_2, \ldots, F_N$ in the given frequency band (a,b) should be found that satisfy the following conditions: $L = \sum_{i}^{N} \lambda_i F_i$ where $\lambda_i \in (\,, \pm 1, \pm 2, \pm \ldots)$ falls within the band so that its distribution along the frequency axis is in such a way that on both sides of each number there is a large segment which is free of linear combination L, that is $L_I \longrightarrow \frac{F_i + F_{i+1}}{2}$. The solution is obtained in the form of a general term of the numerical series which reflects the dependance of the carrier frequency on its number. That is $F_X = f(X)$. There will be two cases to be considered.

1. Uniform distribution of frequencies over the bandwidth.
2. Nonuniform distribution of frequencies (method of forbidden lines).

Only the first case will be considered here. The second case will be left as a reference (8) for those who are interested to pursue this problem further.

Case 1: Uniform distribution of frequencies over the bandwidth.

$f(X)$ being a linear function (that is, of order one), it could be written that $F_X = A+BX$. Suppose the following happens: $A \pm BX_I = A + BX_i \pm A \pm BX_k$, that is the sum or difference of two frequencies coincide with a third frequency. From the above equation $X_I = X_i \pm X_k + \frac{A}{B}$ is obtained, where X_I is the frequency subject to distortion. This form could be generalized and stated as follows: the frequency subject to distortion is a linear combination of the number of combining freauencies added to the ratio of coefficient ($\frac{A}{B}$).

For $\frac{A}{B} = \frac{1}{2}$, all combination frequencies will be exactly between operating frequencies. It could be seen, however, that when there are odd numbers of frequencies the coefficients A, B will not be entered into the problem. That is,

$$A + BX_I = A + BX_i + A + BX_k - A - BX_j$$

$$BX_I = B\ (X_i + X_k - X_j)$$

$$X_I = X_i + X_k - X_j$$

Therefore the conclusion is that the choice of frequencies with specified values of the coefficients decreases the crosstalk, but it will not completely eliminate it.

III. SUMMARY

The main objective of this paper was to introduce the new approach toward the simplification of controlling loads in a numbers of substations remotely. Use of the ordinary electrical distribution networks for transmissions of control signals, ripple control was introduced. Ripple control was further studied and its basic equipment, installation building blocks, and main functions were explained.

How these ripple control signals could be transmitted and what kinds of channels should be used to get the orders from the main station to the substation with maximum efficiency was then introduced.

The signals to be sent could be generated either automatically or manually. The automation of distribution systems and power line carrier communication was therefore studied. Introducing these means of transmitting signals through networks of interest brought up some basic questions about the problems that exist in each type of equipment. Crosstalk generated in multichannel systems mainly by noise entering the network and getting amplified in following sections of the network was also studied. Stating the problem without any answer or at least attempting to answer of course was not the purpose of raising the question, so the solution, or at least some guidance and possibilities for the solution of such problems, was discussed.

IV. REFERENCES

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V. APPENDICES A & B

5.1 APPENDIX A

Design Principles of Multichannel Communication System

One of the most common principles for multichannel communication is the frequency division of the channels which provides for the continuous transmission of information. The design of such a system linked by the Power Distribution Network (PDN) can be carried out in two basic ways.

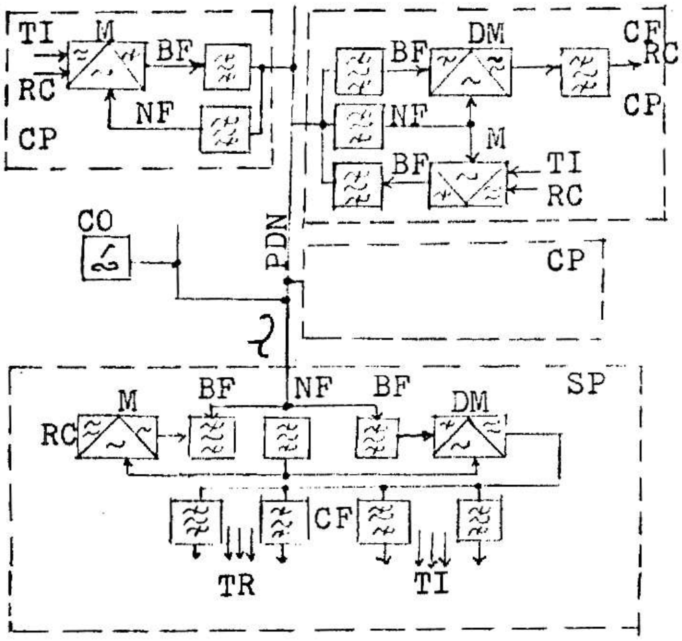
1. By high-frequency multiplexing of the PDN with a number of independent channels which serve each point separately.
2. By using a single carrier frequency (SCF) channel common to all the distributed points.

There are some problems with the first method, such as:

1. The range of the frequency not being utilized economically.
2. The need for a large amount of receiving/transmitting apparatus.

Using SSB, the number of channels in the same range can be increased but there is the disadvantage of the complexity of the apparatus.

The second method, because it uses an absorption modulation method, and also because of the impossibility of using SSB, has not been used extensively. This method, however, has been developed and perfected. A block diagram of a channel for transmitting remote-control signals is shown in Fig. 5.1.



CP : Controlled Points

M : Modulation

BF : Bandpass Filter

NF : Narrow-band Filter

DM : Demodulation

CO : Oscillator

PDN : Power Distribution Network

SP : Info. gathering point

SCF : Single Carrier Frequency

SSB : Single Sideband

CF : Channel Filter

FIG. 5.1 BLOCK DIAGRAM OF A TRANSMITTING CHANNEL

This figure works as follows:

1. A carrier frequency common to the entire system from CO travels along PDN to all points where it is isolated by NF.
2. This signal after being amplified is used to supply all the M and DMs.
3. When transmitting and receiving signals that contain information, the signals are kept separated by BF. Having done this there is no need to use any special synchronizing device because all frequency conversions are performed in synchronization.
4. Now one can receive signals from all CP's at SP with a

SCF using only one M.

One can operate the subchannels in the opposite direction. Fig. 5.1 shows the simplicity of the apparatus compared with method one which uses a system of separate high-frequency channels.

EFFICIENCY IN THE UTILIZATION OF THE FREQUENCY RANGES

Fig. 5.2 shows the distribution of carrier and subcarrier frequency.

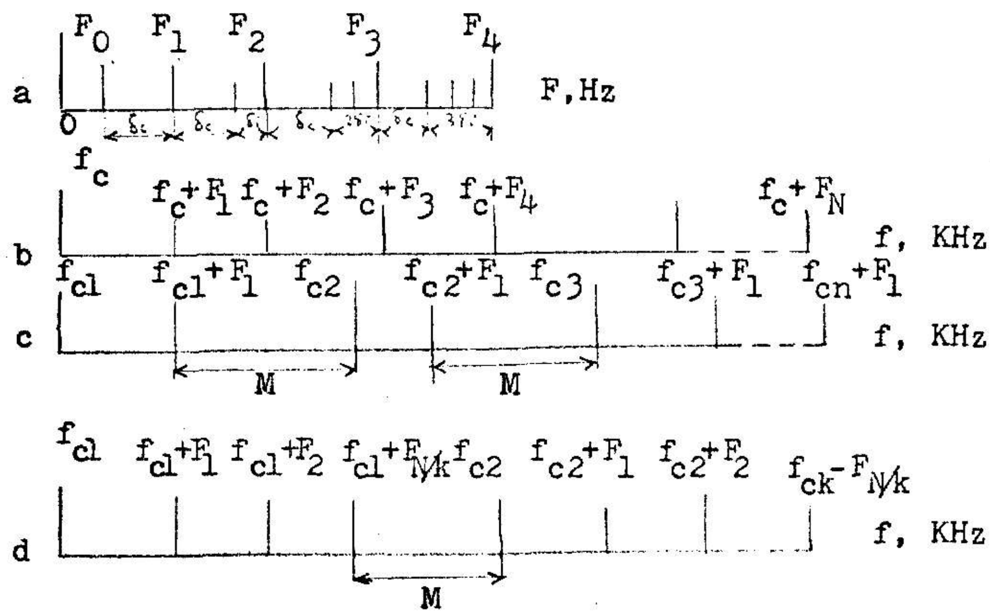


FIG. 5.2 DISTRIBUTION OF SUBCARRIER FREQUENCIES

The choice of such carrier frequencies in both methods is made in the same way. It has been shown (Appendix B) that when the subcarrier frequencies are distributed over the range with a uniformly increasing spacing (Fig. 5.2a) the minimum crosstalk is attained. This distribution could be written in the form

$$F_x = F_o + X\delta_c + \frac{X(X-1)}{2}\delta_i \qquad (1)$$

where X = order number of subchannel.

F_o = some initial frequency value (the design value for the beginning of the range).

δ_c = constant part of the spacing between the carrier frequencies of the subchannels.

δ_i = increment in the spacing when shifting from one subchannel to the next.

Suppose each CP requires one subchannel. Fig. 5.2b shows the frequency distribution of a system having a common carrier-frequency oscillator. Fig. 5.2c shows a system having separate SSB channels for each CP.

It is therefore clear that one can save in frequency range by using a small number of subchannels.

As the number of subchannels increases the efficiency in using the frequency range decreases. At some number of channels N, the system having separate channels and the system having a common carrier frequency become equal. This can be determined if the following assumption is being made:

1. The same frequency band for both systems.
2. An identical number of subchannels n at CP.

$$F_o + N\delta_c + \frac{N(N-1)}{2}\delta_i = \frac{N}{n}\left(F_o + n\delta_c + \frac{n(n-1)}{2}\delta_i\right) + \left(\frac{N}{n} - 1\right)M \quad (2)$$

It is assumed that X = N in equation (1).

M is spacing in KHz and is so chosen that there is no interference between the separate channels. The solu[illegible]n of (2) yields:

$$N = \frac{F_o+M}{n\delta_i} + \frac{n}{2} + \sqrt{\left(\frac{F_o+M}{n\delta_i} + \frac{n}{2}\right)^2 - 2\left(\frac{F_o+M}{\delta_i}\right)} \quad (3)$$

When N runs between 50 and 80 channels, it is advisable to divide the entire range of frequencies along PDN into K parts with spacing M when the number of subchannels is high. This is seen from Fig. 3.2d. The best way to utilize the frequency range is to minimize the function that describes the dependance of the frequency band occupied by all the systems on the distribution of the number of CP's between them:

$$\Delta f = K \left(F_o + \frac{N}{k}\delta_c + \frac{\frac{N}{k}\left(\frac{N}{k} - 1\right)}{2}\delta_i\right) + (k-1)M \qquad (4)$$

$$\Delta f_{min} = N\sqrt{2\delta_i(M+F_o)} + N\left(\delta_c + \frac{1}{2}\delta_i\right) - M \qquad (5)$$

This is achieved for the number of independent systems.

$$K = N\sqrt{\frac{\delta_i}{2(M+F_o)}} \qquad (6)$$

A practical example gives more insight into the above situation. For example:

$M = 2$ KHz

$F_o = 660$ Hz

$\delta_c = 64$ Hz

$\delta_i = 8$ Hz

The estimated number of channels that can be placed in Δf band is given in Table 3.

Type of Channel	No. of subchannels for Δf, KHz		
	20	50	100
Separate channel with SSB	36	90	186
One channel with a SCF	63	104	150
System of channels with a SCF	65	175	367

TABLE 3. ESTIMATED NUMBER OF CHANNELS IN Δf BAND

Therefore using several systems whose number is found from equation (6) and a common carrier-frequency oscillator makes it possible to set up a channel on a PDN for a large remote-control system serving several dispersed plants that are linked by a common PDN. It can also be seen that the apparatus is simplified and a flexible channel arrangement is obtained.

5.2 APPENDIX B

CALCULATION FOR A TYPICAL LINE OF 200 MILES

From the information given on page 36 through page 39, which was believed to be maximum values, the computer calculation for a typical line of 200 miles is given here (4). Some examples are also given. The flow diagram of this program is given in Fig. 5.3.

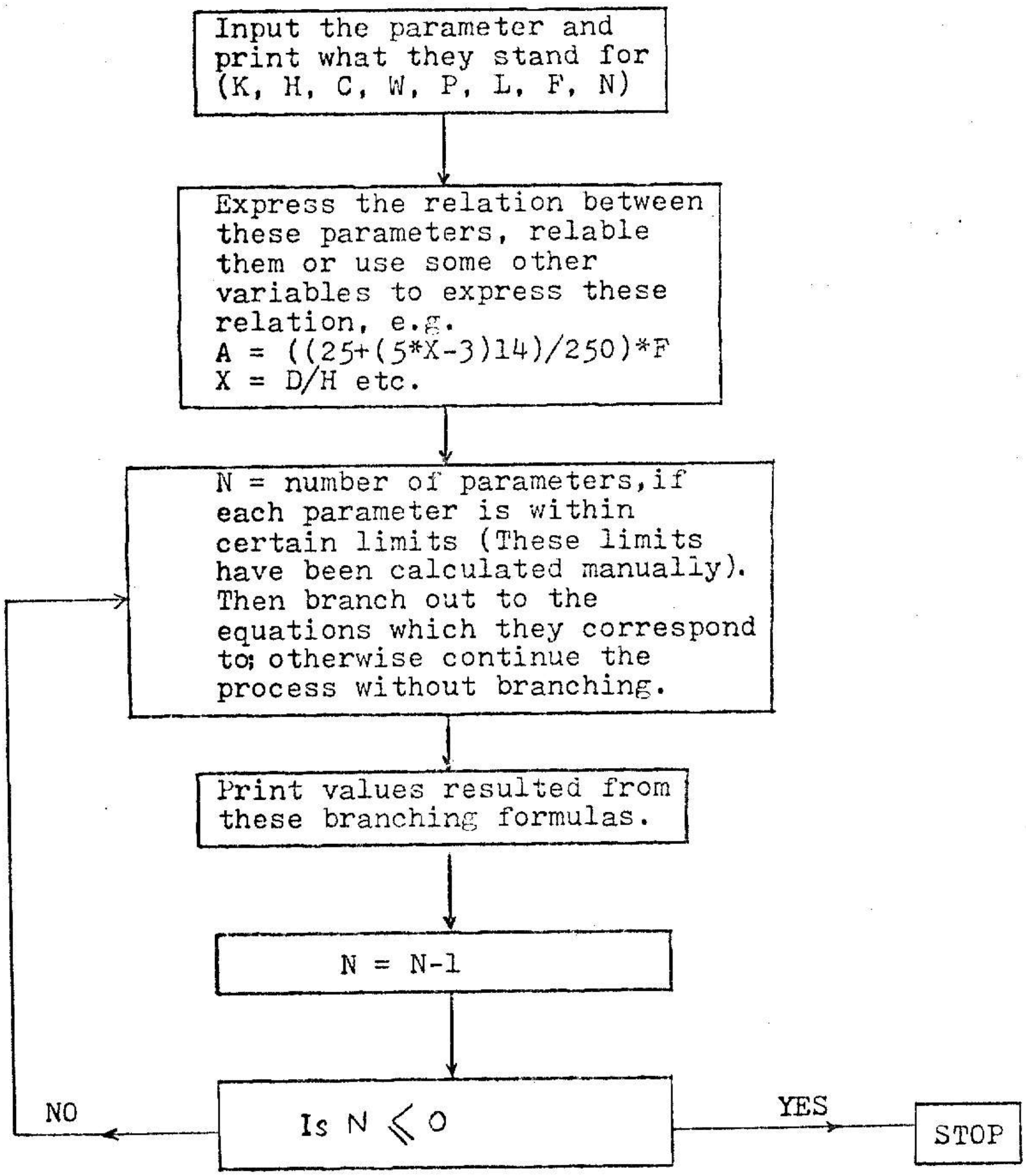


FIG. 5.3 FLOW DIAGRAM OF THE PROGRAM

```
LIST
100  PRINT "WHAT ARE YOUR VALUES FOR K.H.C.W.P",
101  INPUT K,H,C,W,P
105  PRINT "WHAT IS YOUR LINE LENGTH",
106  INPUT L
110  PRINT "WHAT IS YOUR NOISE LEVEL",
111  INPUT N
125  PRINT "WHAT IS YOUR FREQUENCY",
126  INPUT F
140  LET D=1 26*K
150  LET Z=W
160  LET X=D/H
170  IF X<= 6 GOTO  190
180  IF X<= 8 GOTO  202
185  IF X>= 8 GOTO  210
190  LET A=( 118*X^3+ 0875*X^2+ 105*X)*F
200  GOTO  220
202  LET A=((40+(5*X-4)*16)/250)*F
204  GOTO  220
210  LET A=((26+(5*X-3)14)/250)*F
220  LET A=A*L
225  PRINT "LINE LENGTH                =",L
230  PRINT "LINE ATTENUATION                =",A
240  IF F>=125 GOTO  290
250  IF F>=100 GOTO  310
260  IF F>=75 GOTO  330
270  IF F>=50 GOTO  350
280  IF F<=50 GOTO  370
290  LET M1= 00052*F+ 09
300  GOTO  380
310  LET M1= 0008*F+ 046
320  GOTO  380
330  LET M1= 00076*F+ 05
340  GOTO  380
350  LET M1= 00112*F+ 024
360  GOTO  380
370  LET M1= 001563*F
380  IF Z=1 GOTO  390
390  IF Z=2 GOTO  440
392  IF F<12 GOTO  451
393  [illegible]
394  [illegible]
395  IF F<[illegible] GOTO  460
410  IF F>=100 GOTO  480
420  IF F>50 GOTO  490
430  IF F<100 GOTO  500
440  IF F>=50 GOTO  520
441  IF F<12 GOTO  531
442  IF F<20 GOTO  533
443  IF F<40 GOTO  535
444  IF F<50 GOTO  537
451  LET M2= 00455*F+1 393
452  GOTO  550
453  LET M2=F/(202 57+(1 348*F))
454  GOTO  550
455  LET M2=F/(206 232+(1 183*F))
456  GOTO  550
460  LET M2=F/(200.774+(1.313*F))
470  GOTO  550
480  LET M2= 0008*F+ 162
490  GOTO  550
500  LET M2= 0012*F+ 13
510  GOTO  550
520  LET M2= 003*F+ 15
530  GOTO  550
531  LET M2= 009196*F+ 005393
532  GOTO  550
533  LET M2=F/( 2189)+ 0144
534  GOTO  550
535  LET M2=F/(89 25+(1 5*F))
536  GOTO  550
537  LET M2=F/(33 096+(1 67*F))
550  LET S=M2/M1
590  IF A<=C GOTO  610
600  GOTO  630
610  LET A1=(S*A)+C
620  GOTO  640
630  LET A1=S*(A-C)+C
640  PRINT "TPTAL ATTENUATION FOR THE LINE=",A1
650  IF N=1000 GOTO  690
655  IF N=500 GOTO  700
660  IF N=200 GOTO  710
665  IF N=100 GOTO  720
670  IF N=50 GOTO  730
680  IF N=10 GOTO  750
685  IF N=5 GOTO  760
690  LET B=40
695  GOTO  890
700  LET B=47 5
705  GOTO  890
710  LET B=53 5
715  GOTO  890
720  LET B=60
725  GOTO  890
730  LET B=66
735  GOTO  890
740  LET B=72
745  GOTO  890
750  LET B=77 5
755  GOTO  890
760  LET B=80
765  GOTO  890
890  LET R2=-(A1-B)
891  LET R1=-(A-B)
900  PRINT "FREQUENCY                =",F
905  LET Q=Q+1
910  PRINT "SIGNAL TO NOISE RATIO/FAIR      =",R1
911  PRINT "SIGNAL TO NOISE RATIO/WEATHER=",R2
920  IF Q<P GOTO  125
970  REM    H IS THE HEIGHT OF THE CONDUCTORS ABOVE GROUND IN
FEET
980  REM    F IS THE FREQUENCY IN KHZ
990  REM    C IS THE COUPLING LOSS AT BOTH E@@N@DS OF THE LINE

1000  REM    W REFERS TO THE WEATHER 1FOR RAIN 2 FOR FROST
1010  REM    L IS THE LENGTH OF THE LINE IN HUNDREDS OF MILES
```

```
1020  REM   K IS THE DISTANCE BETWEEN CONDUCTORS IN FEET
1040  REM   P IS THE TOTAL NUMBER OF FREQUENCY VALUES
1050  REM   N IS THE NOISE LEVEL IN MILLIVOLTS
9999  END
RUN
WHAT ARE YOUR VALUES FOR K,H,C,W,P? 45? 60? 8? 1? 8WHAT IS YOUR LINE L
ENGTH? 2WHAT IS YOUR NOISE LEVEL? 200WHAT IS YOUR FREQUENCY? 36LINE LE
NGTH                 =          2
LINE ATTENUATION                    =                 14 2605
TOTAL ATTENUATION FOR THE LINE=                       25 525
FREQUENCY                =      36
SIGNAL TO NOISE RATIO/FAIR       = 38 6392
SIGNAL TO NOISE RATIO/WEATHER= 27 915
WHAT IS YOUR FREQUENCY?
STOP @ 126
```

Example 1

```
RUN
WHAT ARE YOUR VALUES FOR K,H,C,W,P? 20? 60? 8? 1? 8WHAT IS YOUR LINE L
ENGTH? 2WHAT IS YOUR NOISE LEVEL? 200WHAT IS YOUR FREQUENCY? 36LINE LE
NGTH                 =          2
LINE ATTENUATION                    =                 4 91597
TPTAL ATTENUATION FOR THE LINE=                       20 6002
FREQUENCY                =      36
SIGNAL TO NOISE RATIO/FAIR       = 48 524
SIGNAL TO NOISE RATIO/WEATHER= 32 8998
WHAT IS YOUR FREQUENCY?
STOP @ 126
```

Example 2

```
RUN
WHAT ARE YOUR VALUES FOR K,H,C,W,P? 45? 120? 8? 1? 8WHAT IS YOUR LINE
LENGTH? 2WHAT IS YOUR NOISE LEVEL? 200WHAT IS YOUR FREQUENCY? 36LINE L
ENGTH                 =          2
LINE ATTENUATION                    =                 5 87482
TPTAL ATTENUATION FOR THE LINE=                       23 0579
FREQUENCY                =      36
SIGNAL TO NOISE RATIO/FAIR       = 47 6252
SIGNAL TO NOISE RATIO/WEATHER= 30 4421
WHAT IS YOUR FREQUENCY?
STOP @ 126
```

Example 3

```
RUN
WHAT ARE YOUR VALUES FOR K,H,C,W,P? 45? 60? 8? 2? 8WHAT IS YOUR LINE L
ENGTH? 2WHAT IS YOUR NOISE LEVEL? 200WHAT IS YOUR FREQUENCY? 36LINE LE
NGTH                 =          2
LINE ATTENUATION                    =                 14 2608
TPTAL ATTENUATION FOR THE LINE=                       32 5446
FREQUENCY                =      36
SIGNAL TO NOISE RATIO/FAIR       = 38 6392
SIGNAL TO NOISE RATIO/WEATHER= 14 9554
WHAT IS YOUR FREQUENCY?
```

Example 4

Example 5

```
RUN
WHAT ARE YOUR VALUES FOR K,H,C,W,P? 45? 60? 8? 1? 8WHAT IS YOUR LINE L
ENGTH? 3WHAT IS YOUR NOISE LEVEL? 200WHAT IS YOUR FREQUENCY? 36LINE LE
NGTH            =         3
LINE ATTENUATION                  =          22 2912
TOTAL ATTENUATION FOR THE LINE=              44 63
FREQUENCY            =    36
SIGNAL TO NOISE RATIO/FAIR      = 31 2038
SIGNAL TO NOISE RATIO/WEATHER= 8 86998
WHAT IS YOUR FREQUENCY?
STOP @ 126
```

Example 6

```
RUN
WHAT ARE YOUR VALUES FOR K.H.C.W.P? 45? 60? 8? 1? 8WHAT IS YOUR LINE L
ENGTH? 2WHAT IS YOUR NOISE LEVEL? 400WHAT IS YOUR FREQUENCY? 36LINE LE
NGTH            =         2
LINE ATTENUATION                  =          14 9608
TOTAL ATTENUATION FOR THE LINE=              25 585
FREQUENCY            =    36
SIGNAL TO NOISE RATIO/FAIR      = 25 1392
SIGNAL TO NOISE RATIO/WEATHER= 14 415
WHAT IS YOUR FREQUENCY?
STOP @ 126
```

Example 7

```
RUN
WHAT ARE YOUR VALUES FOR K.H.C.W.P? 45? 60? 8? 1? 8WHAT IS YOUR LINE L
ENGTH? 2WHAT IS YOUR NOISE LEVEL? 200WHAT IS YOUR FREQUENCY? 72LINE LE
NGTH            =         2
LINE ATTENUATION                  =          29.7216
TOTAL ATTENUATION FOR THE LINE=              52.9212
FREQUENCY            =    72
SIGNAL TO NOISE RATIO/FAIR      = 23 7784
SIGNAL TO NOISE RATIO/WEATHER=  578819
WHAT IS YOUR FREQUENCY?
```

The examples show the resulting S/N ratio and line attenuation for various sets of line parameter. It could be seen from example two that maximum S/N ratio and minimum line attenuation is obtained when the distance between the conductors is twenty feet. This value is obtained when the height of the conductor above ground is sixty feet, the coupling loss at both ends of the line is eight decibel and rainy weather is assumed.

VI. ACKNOWLEDGMENT

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POWER LINE CARRIER COMMUNICATION

by

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B.S., Kansas State University, 1975

AN ABSTRACT OF A MASTER'S REPORT

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ABSTRACT

Power-line-carrier has been recognized as an excellent communication link for the purpose of controlling consumer loads remotely. Many significant developments in PLC systems engineering of particular interest to EHV lines have taken place in the last few years. The search for more efficient and reliable long distance communication links is a continuing program of research in the PLC field. As automation becomes more widely used, greater dependence will be placed upon the system being discussed. Feeder automation could be implemented by using radio and telephone means. Distribution-line-carrier is, however, a better way because it makes it practical to use complete automated distribution. Narrowband FSK modulation has been used in experiments and the result has shown that DLC communications could be achieved at low-cost with low-power equipment. Proper coupling and newly designed equipment permits the application of PLC successfully to the 765-KV system of AEP.

Ripple control as another approach for controlling loads remotely has been studied within the last fifty years starting in Europe. A number of U.S. utilities and manufacturers of electrical equipment are evaluating the ripple control system, and some emphasis is being placed on the development of a two-way system which will include remote meter reading. Some utilities feel that such a feature must necessarily to be included to justify the cost of a ripple control system. Ripple control enables the daily load curve to be influenced from a central point in order to obtain optimum utilization of electricity distribution equipment.