ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

REMOTE METERING OF GAS AND ELECTRICITY DELIVERED TO A CONSUMER

By

William Kerr
R. C. Walker

Project 2042

CONSUMERS POWER COMPA
JACKSON, MICHIGAN

September, 1952

ACKNOWLEDGEMENT

This investigation has been carried on under the guidance of the following Engineering College staff members, who have contributed generously of their time and effort:

W. G. Dow, Professor of Electrical Engineering
M. H. Nichols, Professor of Aeronautical Engineering
R. C. Porter, Professor of Mechanical Engineering
L. L. Rauch, Associate Professor of Aeronautical Engineering
M. B. Stout, Professor of Electrical Engineering

Acknowledgement is also made to Professor A. E. White, Director of the Engineering Research Institute, for his helpful comments on the final report.

W. Kerr
R. C. Walker

TABLE OF CONTENTS

REMOTE METERING OF GAS AND ELECTRICITY DELIVERED TO A CONSUMER

I. INTRODUCTION

This investigation has as its objectives the assembling of the known pertinent information on the subject of remote metering of electric energy or gas delivered to a consumer, and the recommendation of a research program pointed toward the development of suitable equipment for this purpose.

Recent trends in industrial processing and control place increasing emphasis on the transmission of information concerning certain pertinent variables such as temperature, pressure, voltage, and rates of flow of various quantities from the point of direct measurement to some remote location. This type of transmission of information has been given the general name of telemetering.

The increasing complexity of modern science and industry and the need for complete and accurate information has made telemetering an important part, not only of the present-day factory or electrical generation and distribution system, but also of many other complex integrated systems as well. The rapidly growing technology of guided missiles, for example, makes extensive use of telemetering using air-to-ground radio channels. The interest generated as a result of the more recent types of applications has contributed to rapid progress in both techniques and equipment.

Because of this progress, it is perhaps wise at this time to reexamine the problem of reading the electric watt-hour meter or the gas meter of each individual consumer from a remote centralized location. This is a telemetering problem that has intrigued many inventors and engineers since the early days of the electrical generation and distribution of energy. The information obtained by telemetering might be used by an automatic computing machine for computing customer billing.

The present investigation indicates that, of the systems that are technically possible, two are most nearly practical. In this report these two systems are described and analyzed in some detail. Several possible variations of the two systems are considered, and recommendations for further investigation are made. It is the judgment of those who have taken part in this investigation that there is a very good probability that remote metering of gas and electricity delivered to the consumer can be made economically feasible by a reasonable development program. Such a program is outlined in section VI of this report. The support of such a program would seem to be a good risk.

II. SURVEY OF PREVIOUS WORK ON REMOTE METERING

As early as 1903 a system had been developed for the remote reading of a watt-hour meter.[1] The device incorporated a series of counting dials actuated by a meter shaft, each winding up a small spring as it was displaced from zero. An electrical impulse sent from a central station released the wheels in succession and as it returned to zero each wheel actuated contacts to transmit pulses representing its displacement from zero. These pulses, received at the central station, could be interpreted to represent the meter reading.

A system patented in 1927 made use of coded impulses transmitted by a scanning device located at the meter register.[2] These coded impulses were received audibly over a telephone circuit, and manually decoded.

A scheme developed about 1931 made use of resonant reeds located at the meter register.[3] Associated with each decade dial of the meter was a set of ten reeds, each resonant at a different frequency. An electromagnet energized by a variable-frequency generator at a remote location tended to set the reeds in motion. Located on the meter spindle was a set of helically arranged segments. As the different reeds vibrated, contact was eventually made with a particular segment determined by the dial setting, short-circuiting the electromagnet. This caused a change in the signal to which an observer was listening, thus indicating the dial position.

---

1 - U. S. Patent No. 784,713 granted to C. H. Thordarson.

2 - U. S. Patent No. 1,621,939 granted to H. C. Lowe.

3 - U. S. Patents Nos. 1,849,870 and 1,889,597 granted to A. S. Fitzgerald, assigned to the General Electric Co.

About 1934, a British affiliate of the Sangamo Electric Company devised a system which involved equipping each meter dial with a spiral-shaped cam.[4] Motor-driven wipers traveling at a uniform speed could be made to traverse the cams, producing a contact whose duration time depended on the dial position. Other fixed cams produced a code giving the meter identification. This code, received at a central location, was automatically decoded and recorded. The communication channel was a wire line installed specially for this purpose.

Probably the most elaborate system yet devised is described in a set of patents issued to Ward Leathers from about 1941 to 1943.[5] The patents disclose a considerable number of modifications, but make use generally of a rheostatic element located at the meter in which resistance units corresponding to the dial positions form parts of a rheostat, so that each significant dial position is represented by a definite resistance value. This resistance is measured automatically from a remote location and the corresponding dial readings are recorded automatically. Apparently the International Business Machines Corporation, by whom Leathers was employed, spent considerable time and effort investigating remote metering during this period.

As indicated above, there has been much interest in the problem of remote metering of gas and electricity delivered to the ultimate consumer. However, none of the above methods has been able to compete successfully on an economic basis with the manual method of reading meters on any large scale.

III. ANALYSIS OF PROBLEM

The chief disadvantage of all the schemes for remote reading of consumer meters that have been proposed in the past has inevitably been an economic one. There are at present many ways in which remote metering can be done. The problem is one of finding a method that is economically feasible. The successful solution thus must consider not only the technical details of the system but also the economic ones. A very careful analysis is indicated.

In the present approach to the problem it is assumed that the meters now used to measure gas and electricity will, with minor modifications, still be used as measuring devices. The remote metering system

4 - British specification No. 15569/34.

5 - See, e.g., U. S. Patents Nos. 2,319,412; 2,304,698; and 2,283,070.

simply transfers the operation of meter reading from the meter to a receiver at a remote location and there makes use of the reading for automatic billing. Although it is possible that some other methods of measurement might be used in a remote metering scheme, the present investigation has not produced one.

It seems reasonable to assume that the transfer of information over the distances that normally will be involved in a remote metering scheme can be done most readily by electrical methods of communication. Such an assumption is made in the following analysis.

For a functional analysis, a remote metering system may be thought of as having three general components. These will be labelled as the end organ, the information-carrying channel, and the receiver. The end organ is a device at the meter for translating the meter reading into a form suitable for transmission over the second component, the information-carrying channel. The information channel is a medium which can be used to transmit the suitably coded metering information to the third component, the receiver. The receiver accepts the information from the information-carrying channel

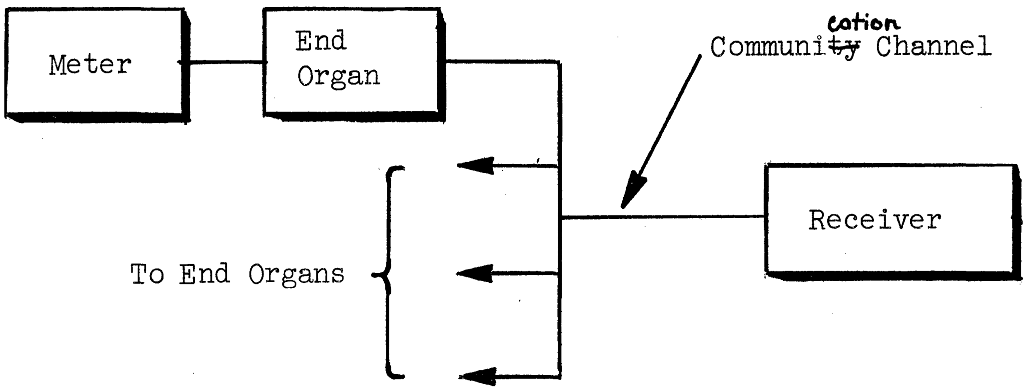

Fig. III-1. Block Diagram of Remote Metering System.

in coded form and converts it to a form suitable to whatever use of the information is desired. This use might be that of automatic billing of consumers.

The costs of a remote metering system may logically be divided into initial costs and maintenance costs. Any system analysis must, however, consider these two together, since they are not in general independent. Both the initial cost of the meter end organ and its maintenance must be kept to a minimum. Of necessity, then, it must be as free of gadgetry as is practical. The receivers, on the other hand, since there will be fewer of them, can well be more elaborate. The communication channel must have a small cost per customer and thus must almost of necessity be some existing installation.

Because the information-carrying channel chosen will determine to a large extent both the type of end organ and the type of receiver used, it will be considered first.

Information Channel

Several types of transmission channels are possible, such as the power distribution lines, existing telephone circuits, separately installed wire communication circuit, and a radio communication channel. In Table III-1 are listed these various possibilities, together with some advantages and disadvantages of each.

Of the available channels, the combination of economic and technical considerations would seem to favor either the first or second listed, i.e., existing power distribution lines or existing telephone circuits. These two systems will thus be considered in somewhat more detail.

Power Distribution Lines. For the past twenty years or so, considerable use has been made of electric high-voltage transmission lines as channels for transmitting direct communication, metering, and control information by means of carrier-frequency methods using frequencies usually between 30 and 200 kc. There have also been several applications of the distribution system (voltages between about 2400 and 7200) as a carrier channel, particularly by radio amateurs operating during World War II, and by civilian defense communication networks. Various branches of the Bell Telephone System have also used electric distribution circuits in setting up carrier systems designed mostly to serve rural or remotely located customers.[6] Although these have had moderate success, much of the information available in published form is of a qualitative nature. All of it indicates that many variables play a part in the transmission of radio-frequency energy over distribution circuits.

However, enough information is available (see Appendix I) to indicate that the region around 100 kc might be used for transmission of remote metering information.

From available information on the electrical noise spectrum to be expected and the transmission characteristics needed for a possible system, a study was made (see Appendix II) which indicated that, with a reasonably obtainable value of power from the end organ, transmission of information

6 - Barstow, J. M., et al., "Rural Carrier Telephony", Elec. Engrg., 66, 425 (May 1947).

TABLE III-1

POSSIBLE COMMUNICATION CHANNELS FOR REMOTE METERING SYSTEM

Communication Channel	Advantages	Disadvantages
Power Distribution Lines	Owned and controlled by utility (except in case gas alone is supplied customer by utility). No additional installation of lines necessary. Can be adapted for use at all times without affecting power distribution.	Coupling from end organs or from low-voltage distribution circuits to higher-voltage distribution circuits cannot be done with power transformers at radio frequencies (100-500 kc); presently available coupling methods are expensive and would require safety engineering. Line termination impedance varies considerably with the 60-cycle loading of the transformers; thus some form of line trap (as in carrier practice) probably would be needed at both transmitting and receiving ends. Multiplicity of possible paths makes directing of signal energy somewhat uncertain. High noise voltage is present, which means that large signal voltage is necessary to override it. Probably the substation represents the largest unit of centralization.
Existing Telephone Circuits	Fairly constant line and termination impedances. Low background-noise level on channel. Centralization possibilities large. Probably a whole city could be handled from one location. (Rural situation might be complicated by independent telephone companies.)	Telephone company would charge for use of lines. Care would be necessary to prevent interference between ordinary uses of telephone lines and metering. Electrical building codes might have to be revised to permit connection of telephone circuit to metering circuit.

TABLE III-1 (Cont'd.)

POSSIBLE COMMUNICATION CHANNELS FOR REMOTE METERING SYSTEM

Communication Channel		
Existing Telephone Circuits (cont'd.)	No high-volatage coupling and associated safety problems, as there are in use of electrical distribution lines.	Some modification of existing telephone switching equipment might have to be made (e.g., a method for inhibiting ringing when contact is made with called telephone line). Switching system which will connect end organ to and disconnect it from telephone lines in response to remote order is necessary. Metering service dependent on continuity of telephone service. Not all of utility's customers have telephones. Memory device at meter is necessary, since telephone lines cannot be used continuously. In some cases meter may be rather remote from telephone circuit.
Separately Installed Wire Communication Channel	Constant termination impedance. Low background-noise level. Owned and controlled by utility. Independent of customer's utility service or telephone.	High cost of original installation. Addition cost of maintaining communication line. Electric building code might cause difficulty
Wireless Communication Channel	Owned and controlled by utility. No line wire maintenance or coupling problems. Independent of customer's electric or telephone service.	High power necessary for each transmitting unit because of spreading of radiation. Privacy inadequate (easily interfered with and might easily interfere with other services). Controlled by Federal Communications Commission.

over the distribution circuits is probably possible if the number of end organs in one sectional unit is not too large.

The difficulties that are most apparent will be discussed more fully in a description of a possible scheme using this mode of communication. Among the more obvious are high electrical noise background and poor routing of transmitted signal energy.

Telephone Circuits. From a purely technical point of view, telephone circuits appear almost ideal as a communication medium for a remote metering system. Because the task for which they have been designed is communication, they offer a medium of low noise, low attenuation, and maximum privacy. With very small power at the sending end (of the order of milliwatts), a usable signal can easily be transmitted to any point in even a large city. The presently existing telephone automatic switching system also allows an individual customer to be selected and identified on the basis of his telephone number alone (at least where the dial system is used, and it probably will be installed in most communities within ten years). The difficulties inherent in this system include the working out of an economically satisfactory agreement with the telephone company allowing use of their lines for this purpose. (Of course, the telephone company might install, furnish, and service the equipment.) More details will be given in the description of a typical system using telephone lines as the communication channel.

End Organ

End organs may be classified as having or not having memory. Those not having a memory transmit information indicating, for example, the measurement of one kilowatt-hour of energy, instantaneously as it is recorded by the meter. Those having a memory store information indicating, for example, the number of kilowatt-hours measured over the period of one month, for transmission at some selected time. One important difference in the two systems is that for randomly occurring information, the end organ with no memory requires the continuous use of a communication channel. The end organ with memory needs the channel only during the selected interval during which its information is being transmitted to the receiver. Since the register of the presently used watt-hour meter is a memory device, it is possible to use it as part of the memory system of the end organ.

The signal received at the centralized location from the end organ must contain two types of information, namely, information as to quantity metered and information giving the identity of the originating meter.

Memoryless End Organ. The memoryless end organ, since it requires the continuous use of a channel, might use the power distribution lines as a communication channel, but it seems unlikely that it could employ the telephone lines. One possible end organ design would use a coded system of pulses for identification (see Section IV-A) and would transmit one pulse group for each unit of gas or electricity metered. These pulses would be received, identified, and stored at the receiver for use in periodic billing of the customer.

Memory-Type End Organ. Since the telephone lines could probably not be continuously available to the remote metering scheme, their use would require a memory-type end organ. One such end organ would be of the active type, i.e., it would originate and transmit signals. Such an end organ is described in detail in Section IV-B. This end organ is automatically interrogated once for each dial of the meter (or at least each dial that is read) by a centrally located machine. It replies by transmitting a voltage of a certain frequency, the particular frequency being determined for each dial by the dial position. The signals to and from the end organ are transmitted over existing telephone lines.

At the receiver these voltages are interpreted as dial positions and from them a meter reading is obtained. The identification of the meter is entirely in terms of the customer's telephone number.

Receivers

For Memoryless End Organ. Such a receiver consists essentially of four parts: a filter to receive the signal and reject noise that is outside the communication channel, an amplifier to increase pulses to usable size, a detector to convert r-f pulses to dc, and some sort of recorder or printer to record the pulses. The filter, amplifier, and detector would be quite conventional. The recorder should probably be designed for punching a tape or card to correspond to the coded pulses. This tape could then be fed into a machine which could sort out and store the signals for customer billing.

For Memory-Type End Organ. The receiver for the memory-type end organ employing telephone lines as the communication channel must secure the customer's telephone line, interrogate the end organ, and interpret the reply in terms of a meter reading. For the active-type end organ described above, the receiver must include a mechanism for automatically calling a designated customer's telephone number, and at the same time recording the called number for identification. Once the customer's telephone line is secured, the machine must apply a voltage of suitable frequency to the called circuit to prevent the telephone bell from ringing. Next the end organ must be directed to read each meter dial in turn. The machine then "hangs up". It might immediately repeat the entire process to decrease the probability of incorrect information or incorrect identification. With such a system, all of a city could be metered from one central location.

IV. SUGGESTED SYSTEMS

The two systems that seem to offer the greatest likelihood of success are, as indicated above, a system which uses the electric power distribution lines as the communication channel and includes a memoryless end organ, and a system which uses the existing telephone circuits as a communication channel together with an end organ having a memory. Each of these systems would employ the presently used watt-hour meter as the measuring device for electric energy and the presently used gas meter as the measuring device for the quantity of gas consumed. For either system the register would have to be suitably modified in order to furnish electrical contacts to indicate the position of the register dials. Enough of the present register should be retained to indicate the meter reading in the event that malfunctioning of the automatic meter-reading device occurs.

IV-A-1. A System Using the Electric Distribution Line as an Information-Carrying Channel.

An illustrative system of remote metering would consist of a centrally located receiver serving a group of meters, with each end organ transmitting an identified signal instantaneously as the meter registers a basic unit (e.g., a kilowatt-hour of electric energy). All these signals would be transmitted over a common information-carrying channel to the receiver. The receiver would provide storage for all the signals received throughout one billing period. At the end of such a period, the stored signals could be sorted and integrated into individual meter totals. This information might then be used for billing.

A basic requirement of such a system is that the information-carrying channel must be available at all times to all meters. This would preclude the use of lines that are being used for regular telephone service. The electric power distribution system, however, fulfills this requirement and also has the advantage of being already installed. Therefore, it has been selected for use in the system to be described.

One disadvantage of the use of electric distribution lines as a communication channel is that ground faults sometimes develop on the three-phase distribution circuit. If a delta ungrounded system is used, a ground fault on one line can be tolerated for a considerable time from a power system viewpoint. However, such a ground would cause a loss of signals in a communication system if a phase-to-ground circuit is used. If a phase-to-phase communication circuit is used, however, a ground fault would not block the signals, although it might increase the line attenuation and noise.

One of the problems of an instantaneous metering system using a common communication channel is that of overlapping of signals from two or more meters. Such overlapping can result either in loss of signals because the receiver is unable to sort them, or in the recording of a false signal created by the combining of the mixed signals. This problem sets limits on the amount of information that can be handled within a set tolerance of error. An analysis of this problem has been made (see Appendix II-A) which prescribes certain requirements for the system. These requirements, their effect on system components, and the effects of possible latitudes in these requirements will be discussed after a description of the system.

A block diagram, Fig. IV-A-1, shows the components of the end organ and the information-carrying channel. The receiver components are treated later.

The end organ consists of a package unit of a 100-kc oscillator, a pulsing switch to pulse the oscillator output with a binary coded identification, a power supply, and a relay.

The oscillator uses a transistor. This would require no standby filament power (as would a vacuum tube), and on the basis of recent information,[7] will meet the circuit, life, and power requirements. The power supply uses a germanium diode (again avoiding the need for standby power) and operates from the electric power line, available at the meter. Using present miniaturization techniques, a complete end organ could be built which would fit into the space that is presently available in meter installations. (In the transistor article noted above, transistor oscillator circuits in sealed packages are shown which occupy a volume of less than one cubic inch.)

To each meter, a single conductor drop line is run from the pole on which the distribution transformer serving the particular meter is located. At this pole location is a terminal box and a high-voltage coupling capacitor with lightning and surge protective devices. All the drop lines to the various meters are coupled through the capacitor to an ungrounded conductor of the high-voltage distribution line. The other end of the drop

7 - Morton, J. A. "Present Stage of Transistor Development", BSTJ, 31, 411-442 (May, 1952).

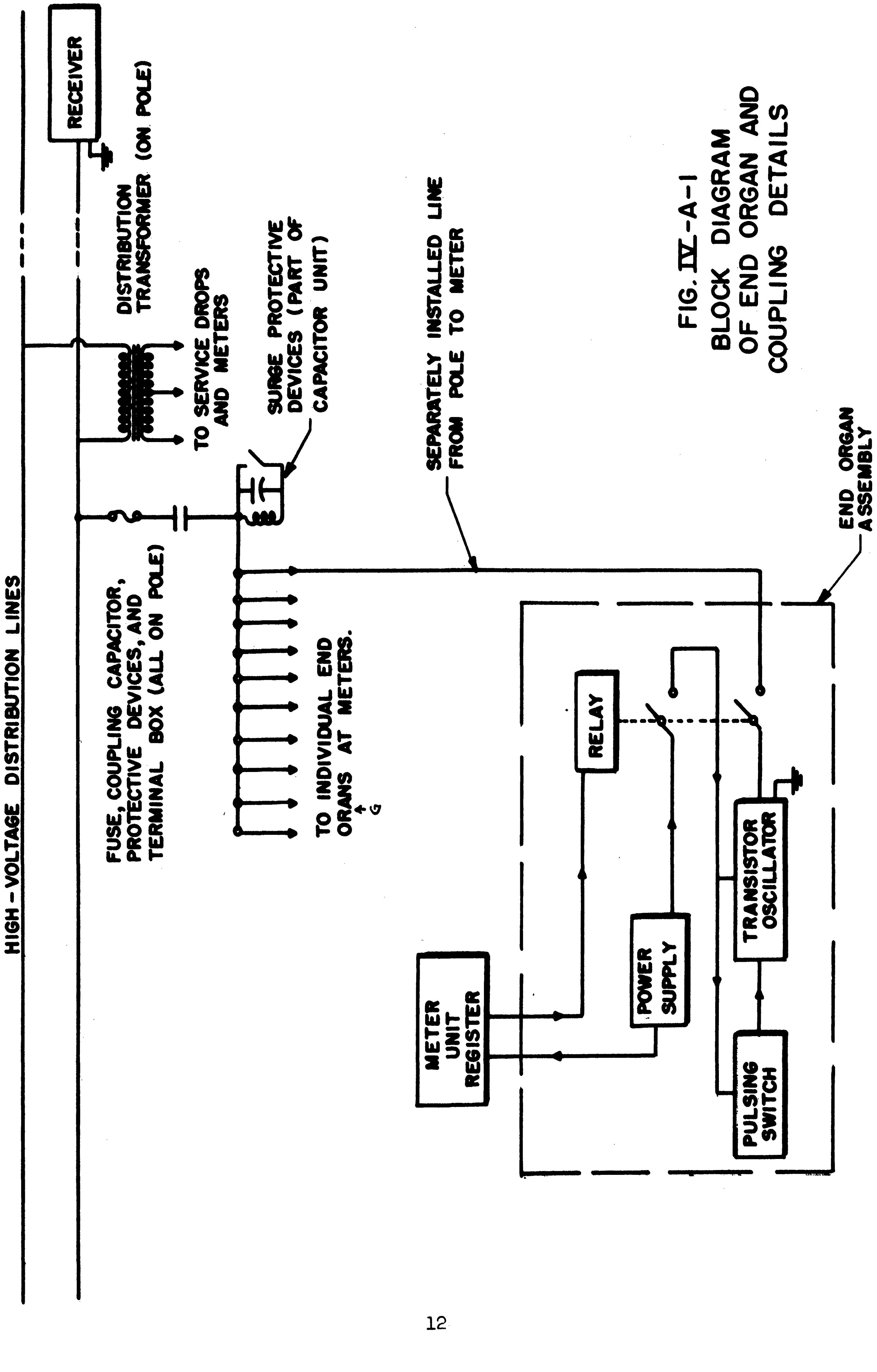

FIG. IV-A-1
BLOCK DIAGRAM
OF END ORGAN AND
COUPLING DETAILS

line is connected to one terminal of the end organ, the other terminal of which is connected to the ground. This provides a phase-to-ground connection.

One point to be considered in the use of a separate open line from the meter to the pole is the possibility of tampering by unauthorized persons. Opening a line would disable the particular end organ concerned; shorting a line would disable many other end organs connected to the same coupling capacitor. Later in this section, the use of the 120-240-volt service entrance lines in place of a separate line is considered. Any tampering with these lines, of course, would affect the electric service.

The operation of the end organ is as follows: the registering of a basic unit by the meter closes the circuit to the relay. The relay, through its double-pole switch, connects the oscillator output to the lines and applies power to the pulsing switch and oscillator. The pulsing switch goes through one cycle of operation and modulates the oscillator output into a prescribed series of pulses. The pulsing switch is latched at the end of its cycle. The relay, operating on a time control basis, opens, and disconnects the double-pole switch. Removing power from the pulsing switch unlatches it and it is again ready for the next registering of a unit by the meter.

A block diagram of the receiver which, as stated above, will serve many end organs, is shown in Fig. IV-A-2. The receiver and recorder might be rather complex and large. They would require adequate housing and protection.

The receiver is coupled to the distribution line with another coupling capacitor and a tuning unit. The receiver consists first of a conventional r-f amplifier and demodulator. Following the demodulator is a pulse shaper to shape the pulses to a uniform amplitude for recording. Because of the short signal duration that is necessary to prevent signal losses through overlapping, it will be necessary first to record the signals on a magnetic tape. Later these signals recorded at high speeds can be transferred to low-speed punched tape[8] for operation in a billing machine, which will sort and totalize the signals.

The above description of the system and its operation must be related to the requirements as set forth in Appendix II-A in the final design. The following set of specifications are taken from the Appendix:

a. The maximum in a group served by one receiver will be considered as 256 meters.

---

8 - See e.g., Kincaid, M. et al., "Static Magnetic Memory", <u>Electronics</u>, <u>24</u>, 114 (Jan. 1951).

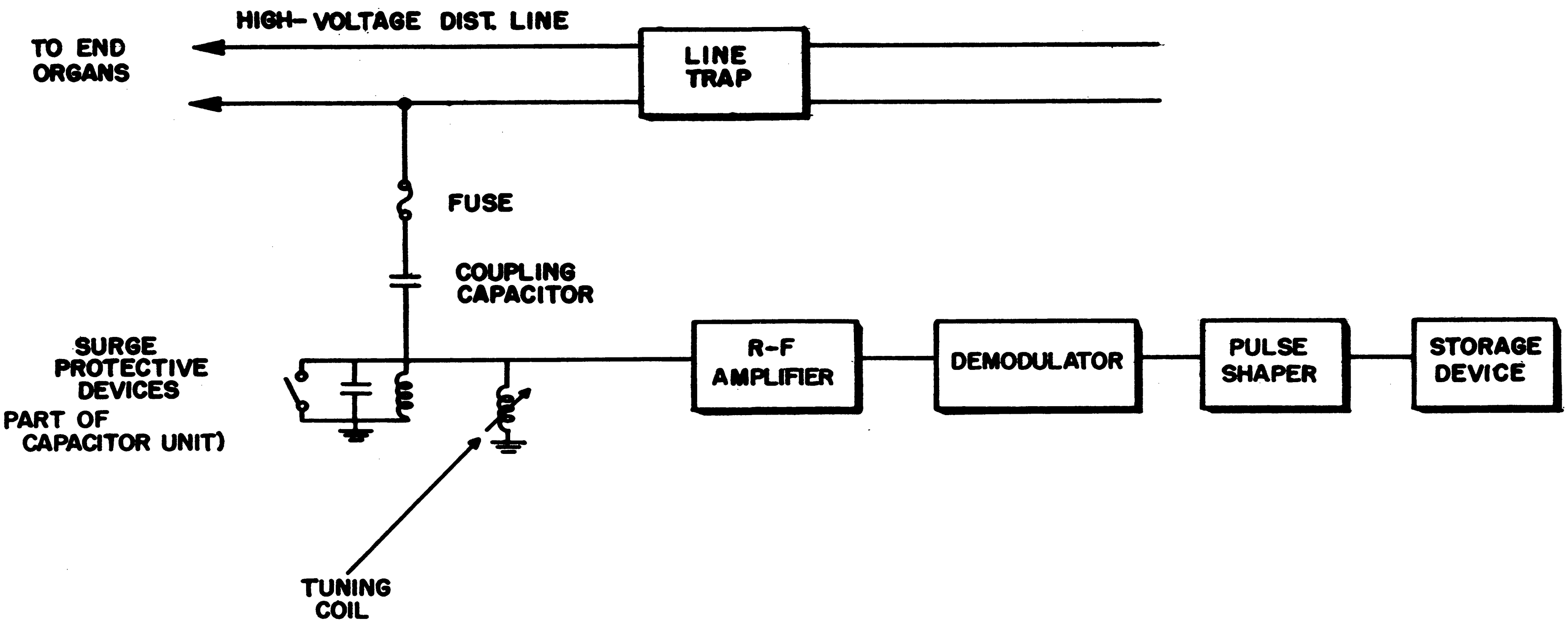

FIG. IV-A-2
BLOCK DIAGRAM OF RECEIVER

b. Signal identification will be done by pulses arranged in a binary code. Thus, since $2^8 = 256$, 8 digits (for pulse or no pulse) will be needed for the signal itself. Since a marker pulse will be needed to indicate to the receiver that a signal is starting, effectively the signal duration will be 9 digits long.

c. A pulse period of 1 millisecond will be used. This gives a total signal duration of 9 milliseconds.

d. It will be assumed that an average of 200 KWH is registered by each meter in a billing period of one month. As shown in Appendix II-A, this results in a percentage of coincidences of less than one per cent.

e. It will be assumed that there are 9 meters per distribution transformer. This results in 28 transformers in the group.

f. It will be assumed that the longest distance from an end organ to the receiver is 5 miles.

g. From information available[9], the following data on loss calculations will be used:

Distribution transformer bridging loss plus coupling capacitor attenuation....	0.2 db
Line attenuation........................	1.0 db/mile

Using the loss calculation data given above, the losses can be computed for the information-carrying channel as:

28 transformers at 0.2 db/each....................	5.6
Maximum line attenuation: 5 miles at 1 db/mile...	5.0
Possible mismatch of impedances between end organ and line....................................	3.0
Total......	13.6 db

From the calculations of Appendix II-A for the requirements listed above and using available data on electrical-noise background, the receiver for this particular system will require approximately one

9 - Adapted from Barstow, J. M., et al., "Rural Carrier Telephony", Elec. Eng. 66, 425 (May 1947).

milliwatt of signal power to operate satisfactorily. Since a reasonable figure for power output of a transistor oscillator is one watt at the present time, the losses from the end organ to the receiver should be kept below 30 db. It seems likely that future transistor development will increase power output to 10 watts, in which case the allowable loss figure could be extended to 40 db.

Thus, on the basis of the above calculation of 13.6 db, the losses are low enough so that the system can work.

One problem that should be considered is that of reflections of the original signal from the many open-circuited drop line taps along the distribution line. Since the end organ is connected to its line leading to the coupling capacitor only while a signal is actually being sent, the other lines represent open-circuited stubs along the line.

Consider the extreme case, shown in Fig. IV-A-3, in which a reflection of the injected pulse travels the maximum distance. If the velocity of propagation along the distribution line is taken as 186,000 miles/second x 0.9 = 167,400 miles/second, then the time for a pulse injected by an end organ at a point near the receiver to go the full 5 miles to the other end of the line and be reflected back is:

$$t = \frac{2 \times 5 \text{ miles}}{167{,}400 \text{ miles/sec}} = 59.1 \times 10^{-6} \text{ sec}$$

$$= 0.06 \text{ millisecond approximately}$$

Since a single pulse duration is 1 millisecond, the echo effect would seem to be small. Also, the reflected signal would be subjected to approximately 20 db attenuation in traveling the line twice, which should appreciably reduce its amplitude with respect to the original pulse.

Perhaps a more important problem is that of loading the distribution line with the capacitive reactance represented by the open-circuited stubs. Although the drop lines from the coupling capacitor to the meter installations will usually be short electrically (the line is very nearly 0.01 wavelength long for each 100 feet of physical length at 100 kilocycles), the combined effect of several paralleled lines might cause mismatching problems. If each drop line is assumed to be 300 feet long, it can be shown that it appears as a capacitive reactance equal to 5.24 times the characteristic impedance of the line at the pole. The characteristic impedance of such a line is of the order of 600 ohms. Thus, if there were

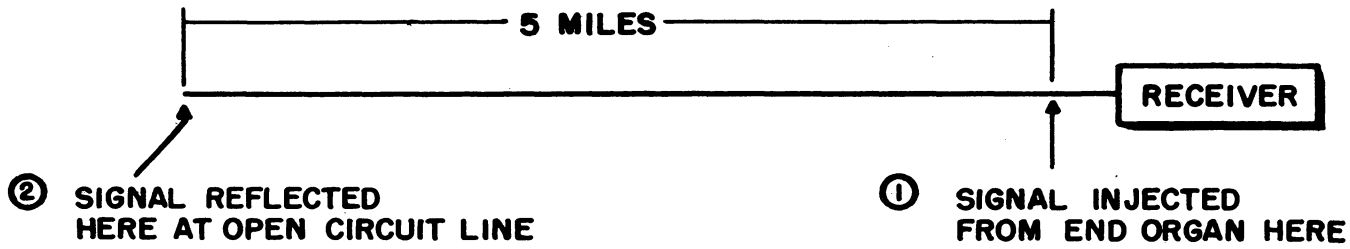

FIG. IV-A-3
REFLECTION PROBLEM

9 of these lines in parallel, the net reactance would be about 350 ohms at each coupling capacitor, for these assumed conditions.*

The above calculations and considerations of the distribution line are applicable only to the example given. The use of an actual line would present loading and reflection problems that could be solved by field engineering, which would develop standard practices to overcome common problems encountered by installation crews.

Since the power required at the receiver (see Appendix II-A) is 1.3 milliwatts, a line loss of 30 db requires a power output from the end organ of 1.3 watts. At the present stage of development it is reasonable to consider transistors as being able to develop this power for short intervals.

The principal problem in the end organ is that of the pulsing switch which must operate in millisecond intervals. As a simple illustration to indicate the concept, a mechanical method will be described. Such switching can be done by electrical means. In order for the signal not to be chopped off, the relay operating the end organ would stay closed for perhaps 100 milliseconds (or even 1 second). This allows a sufficient blank period before and after the 9-millisecond signal duration. The pulsing switch is a revolving wheel with switching notches over approximately one-tenth of its perimeter (if the relay "on time" is 100 milliseconds). When the relay is triggered on, the wheel makes one revolution (at a speed $= 1/10^{-1} = 10$ rps $= 600$ rpm). For the first 25 milliseconds the pulsing switch is "off", for the next 9 it is "on" and "off" for the proper code pattern, and for the final 66 milliseconds it is "off" again.

The major problem at the receiver is the storage of the signals. Because of their short duration and their random occurrence, it would be necessary to store them in a memory system with a fast response time, such as a magnetic tape.

---

* - The impedance looking into an open-circuited line equals $-jZ_o \cot \theta$. For a line 300 feet long at 100 kilocycles, $\theta = 10.8°$ and $\cot \theta = 5.24$.

For a single open wire above ground, $Z_o = 138 \log (4h/d)$, where h = height above ground and d = diameter of the wire. Assume h = 20 feet. d = 0.05 inches (No. 16 wire):

$$Z_o = 138 \log \frac{4 \times 240}{.05} = 138 \log (19{,}200)$$

$$= 138 (4.283)$$

$$= 590$$

Then the line appears as an impedance of 5.24 (590) = 3100 ohms (capacitive).

IV-A-2. Use of the 120-240-Volt Service Line for Coupling the End Organ to Higher-Voltage Distribution Lines

An important modification of the system described in Section IV-A-1 might make use of the low-voltage power lines instead of separately installed lines to carry the pulsed signal from the meter to the distribution transformer. This would still require the use of a coupling capacitor at the transformer, and would not change the losses due to transformer bridging and line attenuation (i.e., these would still be of the order of 10 db for the above example).

However, using the service drop instead of a separate drop line would change the 100-kc loading of the distribution line considerably. In the first place, it would be necessary to devise a filter and coupling unit for insertion in the service cable at the meter. This filter would prevent much of the impulse interference, which is generated in the electric power load, from getting into the signalling system. A proposed unit is shown in Fig. IV-A-4. The parallel coil and condenser are tuned to the oscillator frequency. The capacitors shunted from each ungrounded side of the line to the neutral conductor by-pass radio-frequency interference generated on the load side of the meter and also effectively connect the end organ output to ground.

Since the filter would be permanently installed in the line, it would represent a constant termination to the service drop. The characteristic impedance of the service cable is of the order of 150 ohms and the termination would be matched to this. Now, however, instead of having a number of open-circuited stubs connected to the distribution line, causing a capacitive reactance effect, the system has up to 256 load impedances permanently connected to the line.

While an actual circuit is considerably more involved, if one makes the simplifying assumption that the system consists of a line with 256 identical loads distributed along its length, then only 1/256 of the power output of any one oscillator will go to each load. Since the receiver is merely another load on the line, the loss in db due to this power dissipation would be 10 log (1/256), or 24 db.

This loss, plus the 10 or 15 db to be expected from the rest of the distribution system, puts the total loss near 40 db, which is near the practical limit. For 1.3 milliwatts at the receiver, 13 watts are needed from the oscillator.

However, using the service drops would eliminate the expense of extra wiring and would simplify the end organ relaying circuitry, as the

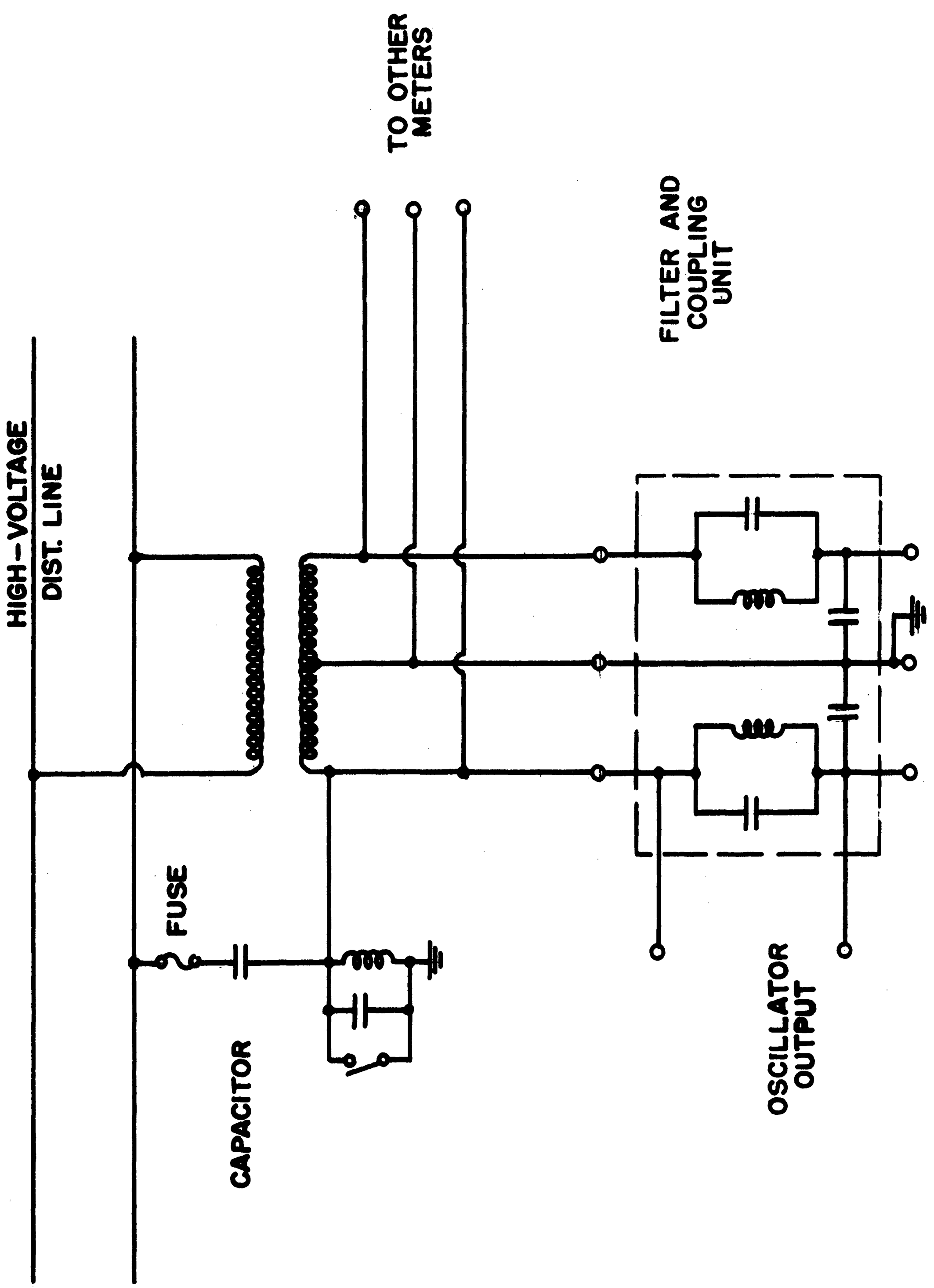
HIGH-VOLTAGE
DIST. LINE
TO OTHER
METERS
FILTER AND
COUPLING
UNIT
FUSE
CAPACITOR
TO METER
OSCILLATOR
OUTPUT

FIG. IV-A-4

oscillator could now be left connected to the line at all times. These advantages are offset by the expense of the filter and the additional oscillator power requirements.

IV-A-3. Other Variations of the Electric Distribution Line System

There are two distinct approaches to proposing variations of this system. One is to impose the original requirements as specified in Appendix II-A; the second is to consider the effect of varying these restrictions.

A variation of the receiver storage problem would use immediate sorting of the incoming signals into 256 channels, these to be added immediately by an individual register for each channel. At the end of the billing period, the information is taken from these registers (perhaps with punched tapes) and they are reset. The use of the information is a standard business machine problem.

Variations can be made by changing the original requirements. If the basic unit of measurement could be changed by a factor of 10 (from 1 KWH to 10 KWH), a number of other variables could be changed, either singly or in combination.

(a) One such compensating change could be made by increasing the number of meters in a grouping from 256 to 2560, and maintaining all the other requirements, except that the signal code would now require 11 pulses plus a marker. This would not change the end organ much, but it would increase the storage and sorting problem at the receiver.

(b) If the number of meters is kept at 256, the signal duration could be raised from 10 to 100 milliseconds, using individual pulses of 10-millisecond duration. This would simplify the pulsing problem at the end organ. It would also slow down the recording rate at the receiver. In addition, the increased pulse duration would allow a smaller communication-channel bandwidth to be used and thus allow a smaller power output to be used at the end organ. It should be emphasized that changing the unit of measure from 1 KWH to 10 KWH allows definite simplification of the system. This should make the system both more dependable and less expensive in initial cost.

Using a phase-to-phase connection to the distribution line rather than a phase-to-ground connection reduces attenuation and noise problems (according to power system carrier current practice). It also minimizes metering outages due to grounds on the power system.

The problem of having more than 256 meters on one line could be solved by frequency division multiplexing, that is, the use of a different carrier frequency by each of several end organs. The receivers could all be located at one central location. This is illustrated by Fig. IV-A-5.

In the receiver described in Section IV-A-1, no provision was made for the rejection of overlapping or coincident signals. From the calculations made in Appendix II-A, it would seem that the percentage of coincident signals might be so small as to be negligible. However, it must be recognized that such coincidence of signals would result in undercharging some meters (through loss of identification of their signals) and overcharging other meters (through the creation of false signals). Therefore, it might be advisable to provide some means of preventing such errors caused by coincident signals. If overlapping signals are rejected, no meter would be overcharged, although some would be undercharged.

One solution to this problem would require that each end organ send out two identifying signals for each unit measured, one immediately following the other. The receiver would compare the two signals received and would record a unit only if the two were identical.

There is still a possibility that two different signals could overlap and produce a combined signal which would have two identical halves. Suppose that a spacing of one pulse period is used between the two parts of any repeated signal. Then if an interfering signal starts within one pulse period before or after the start of the original signal, the combined pulse pattern would have two identical halves. Calculations using the single-signal duration of 9 milliseconds considered in the system above, with a spacing of 1 millisecond between signals, show that the percentage of coincidences would now be about 20 per cent of that calculated on the basis of single signals and no rejection method.*

---

* From Appendix II-A, the percentage of coincidences is equal to 200 RD, where R is the rate of signal production and D is the signal duration in seconds. For this calculation, R is constant.

For a system using only single signals of 9 millisecond duration, per cent coincidences = $200\ R\ (9 \times 10^{-3})$.

If double signals are used, with a spacing of 1 millisecond, uncorrected per cent coincidences = $200 \times R \times (19 \times 10^{-3})$.

However, with a rejection system, only those overlapping signals starting within $\pm$ 1 millisecond of the start of the original signals cannot be rejected. Therefore, the chance that the interfering signals can occur without rejection is 2/21.

Corrected per cent coincidences = $200 \times R \times (19 \times 10^{-3}) \times 2/21$.

Then the ratio of per cent coincidences (double-signal system using rejection) to per cent coincidences (original single-signal system) is:

$$\frac{200 \times R \times (19 \times 10^{-3})\ 2/21}{200 \times R \times (9 \times 10^{-3})} = \frac{2 \times 19}{21 \times 9} = \underline{0.201}.$$

For a single-signal duration D, a signal pulse period S, and a spacing S between repeated signals, the condition that D is much greater than S gives a ratio of percentage of coincidences of the corrected system to the original system of approximately 2S/D.

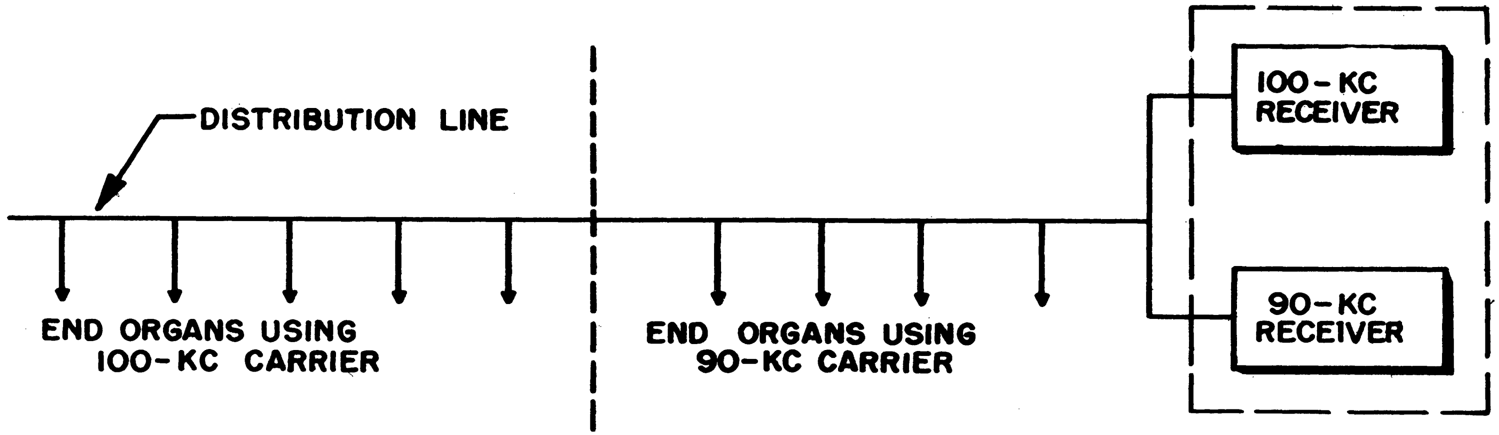

FIG. IV-A-5
FREQUENCY DIVISION MULTIPLEXING

A second system of coincidence rejection could make use of the marker pulses which are required at the beginning of each signal. If the marker pulse was made distinctive from the signal pulses (e.g., a double period pulse), the receiver could measure time intervals between two marker pulses. If markers were received in an interval less than a given time interval (the duration of a single signal), the information accompanying these markers would be rejected.

IV-B-1. A System Using Telephone Lines as an Information-Carrying Channel

Any use of the telephone company's lines as communication channels must, of course, be approved by them. It would seem, however, that since the use factor of the typical residential telephone subscriber's line is low, it would be desirable from the telephone company's point of view if other uses could be found for it. If a metering system could utilize the line in the period in which normal usage is extremely low, it would add to the usefulness of the line without interfering with its use in voice communication. Traffic studies made by the telephone company probably indicate when such periods occur. However, in order that such use be at all attractive to them, it probably must involve a minimum of change in presently used telephone company equipment. It is also important that the availability of the line to the telephone subscriber be decreased very little if at all as a result of its use for remote metering.

Since telephone lines are designed and used as communication channels, they are characterized by low noise background, fairly uniform line and termination impedances, low attenuation (at least within a range of frequencies from about 200 to 3000 cycles per second), and, very importantly, a presently existing switching system which allows any one subscriber to make connection from his line to the line of any other telephone subscriber in a given area easily.

The chief technical disadvantage would seem to be the fact that some users of gas and electricity do not have telephone service. (Maybe, however, the telephone company could still furnish lines for these if they are not in isolated regions.)

Considering the above facts, the following remote metering scheme is suggested.

End Organ. The details of the meter end organ are shown in Fig. IV-B-1. The basic element is an oscillator using a transistor whose frequency of oscillation is controlled in turn by the position of each of several meter dials. This control is effected by means of a resonant circuit the capacitive component of which is determined by the setting of a ten-position switch. The setting of this switch, there being one switch

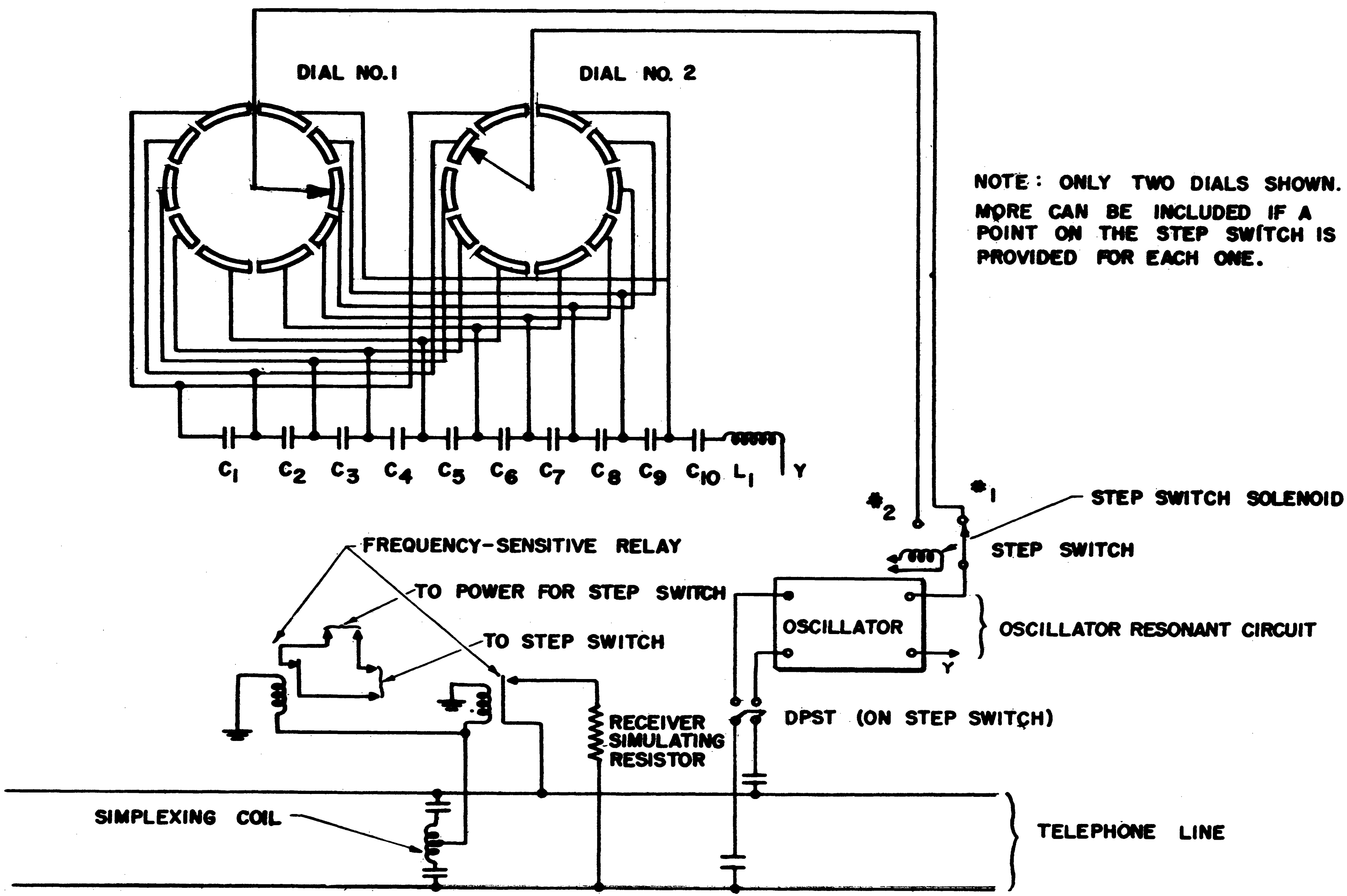

FIG. IV-B-1. END ORGAN FOR TELEPHONE LINE CHANNEL for each dial, is determined by the position of the meter dial. Thus, to each position of a selected meter dial there corresponds one of ten possible oscillator frequencies. These frequencies are selected to lie between about 200 and 3000 cycles per second.

The dial selector mechanism consists of a stepping switch actuated by a frequency-sensitive relay. The stepping switch not only connects to each of the meter dial switches in succession, but at the same time applies power to the oscillator. Power for operating the stepping switch is controlled by a fixed-frequency voltage transmitted from the control center over a simplex circuit. The simplex circuit is used rather than the telephone line itself in order that the relay not be tripped by voice voltages appearing on the telephone lines during normal conversations.

A simple transistor oscillator using the a-c line voltage as a power source can easily deliver approximately 100 milliwatts of power. This is about 38 db above the average power out of a telephone transmitter in normal conversation. Assuming a maximum attenuation of 40 db between oscillator and receiver (the telephone company uses less than 40 db as top for their intracity transmission), 10^{-5} watt arives at the receiver. This is quite adequate, since it represents approximately 0.07 volt at the receiver. (Assuming a 500-ohm line, $10^{-5} \times 500 = E^2, E = \sqrt{50} \times 10^{-2} = 0.07$.) On the other hand, this power level is not high enough to cause a cross-talk problem. The stability of the oscillator can easily be made such that it will stay within a usable frequency range as determined at the control center. The output of this oscillator is coupled directly to the telephone line.

In the normal operation of the telephone central office switching system, a ringing voltage is applied to a called subscriber's line as soon as it is determined that the line is not busy. The picking up of the subscriber's receiver automatically removes this voltage. Since it is necessary that the subscriber not be disturbed by the automatic meter interrogation process, some method must be used to inhibit the ringing of the subscriber's call bell when the automatic dialing mechanism at the control center dials his number. This might be done by using a frequency-sensitive relay to place a circuit across the telephone line that simulates the lifting of the subscriber's receiver. This relay could be actuated by a fixed-frequency voltage transmitted from the control center over the simplex circuit at the time the call is being made and thus applied to the relay as soon as the subscriber's line is secured. By this means the ringing voltage would be removed from the line before it rings the subscriber's call bell very much, if at all.

This remote metering device requires a meter register having dials equipped with ten contact switches. This might involve either the use of a different type of register from the one now used, such as the register proposed by Ward Leathers in his schemes for remote metering[10], or a modification of the existing register similar to that proposed by a patent granted to Panissidi[11].

This system has some obvious advantages over a memoryless system. In the first place, the speed of response of the control-center receiver does not need to be as great as that of the memoryless-type system with its random pulse rate, because with the memory system the number of meters read per unit time can be selected to meet the requirement of a particular reading system. In the second place, since this system will read the actual dial indication at any time, as many repetitions of the original reading can be made as seems desirable for a specified accuracy. It also follows that with this system, if a mistake is made at one billing period it can be rectified at the next billing period in the same way that a mistake made in a manual reading of the meter is corrected. In addition, this system has the advantage that a temporary electric power outage would not affect it unless it occurred just at the time of interrogation. In this case the interrogation could be repeated later. For the memoryless system, however, an electric power outage disables the gas meter end organ during the outage if it is using the electric line as a power source.

<u>Receiver or Control Center</u>. The components of the control-center receiver include the following: (a) an automatic dialing mechanism, (b) a transmitter of fixed-frequency alternating voltage sufficient to actuate the ringer inhibiting relay, (c) a transmitter having a suitable number of fixed frequencies so that the frequency-sensitive step-switch-actuating relay of the desired customer on a multi-party line may be chosen, (d) an amplifier for amplifying the alternating voltage transmitted by the end organ, and (e) some means of relating the received frequency to a dial position. This relation might be established by connecting ten frequency-sensitive relays to the output of the amplifier, letting each relay represent a position or number on the meter dial. The relays might actuate a tape puncher which would punch holes in a tape to correspond to the dial reading[12]. (See Fig. IV-B-2 for block diagram.) Alternatively, a set of bandpass filters might be connected to the amplifier output, the output of each filter to correspond to one dial position.

Most of the components of the above-described metering control center could be built with existing information, although there would

10 - U. S. Patent No. 2,283,071.

11 - U. S. Patent No. 2,319,432.

12 - For a possible coding scheme, see Mezar, J., "Fundamentals of the Automatic Telephone Message Accounting System," <u>Trans. AIEE</u>, <u>69</u>, pt. 1, 255-69 (1950).

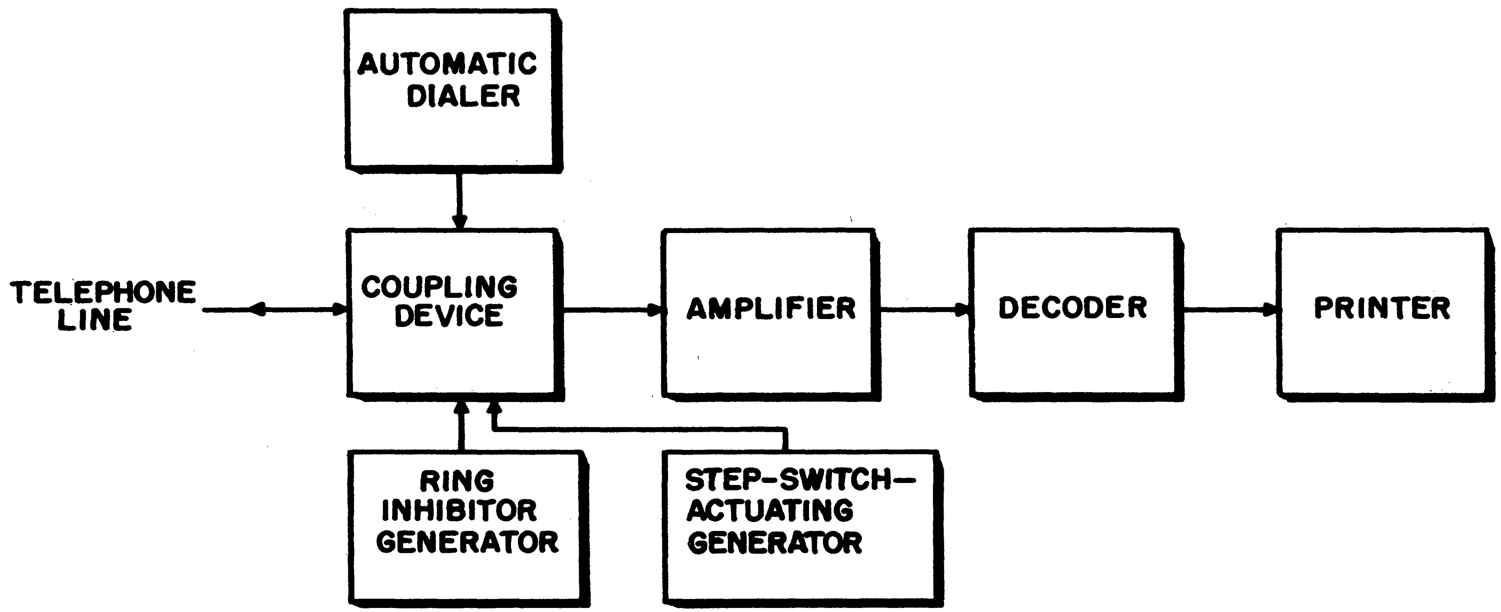

FIG. IV-B-2
BLOCK DIAGRAM, REMOTE METERING CONTROL CENTER, TELEPHONE LINE CHANNEL

probably have to be some development work done on the automatic dialing system and the allied coding system used to select the desired customer's relay on a multi-party line.

As an estimate of the number of separate receivers needed, assume that the off-peak hours for telephone usage are 1:00 AM to 5:00 AM and that 2 minutes per meter are required to obtain a reading. In a 30-day month, one receiver would be able to read 30 x 4 x 60/2 = 3600 meters. Thus, if the end organ is interrogated once a month, each 3600 meters would require one control-center receiver. Each control-center receiver requires a separate telephone line into the telephone exchange. The number of receivers needed could be considerably decreased if the time during which readings are made could be increased or the time per meter for a reading decreased. It seems reasonable to expect that each of these might be bettered by a factor of 2, thus requiring only one receiver per 14,400 meters.

IV-B-2. Variations of Telephone Line System

There are several possible alternative systems using telephone lines as communication channels. One of these might use as an end organ a mechanism somewhat like the dialing mechanism of the present telephone subscriber's set. One of the dialing mechanisms would be mechanically coupled to each meter register dial. As the register dial pointer rotates the dial mechanism would be wound up against a spring. A release mechanism operated by a solenoid could be actuated by means of a signal transmitted over the telephone lines from a remote location. When released the mechanism in returning to zero would open and close a set of contacts a number of times depending upon the original displacement from zero. These contacts would serve to transmit pulses over the telephone line in the same way that pulses are transmitted by the ordinary telephone dialing mechanism, the number of pulses serving as an indication of the displacement from zero. Since the telephone company at present uses a pulse signalling system successfully, it should be practical to transmit pulses over its lines.

Some method of checking a reading is desirable. For this purpose the release might allow the mechanism to return only halfway to zero for a first interrogating signal, transmitting as it does so an appropriate number of pulses. The second interrogating signal would then return the mechanism to zero, transmitting a like number of pulses as a check of the first transmission.

One way to simplify the meter end organ that has memory is to make the memory requirement small. This can be done by making readings more frequently. For example, if the reading period is made small enough so that no meter will measure more than 10 KWH between readings, only the "units" dial need be read. In this case both the stepping switch and one of the frequency-sensitive relays could be eliminated from the meter and organ that uses the transistor oscillator. This simplifies the end organ as well as reducing its initial cost. Another alternative is that of reading only every 10 KWH rather than every KWH as is now done. In this case only the "tens" dial need be read. Readings would then be made often enough so that no customer would use more than 100 KWH between readings.

Instead of a system which actually reads a dial, a system might be used which asks the end organ whether a fixed amount of electrical energy or gas has been used since the last interrogation. A "yes" answer would register at the receiver as that fixed amount and be totalized. At the same time the end organ would be placed back in the "no" position, where it would remain until tripped again by the consumption of the fixed unit. A "no" answer would verify the operation of the end organ, but not be totalized. This end organ might, for example, transmit only two possible frequencies, one signifying "yes" and one signifying "no". It could be somewhat simpler than the end organ which actually reads the dials.

IV-C. System Comparisons

The problem of cost is one which is difficult to assess at the early development stage on a unit that may be mass produced. It is obvious that the end organ finally adopted must have a low unit cost. Tentative estimates as to the allowable cost range from perhaps $5 to $25 per unit, including the complete installation. Whatever cost estimate is arrived at for a system in the development stage is certain to be modified by large-scale production and by possible later simplifications.

In Table IV-C-1 and IV-C-2 are parts lists for the memoryless and the memory-type end organ respectively, including a cost estimate for the parts based on present small-lots cost. For either type of end organ, this cost is of the order of $50. It is probable that quantity buying would reduce this amount to $10 or less. This figure seems reasonable in the light of prices for radiosonde transmitters, plug-in units for computers, and small packaged amplifiers. As an example of how quantity buying might affect prices, consider the coupling capacitor used in the power distribution line system of remote metering to couple from the end organ drop line to the electric distribution line. The price for one presently available capacitor with a 15-KV rating is about $200. Since at the present time these capacitors are used in limited numbers for carrier-current systems, it seems certain that large quantity buying would reduce this price considerably.

Although the 15-KV rating is the lowest voltage rating presently available, it is likely that sufficient demand would make available a lower-voltage unit, with still further lowering of price.

TABLE IV-C-1

END ORGAN PARTS LIST FOR POWER LINE SYSTEM
(Estimated Present Small-Lots Cost)

1	Coupling Capacitor (used by group of 9 end organs), \$200/9	\$22.25
1	Transistor	10.00
1	Double-Pole Relay	2.75
1	Pulsing Switch Assembly	5.00
	Oscillator Parts: 2 Resistors 0.30 1 Capacitor 0.20 1 Inductance 0.50	1.00
1	Rectifier	0.75
1	Two-Section Filter Condenser	1.00
	Hardware, Wire, Etc.	2.00
		44.75
	Labor	10.00
	Installing Drop Line	5.00
		\$59.75

Note: Quantity purchasing might decrease the above figure to as little as \$10.00 or less.

TABLE IV-C-2

END ORGAN PARTS LIST FOR TELEPHONE LINE SYSTEM
(Estimated Present Small-Lots Cost)

1	4-Decade-Dial Mechanism with Ten-Point Switch on Each Dial	$10.00
12	Condensers at $.20 ea.	2.40
1	Inductance	.50
1	Step Switch	5.00
2	Frequency-Sensitive Relays at $6.00 ea.	12.00
1	Simplexing Network	2.00
1	Transistor	10.00
1	Rectifier	.75
1	Two-Section Filter Condenser	1.00
4	Resistors at $.15 ea.	.60
		46.25
	Labor	10.00
		$56.25

Note: It seems reasonable to suppose that large-quantity purchasing might decrease the above figure to as little as $10.00 or less.

The transistor is another item whose cost figure is uncertain. Quantity production, however, will certainly bring the prices in line with those of presently available receiving-type tubes.

The cost of the information-carrying channel will depend, in the case of the electric distribution line system, on the modifications of the presently existing electric distribution lines that are necessary in order to allow their use as a communication channel. These modifications include line traps for routing of the r-f signal. Some rental would be charged for the use of the telephone lines used in the telephone line system, and this will add to the cost of this system.

Cost figures for the receivers are not given. It is important to note that, as described above, the power line system requires a receiver for about every 250 end organs, while the telephone line system requires a receiver only for about every 3600 (minimum figure) end organs. If it could be assumed that the two systems were about the same with respect to total cost of end organs and channels, the telephone line system has a definite cost margin advantage here. There are a number of other points to be considered:

a. Storage of Signals. Since the telephone line system has memories built into the end organs, the receiver would require none if interrogation is done only at billing-period intervals. The information obtained could then be converted immediately to billing use. If interrogation is done at more frequent intervals, the receiver would require some memory and storage facilities.

The power line system requires a complete memory and storage system at the receiver. Since the end organs are memoryless, the receiver must store and later sort all the information it receives throughout a billing period. Another subsidiary problem of this storage and sorting is that the required signal-reception rate is much greater than the rate at which present-day punch card systems can operate. Therefore, the signals must be first received and stored at the high-speed rate and later converted to low-speed billing information. This problem is encountered in other telemetering systems.

b. Housing of Equipment. The telephone line receiver can be conveniently housed in any building served by telephone lines. The power line receiver housing could require some extra construction, especially if it is inconvenient to locate it in an existing substation.

Thus from the standpoint of costs, the following statements may be made:

a. The relative costs of the end organs would be approximately the same for each system.

b. The power lines would require an initial adaptation cost for their use as an information channel. The telephone lines would require a rental fee.

c. The total cost of the receivers in the power line system would be higher than that of the telephone line system, since the telephone line system requires a much smaller number of receivers.

End organs in both systems use transistors rather than vacuum tubes as the basic active element in their oscillators and semiconductor rectifiers in their power supplies. Besides eliminating the stand-by power problem that vacuum tubes would introduce, these elements have almost an infinite life in this type of service. Since the end organs would be used for only a minute or two each billing period, electrical or mechanical failure of other parts should be small.

Some consideration would have to be given to temperature effects on the end organs if they are located out-of-doors, as in some electric meter installations.

Consideration was given to the possibility of using the power line as a communication channel for a remote metering system having an end organ with memory. Such an end organ must be interrogated periodically. The chief difficulty inherent in such a system is that of selecting and identifying a particular end organ for interrogation. If several hundred end organs are included in a grouping served by the same receiver, each one must be separately identified by an interrogator. This identification requires a separate section of the end organ which is responsive to perhaps a chosen frequency (in which case a separate frequency is required for each end organ) or to a certain sequence of pulses. The circuitry involved in such a section might well be more complicated than the transmitting section of the end organ. The resultant end organ would probably be too complicated to be economically feasible. For this reason it was decided that for the memory-type end organ some method of identification involving the transmission channel itself (e.g. the telephone switching system) was essential.

Another possible system would use an end organ capable of answering "yes" or "no" to an interrogation which asks whether a certain quantity of energy has been used since the last interrogation. The interrogation system might be the 720-cycle system used for turning on hot-water heaters on some power distribution systems. The answering signal from each end organ would be generated by a transistor r-f oscillator and transmitted over the distribution system to a central receiver. Identification would be in terms of a distinct time delay built into each end organ. Thus a group of end organs would be interrogated simultaneously. The first end organ would then answer either "yes" or "no" after a time delay of one unit. The second end organ would answer after a time delay of two units. All the rest of the group would answer in succession. The chief difficulty here would seem to be that of building accurate but inexpensive delay mechanisms into each end organ.

V. FUTURE TRENDS

Past experience has seemed to indicate that the problem of remote metering will be solved only when technology has advanced sufficiently to make the equipment economically practical. For example, an inquiry addressed to Mr. J. C. McPherson, vice president and chief engineer of IBM, elicited the following comment concerning the work done by Leathers in the early 1940's: "Our initial investigation after acquiring his [Ward Leathers'] group of patents indicated [in 1943] that meter reading by automatic means was not a commercially practical thing because of the large and widespread initial costs involved."

However, at present there seems to be a feeling among people in touch with latest developments that remote metering is not only feasible, but will not be long in coming from some direction. For example, Dr. W. R. G. Baker, vice president in charge of electronic development for the General Electric Company, is quoted in the July, 1952, issue of Electronics as predicting devices that read household meters and automatically transmit the information to distant electronic business machines for automatic billing.[13]

Mr. W. W. McDonald, executive editor of Electronics, commented in reply to an inquiry this summer concerning the future possibilities of remote metering, "Telemetering is coming into widespread use for industrial applications. The next step obviously will be to utilize the technique for something which serves the ultimate consumer."

The trend toward automatic processing and even automatic factories is a well developed one. In the present situation it would seem desirable to introduce an automatic remote metering system even if for the time being the system reads meters with no improvement in cost over the manual method. For one thing, the automatic system eliminates the possibility of much

13 - "Industry Report", Electronics, July, 1952, p. 22.

human error. For another, it means more interesting work, and thus a better quality of work from the personnel required in the meter reading process. It would seem to be considerably more interesting to maintain an automatic remote metering system than to trudge from door to door reading meters. The working force would be more skilled and much smaller and consequently more flexible than that presently used to read meters.

It seems likely that some organization, either in industry, in the private utility business, or perhaps even in the publicly owned utility field, will arrive at a successful solution to this problem before very long.

Conversation in June of 1952 with Dr. Ellsworth D. Cook, Division Engineer of General Electric's General Engineering and Consulting Laboratory, indicated that he thinks the problem of remote metering can definitely be solved now. However, in his opinion the risk capital involved in the necessary development will have to be furnished by those to whom the benefits will go. Thus if remote metering is to become a reality, utilities will probably have to provide the impetus. Such an undertaking as the development of a remote metering system probably represents a long-term investment. A considerable amount of presitge would undoubtedly attach to such an accomplishment.

Since the number of electric and gas meters in the United States alone is probably nearly 70 million,[14] there is a large potential demand for a remote metering system. Because economic considerations must play so large a role in determining the final design of any successful system, it is likely that the final solution to the problem will have undergone a considerable process of evolution from any original proposal. Experience gained in working with and testing possible systems will inevitably be necessary in arriving at the solution to any problem which depends as much as this one does for its successful solution upon a very small economic margin.

The remote metering scheme which proposes the use of existing telephone circuits as the information channel has been discussed unofficially with several telephone company engineers. Their opinion is that no serious technical difficulty stands in the way of such usage. There is, of course, an important policy decision to be made both by the telepone company and by the utilities before any such system can be employed. There would seem to be a possibility that the telephone company might even be interested in manufacturing and maintaining the meter end organ, since any means for increasing the return on their investment, much of which is in the subscribers' telephone lines, should be attractive to them.

---

14 - From data in "Statistical Abstract of the United States for 1951" published by the United States Department of Commerce.

The arrangements that have been made for the use of telephone lines in connection with Phonevision,[15] a process whereby the telephone company bills the home television user for and supplies him with an electrical signal which enables his set to receive certain programs, indicates the interest that the telephone company may have in other uses for its lines.

VI. RECOMMENDATIONS FOR FURTHER INVESTIGATION

It is the consensus of those who have participated in this investigation that it is distinctly probable that a successful remote metering system can be developed making use of equipment and techniques that are either presently available or will be so in the immediately foreseeable future. Because of the rather unusual telemetering problems involved in remote metering, a considerable amount of development will have to be done both in the laboratory and in the field before definite answers to many of these problems can be obtained.

It is recommended that further development of remote metering systems be undertaken with emphasis being placed upon the two systems described in Section IV. Both systems should be investigated until enough information is obtained to indicate a clear superiority of one system over the other. Further effort could then be concentrated on the superior system.

For the proposed system using the electric distribution lines as a communication channel, prototype end organs should be built. Measurements of signal reception at locations remote from the end organ should be made using various methods of coupling from the meter end organ to the high-voltage distribution lines, various lengths and arrangements of the distribution lines, and different attenuations due to varying numbers of end organs connected to the line but not delivering power.

One difficulty reported by all of those who have used power lines as carrier channels is that of making exact quantitative calculations of transmission data that prove significant. Most of the published information on carrier transmission concerns the application of carrier to high-voltage transmission lines. Very little work seems to have been reported on the application of carrier to distribution circuits, and almost none in

15 - See for example, "Zenith Phonevision," by M. M. Hubbard, FM-TV, 10, 26, (Nov., 1950).

application of carrier to 120-240-volt lines.[16,17] The available data directly applicable to this problem are thus rather meager and somewhat qualitative. It is entirely likely that further investigation and measurement of the important parameters involved in this system will reveal possible simplifications and improvements.

Since it is the meter end organs that contribute most to the cost of the system, there being more of them, additional investigation should concentrate first on them. The design of the receivers used at central locations or control centers can be somewhat more flexible, since one receiver may perhaps serve several hundred meter end organs. Some of the problems involved in receiver design are the development of a method for the rejection of coincident signals (if coincidence rejection is used) and a method for the high-speed transfer of received data to a storage system, perhaps punched tape.

For the proposed system using the telephone lines as communication channels, transmission calculations are considerably easier to make, since data are available on the transmission characteristics of telephone systems. Additional information is needed, however (and this would probably have to be a policy-level decision), on how much attenuation of voice voltages can be tolerated due to the presence of the simplexing network across the line. Additional investigation of possible variations of the proposed end organ is also needed, since by such means considerable simplification might be effected. A working model of the proposed end organ should be built and tested either on a telephone system or under similar conditions. Some unforeseen problems may arise, but on the other hand, familiarity with the system will also suggest improvements. Details of the receiver or control center need to be worked out, particularly a mechanism for the automatic dialing of a desired telephone number. However, the fact that only one receiver is needed for several thousand meter end organs allows its design much more flexibility than that of the end organ.

Before very much work is done on a system using telephone lines, the telephone company will have to be approached to see if a satisfactory arrangement can be made for the use of their lines. Such negotiation will have to be done between officials of the companies concerned.

---

16 - A British Broadcasting Company engineer, P. P. Eckersly, has proposed the use of urban electric distribution cables for distribution of BBC programs over a "wired radio" channel. This is described in the December 1941 issue of Wireless World.

17 - Wightman, P. E. and H. H. Lyon, "Carrier Line Transmission at 150-160 kc", Communications, p. 13, August 1943.

The initial part of an investigation of the two systems would consist chiefly of laboratory work concerned with the development of end organs suitable for use with the two systems. The appropriate level and duration of effort for an investigation would depend on such matters as rapidity of progress desired and the results obtained in the first few months of work. The proper initial level should be determined in conference.

After an initial program of development of the end organ has been generally successful a second phase involving modest field testing of a small number of end organs will be needed. These field tests should allow a decision to be made as to which of the two systems is likely to be the more successful. Similar, more extensive tests on the selected system should then be made. In this way enough information and experience can be gained so that a final decision can be made as to the probable overall economic and technical feasibility of a remote metering system.

At the end of this second phase it should be possible to specify the actual equipment to be used for a rather extensive trial installation of a remote metering system to be carried out on a selected portion of a utility system.

APPENDICES

APPENDIX I

FREQUENCIES USED FOR POWER-LINE TELEMETERING

In the last twenty years there has been extensive use of electric power lines as carrier channels for communication, telemetering, or relaying. The more successful results can be divided into two general ranges of frequencies, radio and audio, each of which requires different analysis and technique. As a general classification here, the term "audio" will cover those frequencies above the power-system frequency (50 or 60 cycles) up to perhaps 1000 cycles. "Radio" frequencies will be considered as those of 30 kilocycles and above.

Electric power systems are designed and analyzed in terms of a 60-cycle frequency. With this approach, the design equations and specifications are obtained by starting with fundamental equations and examining them with relation to the magnitudes involved at 60 cycles. As a result, some terms of these equations can be ignored or modified.

When a system which has been designed and built for 60-cycle operation is to be used at other frequencies, the basic equations must be re-examined. And, as might be expected, factors that were unimportant at 60 cycles sometimes become of major importance and vice versa.

The major factor that limits the use of radio frequencies on power lines to an upper limit of about 200 kilocycles is the wavelength of the line. At 60 cycles, the wavelength is approximately 3000 miles and even the longest transmission lines are electrically short. However, at 60 kilocycles, the wavelength becomes 5000 meters (about 3 miles) and at 600 kilocycles, which is at the lower end of the broadcast band, the wavelength is only 500 meters, or about 1/3 of a mile.

At these high frequencies, short tap lines and spurs can easily be a wavelength, or multiple, long and can cause a great amount of trouble with undesirable loading or reflections. Also, if frequencies above 200 kilocycles are used, interference problems with broadcast transmission and reception can be expected and are observed.

While power-line carrier current applications have had a high-frequency limit of 200 kilocycles, recent work has been done in using rural power distribution lines for telephone communication, using modulated radio-frequency carriers.[6] In these systems, in order to provide sufficient bandwidth and channels, frequencies up to 450 kilocycles have been used.

In using radio frequencies on a power-line carrier system, techniques which have been developed for regular radio service are used in the transmitting and receiving equipment. As lower and lower frequencies are used, the tuning and coupling circuits become excessively bulky and it also becomes difficult to design tuned circuits with proper bandwidth. These problems have put a low-frequency limit to the use of such techniques at 30 kilocycles.

While the actual application of radio-frequency carriers to power lines is still semi-empirical and semi-analytical, a number of basic ideas have been formulated. These are summarized in various articles in the literature.[18,19] Some of these points are:

a. Coupling to the high-voltage line is done by means of capacitors. Tuning equipment in the form of series and parallel resonant circuits is often used with the capacitor.

b. Transformers designed for power transmission and distribution will not pass radio-frequency signals. They must be bypassed by capacitors if such signals are to go from one side of the transformer to the other.

c. The bridging loss of distribution transformers up to a 5-KVA rating is small, being about 0.2 db per transformer for signals in the 100-kilocycle range.

d. Attenuation loss along distribution lines at 100 kilocycles is approximately 1 db per mile.

e. Line traps are used extensively to keep the signals out of parts of the power system that are not part of the communication line. Losses in spur lines and taps (of length greater than 1000 feet and less than 20 miles) are of the order of 3 db per tap and justify such trapping.

f. Since so little carrier power is passed through transformers to the power load, the carrier losses in this load can be neglected.

---

18 - Rives, F. M., "Application of Carrier to Power Lines," AIEE Transactions, 62, 835 (1943).

19 - Cheek, R. C., "Power Line Carrier Applications," Electrical Transmission and Distribution Reference Book, Westinghouse Elec. Corp. Fourth edition, 1950, p. 401.

An important point is to be noted in adapting transmission-line carrier-current techniques to the use of a distribution line as an information-carrying channel for remote metering. In present utility telemetering practices, the signalling is done directly between a relatively few points. In such cases extensive efforts can be applied to make the correcting power line usable as a communication channel. This means that the effect of undesirable taps, spur lines, and loads can be suppressed by use of line traps and by-pass capacitors. However, if distribution lines are used in remote metering of customer's meters, since these meters are located at all points on the line and at the very ends of the lines, one must deal with the electrical communication characteristics of the entire system.

The use of audio frequencies has been developed more as a means of mass relay operation than for point-to-point communication. In this country, General Eelctric has developed a system using 720 cycles as a means of turning on and off street lights and hot water heaters connected to power systems from a central location. This system, or modifications of it, have been used by a number of power companies.

In England and Europe, extensive application of this method has been used for such control.[20] Systems have been developed which use a number of frequencies (320, 370, 420, etc., to perhaps 670 cycles) to turn street lights off and on (sectionalizing control to main and secondary streets at different times), operate store window lights, sound air-raid alarms, etc.

In most of the systems which have thus far been reported, a single large generator at a central location operates a large number of relays at remote locations simultaneously. There has been no system reported as yet which uses individual relay control.

Whereas radio-frequency carrier systems utilize vacuum-tube and radio-circuit techniques, the audio systems developed are adaptations of power-system design. One article describing the General Electric 720-cycle system[21] and the article describing the English and European systems give design analysis. The existing 60-cycle system as it might be altered by the application of voltages of higher frequencies is used for the analysis. The result is that, while impedance values change, the system is still a large-current system. In the final design, alternators are used as a source of signalling power and large-current relays and controls are employed. The KVA rating of the generators is an appreciable fraction of the rating of the

20 - Barker, H. P., "Centralized Control of Public Lighting and Off-Peak Loads by Superimposed Ripples", Jour. IEE, 83, 823-836.

21 - Woodworth, J. L., "Application of 720-Cycle Carrier to Power Distribution Circuits," AIEE Transactions, 62, 903 (1943).

distribution lines on which they are used (since all the 60-cycle power equipment also takes power at the audio frequency). A voltage of 5 to 10 volts at the audio frequency is used on the 120-volt lines for the relay operation.

APPENDIX II

A. Analysis of System Using Memoryless End Organ

Consider a remote metering system having a memoryless end organ and using a communication channel which is common to a group of end organs and a receiver. Some method of identifying the signal sent by a particular end organ is needed. One possibility is the use of a group of pulses so arranged as to represent a number in the binary number system. Each end organ would then be represented by a different number or pulse arrangement. This characteristic code group would be transmitted once by the end organ for each unit of the quantity being measured. The complexity of this signal would depend on the number of individual meters in a group that must be separately identified. For example, a grouping of 256 meters requires a binary number at least as large as 256, and thus a minimum of 8 binary digits or individual pulses in the characteristic signal ($2^8 = 256$).

In order that a receiving unit make positive identification of a signal, it must, of course, have the same general form when it arrives at the receiver as when transmitted. Those influences contributing to distortion of the transmitted signal may be divided into two categories, (1) signals from other meters or end organs and (2) extraneous or noise voltages in the information-carrying channel. The first source of interference can be treated as a problem in probability; i.e., knowing the number of meters and the average signalling rate, the probability that two signals will occur within a specified interval can be predicted. The second source can be treated if sufficient information is available concerning the noise-voltage characteristic of the transmission channel and the method of transmission used.

"Signal-Signal" or Coincidence Interference. Assume:

(1) A 250-meter group of electric meters.
(2) Average Consumption of 200 KWH per month per meter.
(3) One identifying signal transmitted per KWH.
(4) A 9 digit code group used for identification of meter.*
(5) Period of individual pulses is .001 sec.

If calculations are made on a per-second basis for the group the average consumption rate is

---

* First digit used as marker for beginning of group.

$$\text{KWH/sec} = \frac{200 \times 250}{30 \times 24 \times 3600} = 1.93 \times 10^{-2}/\text{sec.} \qquad \text{(A-1)}$$

Assume that at peak periods the consumption is ten times average; thus:

$$(\text{KWH/sec})_{\text{peak}} = 0.193/\text{sec.} \qquad \text{(A-2)}$$

If the identifying signal consists of 9 digits, each of .001-second duration, the signal duration is .009-second. The coincidence rate at peak periods may be computed as the product of the probability that a signal will occur in some designated .009-second interval during this period and the probability that another signal will occur within .009 second of the starting time of the first (either before or after), multiplied by the number of .009-second intervals in one second. The first factor is simply the average rate of occurrence of signal at the peak period times the length of the .009-second interval. The second is the average signal rate times an interval of 2 x .009 second. The third is 1/.009, or 111. Thus:

$$C = (0.193 \times .009)(0.193 \times 2 \times .009) \times 111 = (0.193 \times .009)^2 \times 2 \times 111 = 6.69 \times 10^{-4}/\text{sec.} \qquad \text{(A-3)}$$

The percentage of coincidences is thus:

$$\%C = \frac{6.69 \times 10^{-4}}{0.193} \times 10^2 = \underline{0.347}. \qquad \text{(A-4)}$$

If one assumes that a coincidence results in billing the wrong customer, and further, if one assumes that the probability of incorrect billing because of a coincidence is equally probable for each customer, then the percentage error in customer billing will, on the average, also have a maximum value of the order of 0.347 per cent. (It is, however, probably not correct to assume equal probability of incorrect billing due to coincidence, since probably the customers with the largest numbers of pulses normally present in their identifying signals will be billed incorrectly most often.) Note that the above calculation gives the coincidence rate for the peak-load period. A more complete calculation would consider the coincidence as a function of the varying daily load.

Noise Interference. Assume:

(1) Equally-spaced signal pulses of .001-second duration.
(2) On the average half the pulses are missing.
(3) The noise is predominantly impulse noise.
(i.e., because of the phase relationships of the Fourier components, the peak value of the noise is proportional to the bandwidth.)

For the transmission of .001-second pulses the minimum bandwidth is 5×10^2 cycles.[23] Knowing the peak impulse noise per unit bandwidth at the appropriate frequency, the peak noise for a channel of specified bandwidth may be computed. The frequency spectrum in the region near 100 kc seems to be a promising one for transmission of signals over the power distribution circuits. The above signalling system might be used in this region by pulse-modulating a 100-kc r-f carrier. The noise spectrum of interest will thus be near 100 kc.

An improvement threshold can be defined for the pulse-modulated system. Let the improvement threshold be defined by making the pulse height equal to twice the peak noise voltage. With this definition (see Appendix II-B):

$$\frac{S}{K} = \sqrt{2} \times (\text{bandwidth}), \qquad \text{(B-2)}$$

where S is RMS pulse voltage and K is peak noise voltage per unit bandwidth.

Measurements reported by Cheek and Moynihan[24] seem to indicate that a value of K equal to 1.25×10^{-3} volt per cycle may be reasonable. Thus for the proposed system

$$S = (1.25 \times 10^{-3}) \times \sqrt{2} \times (5 \times 10^2) = .883 \text{ volts} \qquad \text{(A-5)}$$

gives the pulse RMS voltage. If the pulses amplitude-modulate an r-f carrier

$$S_{RF} = \frac{S}{\sqrt{2}} = \frac{.883}{\sqrt{2}} = .625 \text{ volt}. \qquad \text{(A-6)}$$

If a value of 300 ohms is assumed for phase-to-ground impedance,[25]

$$P_{RF} = \frac{(.625)^2}{300} = 1.3 \times 10^{-3} \text{ watt}. \qquad \text{(A-7)}$$

This represents the average power of a signal at the receiving point that will be at the improvement threshold.

In Appendix II-C are shown additional calculations for other meter groupings and several different signal pulse periods.

---

23 - Goldman, S. - Frequency Analysis Modulation and Noise, McGraw-Hill Book Co., Inc., New York, 1948, p. 85.

24 - Cheek, R. C., and Moynihan, J. D., AIEE Transactions, 70, Part I, 1127; Part II, 1325 (1951).

25 - See Burridge, G. E.; and Jong A. S. G., AIEE Transactions, 70, 1338, (1951).

B. Improvement Threshold for Pulse-Modulated AM in Presence of Impulse Noise

Equate pulse height ($\sqrt{2}$ S if it is assumed that on the average half the pulses are absent) to twice peak noise to get

$$\sqrt{2}\,S = 2 \times (\text{peak noise}). \qquad \text{(B-1)}$$

Since peak noise is proportional to bandwidth for impulse noise, (B-1) may be written

$$S = \sqrt{2}\,K \times (\text{bandwidth}), \qquad \text{(B-2)}$$

where K is peak noise per unit bandwidth.

For the AM channel this becomes

$$S = K \times (\text{bandwidth}). \qquad \text{(B-3)}$$

C. Additional Calculations

In Table II-C-1 are results of calculations for additional groupings of meters. Note that three factors determine coincidence rate. They are rate of energy consumption measured by the individual meters, number of meters in a group, and the length of the identifying pulse code group. The improvement threshold for the pulsed radio-frequency signal is determined entirely by the period of the individual pulses used, since this period determines the necessary communication-channel bandwidth.

From the table it is evident that the coincidence rate is decreased by decreasing the period of the individual pulses. The improvement threshold is, however, increased by this decrease in pulse period, requiring more power of the end organ. Thus a compromise must be effected between coincidence rate and the signal power required of the end organ.

The usage rate assumed for the computations in the table is ten times an assumed average rate of 200 KWH per month per meter except for numbers 5, 6, and 7. For these calculations a peak usage rate of forty times the average is assumed.

TABLE II-C-1

No.	No. of meters in group	Usage Rate for Group, KWH/sec (Maximum)	No. of Pulses in Identifying Code Group	Period of Individual Pulses, Sec	Length of Code Group, Sec	Coincidences per Second	Percentage Coincidences at Peak Usage Period	Bandwidth, Cycles (Minimum Required)	Threshold Power at Receiver, Watts (300-ohm line to ground)
1	100	0.077	8	10^{-3}	8×10^{-3}	9.48×10^{-5}	0.123	5×10^{2}	1.3×10^{-3}
2	250	0.193	9	10^{-3}	9×10^{-3}	6.69×10^{-4}	0.347	5×10^{2}	1.3×10^{-3}
3	500	0.385	10	10^{-3}	1×10^{-2}	2.97×10^{-3}	0.770	5×10^{2}	1.3×10^{-3}
4	1000	0.77	11	10^{-4}	1.1×10^{-3}	1.31×10^{-3}	0.170	5×10^{3}	0.130
5	1000	3.08	11	10^{-4}	1.1×10^{-3}	2.09×10^{-2}	0.678	5×10^{3}	0.130
6	1000	3.08	11	10^{-5}	1.1×10^{-4}	2.09×10^{-3}	0.068	5×10^{4}	13.0
7	1000	3.08	11	5×10^{-5}	5.5×10^{-4}	10.45×10^{-3}	0.339	1×10^{4}	0.52
8	1000	0.77	11	5×10^{-5}	5.5×10^{-4}	6.53×10^{-4}	0.085	1×10^{4}	0.52